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# BMJ Open

## The Health Effects of Climate Change: An Overview of Systematic Reviews

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# The Health Effects of Climate Change: An Overview of Systematic Reviews

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## Abstract

**Objectives:** In this study, we aimed to develop a synthesis of systematic reviews of health impacts of climate change. Our research objectives were to synthesize studies' characteristics such as geographical regions, years of publication, and authors' affiliations, to map the climate impacts, health outcomes, and combinations of these that have been studied, and to synthesize key findings.

**Design:** We conducted an overview of systematic reviews of health impacts of climate change. We registered our review in PROSPERO (CRD42019145972). We systematically searched the literature using a predefined search strategy, inclusion, and exclusion criteria. We included systematic reviews that explored at least one health impact of climate change. We organized systematic reviews according to their key characteristics, including geographical regions, year of publication and authors' affiliations. We mapped the climate effects and health outcomes being studied and synthesized major findings. No ethical approval was required since we used secondary data. Additional data is not available.

**Results:** We included ninety-four systematic reviews. Most were published after 2015 and approximately one fifth contained meta-analyses. Reviews synthesized evidence about five categories of climate impacts; the two most common were meteorological and extreme weather events. Reviews covered ten health outcome categories; the three most common were 1) infectious diseases, 2) mortality, and 3) respiratory, cardiovascular, cardiopulmonary or neurological outcomes. Most reviews suggested a deleterious impact of climate change on multiple adverse health outcomes, although the majority also called for more research.

**Conclusion:** Overall, most systematic reviews suggest that climate change is associated with worse human health. Future research could explore the potential explanations between these

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associations to propose adaptation and mitigation strategies and could include psychological and broader social health impacts of climate change.

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For peer review only

## Keywords

Health; Climate Change; Overview of Systematic Reviews; Extreme Weather Events; Air Quality; Global Warming

## Strengths and limitations of this study

- A strength of this study is that it provides the first broad overview of previous systematic reviews exploring the health impacts of climate change.
- By targeting systematic reviews, we achieve a higher-order summary of findings than what would have been possible by consulting individual original studies.
- By synthesizing findings across all included studies and according to the combination of climate impact and health outcome, we offer a clear, detailed, and unique summary of the current state of evidence and knowledge gaps about how climate change may influence human health.
- A limitation of this study is that we were unable to access some full texts and therefore some studies were excluded, even though we deemed them potentially relevant after title and abstract inspection.
- Another limitation is that we could not conduct meta-meta-analyses of findings across reviews, due to the heterogeneity of the included systematic reviews and the relatively small proportion of studies reporting meta-analytic findings.

## Summary boxes

### What is already known on this topic?

Multiple studies have documented an association between climate change (and its related environmental consequences) and various human health impacts. But to better understand the multiple health impacts of climate change and to identify gaps in previous literature, we need a detailed over-arching overview of the current literature investigating the climate-health association.

### What this study adds?

This study provides an up to date detailed overview of previous systematic reviews of health impacts of climate change based on a rigorous and consistent mapping of the key characteristics and findings of included reviews. Overall, most systematic reviews suggest a deleterious impact of climate change (and its related environmental consequences) on multiple adverse health outcomes. This study allows to guide health adaptation and to identify key gaps in literature.

## Introduction

The environmental consequences of climate change such as rising temperatures, more extreme weather events, and increased droughts and flooding are impacting human health and lives.<sup>1,2</sup>

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3 Previous studies and reviews have documented the health impacts of climate change; however,  
4 they have focused on specific climate effects,<sup>3,4</sup> health impacts,<sup>5,6</sup> countries,<sup>7-9</sup> or are no longer  
5 up to date.<sup>10,11</sup> To guide future research and action to mitigate and adapt to the health impacts  
6 of climate change and its environmental consequences, we need a complete and thorough  
7 overview of the research already conducted. In this study, we aimed to develop such a  
8 synthesis of systematic reviews of health impacts of climate change. Our research objectives  
9 were to synthesize studies' characteristics such as geographical regions, years of publication,  
10 and authors' affiliations, to map the climate impacts, health outcomes, and combinations of  
11 these that have been studied, and to synthesize key findings.  
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## 16 Methods

17  
18 We applied the Cochrane method for overviews of reviews.<sup>12</sup> This method is designed to  
19 systematically map the themes of studies on a topic and synthesize findings to achieve a  
20 broader overview of the available literature on the topic.  
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## 23 Research questions

24 Our research questions were the following: 1) What is known about the relationship between  
25 climate change and health, as shown in previous systematic reviews? 2) What are the  
26 characteristics of these studies? We registered our plan (CRD42019145972<sup>13</sup>) in PROSPERO,  
27 an international prospective register of systematic reviews and followed PRISMA 2020<sup>14</sup> to  
28 report our findings, as a reporting guideline for overviews is still in development.<sup>15</sup>  
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## 32 Search strategy and selection criteria

33  
34 To identify relevant studies, we used a systematic search strategy. We included studies in this  
35 review if they 1) were systematic reviews of original research and 2) reported at least one health  
36 impact as it related (directly or indirectly) to climate change.  
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39 We defined a systematic review, based on Cochrane's definition, as a review of the literature in  
40 which one "attempts to identify, appraise and synthesize all the empirical evidence that meets  
41 pre-specified eligibility criteria to answer a specific research question [by] us[ing] explicit,  
42 systematic methods that are selected with a view aimed at minimizing bias, to produce more  
43 reliable findings to inform decision making."<sup>16</sup> We included systematic reviews of original  
44 research, with or without meta-analyses. We excluded narrative reviews, non-systematic  
45 literature reviews and systematic reviews of materials that were not original research (e.g.,  
46 systematic reviews of guidelines.)  
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49 We based our definition of health impacts on the World Health Organization's (WHO) definition  
50 of health as, "a state of complete physical, mental and social well-being and not merely the  
51 absence of disease or infirmity."<sup>17</sup> Therefore, health impacts included, among others, morbidity,  
52 mortality, new conditions, worsening/improving conditions, injuries, and psychological well-  
53 being. Climate change (or global warming) could be referred to directly or indirectly, for  
54 instance, by synthesizing the direct or indirect health effects of temperature rises or of natural  
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3 conditions/disasters made more likely by climate change (e.g., floods, wildfires, temperature  
4 variability, droughts.) We included systematic reviews whose main focus was not the health  
5 impacts of climate change, providing they reported at least one result regarding health effects  
6 related to climate change (or consequences of climate change.)  
7

8  
9 On June 22, 2019, we retrieved systematic reviews regarding the health effects of climate  
10 change by searching the electronic databases Medline, CINAHL, Embase, Cochrane, Web of  
11 Science using a structured search (see Appendix 1 for final search strategy developed by a  
12 librarian.) We did not apply language restrictions. After removing duplicates, we imported  
13 references into Covidence.<sup>18</sup>  
14  
15

## 16 17 Screening process

18 To select studies, we first screened titles and abstracts to eliminate articles that did not meet our  
19 inclusion criteria. Two trained analysts independently screened each article. A senior analyst  
20 resolved any conflict or disagreement. Because the topic was new to some team members, to  
21 ensure a high-quality screening process, the trained analysts then re-screened all included  
22 records and the senior analyst re-screened all excluded records. Two analysts then  
23 independently screened the full text of retained articles, again with a senior analyst resolving  
24 disagreements.  
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## 27 28 Data extraction

29  
30 Next, we decided on key information that needed to be extracted from studies. We extracted the  
31 first author's name, year of publication, number of studies included, time frame (in years) of the  
32 studies included in the article, first author's institution's country affiliation, whether the  
33 systematic review included a meta-analysis, geographical focus, population focus, the climate  
34 impact(s) and the health outcome(s) as well as the main findings and limitations of each  
35 systematic review.  
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38  
39 Two or more trained analysts (RR, CB, RN, LC, LPB, RAPR) independently extracted data,  
40 using Covidence and spreadsheet software (Google Sheets). For analysts who were new to  
41 evidence syntheses (CB, LPB, RAPR), the training process included extracting data repeatedly  
42 from the same articles to ensure accurate understanding, weekly group meetings to clarify  
43 understanding, and daily supervision by more senior team members (RR, RN, HOW). An  
44 additional trained analyst from the group or senior research team member resolved  
45 disagreements between individual judgments.  
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## 48 49 Coding and Data Mapping

50 To summarize findings from previous reviews, we used a three-step procedure for coding and  
51 data mapping. First, to map articles according to climate impacts and health outcomes, two  
52 researchers (RR and LC) consulted the titles and abstracts of each article. We developed the  
53 categories for climate impacts separately from those for health outcomes and used a mixed  
54 approach to coding. We started with an inductive coding method, by identifying categories  
55 directly based on our data and followed up with a deductive approach to finalize categories by  
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3 consulting previous conceptual frameworks of climate impacts and health outcomes.<sup>1,2,19</sup> The  
4 same two researchers independently coded each article according to their climate impact and  
5 health outcome. We then compared coding and resolved disagreements through discussion.  
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8 Next, still using spreadsheet software, we created a matrix to map articles according to their  
9 combination of climate impacts and health outcomes. Each health outcome occupied one row,  
10 whereas climate impacts each occupied one column. We placed each article in the matrix  
11 according to the combination(s) of their climate impact(s) and health outcome(s). For instance, if  
12 we coded an article as 'extreme weather' for climate and 'mental health' for health impact, we  
13 noted it in the cell at the intersection of these two codes. We calculated frequencies for each cell  
14 to identify frequent combinations and gaps in literature. Because one study could investigate  
15 more than one climate impact and health outcome, the frequency counts for each category  
16 could exceed the number of studies included in this review.  
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19  
20 Finally, we summarized findings of the studies individually according to their combination of  
21 climate impacts and health outcomes. We re-read the Results and Discussion sections of each  
22 article as part of this step. We first wrote an individual summary for each study, then we collated  
23 the summaries of all studies exploring the same combination of categories to develop an overall  
24 summary of findings for each combination of categories.  
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## 27 28 Quality assessment

29 We used a modified version of AMSTAR-2 to assess the quality of the included systematic  
30 reviews (Appendix 2). Since AMSTAR-2 was developed for syntheses of systematic reviews of  
31 randomized controlled trials, working with a team member with expertise in knowledge synthesis  
32 (AT), we adapted it to suit a research context that is not amenable to randomized controlled  
33 trials. We used items 5, 6, 10, 11, 12, 14, 15, 16 without modification and modified items 1 to 4,  
34 7 to 9 and 13.  
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## 38 Patient and Public Involvement

39 Patients and members of the public were not involved in this study.  
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## 44 Results

### 45 46 Articles identified

47 As shown in the PRISMA diagram in Figure 1, from an initial set of 2619 references, we retained  
48 94 for inclusion.  
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52 **Insert Figure 1 About Here**  
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## Study Descriptions

A detailed table of all articles and their characteristics can be found in Appendix 3. Publication years ranged from 2007 to 2019 (year of data extraction), with the great majority of included articles (n = 69; 73%) published since 2015 (Figure 2). A median of 30 studies had been included in the systematic reviews (mean = 60; SD = 49; range 7 to 722). Approximately one fifth of the systematic reviews included meta-analyses of their included studies (n = 18; 19%). The majority of included systematic reviews' first authors had affiliations in high-income countries, with the largest representations by continent in Europe (n = 30) and Australia (n = 24) (Figure 3).

**Insert Figure 2 About Here**

**Insert Figure 3 About Here**

Regarding the geographical focus of systematic reviews, most of the included studies (n = 68; 72%) had a global focus or no specified geographical limitations and therefore included studies published anywhere in the world. The remaining systematic reviews either targeted certain countries (n = 12) (1 for each Australia, Germany, Iran, India, Ethiopia, Malaysia, Nepal, New Zealand and 2 reviews focused on China and the United States), continents (n = 5) (3 focused on Europe and 2 on Asia), or regions according to geographical location (n = 6) (1 focused on Sub-Saharan Africa, 1 on Eastern Mediterranean countries, 1 on Tropical countries, and 3 focused on the Arctic), or according to the country's level of income (n = 3) (2 on low to middle income countries, 1 on high income countries).

Regarding specific populations of interest, most of the systematic reviews did not define a specific population of interest (n = 69; 73%). For the studies that specified a population of interest (n = 25; 26.6%), the most frequent populations were children (n = 7) and workers (n = 6), followed by vulnerable or susceptible populations more generally (n = 4), the elderly (n = 3), pregnant people (n = 2), people with disabilities or chronic illnesses (n = 2) and rural populations (n = 1).

## Quality assessment

We assessed studies for quality according to our revised AMSTAR-2. Out of 94 systematic reviews, the most commonly fully satisfied criterion was #1 (PICO components) with 81/94 (86%) of included systematic reviews fully satisfying this criterion. The next most commonly-satisfied criteria were #16 (potential sources of conflict of interest reported) (78/94 = 83% fully), #13 (account for limitations in individual studies) (70/94 = 75% fully and 2/94 = 2% partially), #7 (explain both inclusion and exclusion criteria) (64/94 = 68% fully and 19/94 = 20% partially), #8 (description of included studies in adequate detail) (36/94 = 38% fully and 41/94 = 44% partially), and #4 (use of a comprehensive literature search strategy) (0/94 = 0% fully and 80/94 = 85% partially). For criteria #11, #12, and #15, which only applied to reviews including meta-analyses, 17/18 (94%) fully satisfied criterion #11 (use of an appropriate methods for statistical combination of results), 12/18 (67%) fully satisfied criterion #12 (assessment of the potential

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3 impact of RoB in individual studies) (1/18 = 6% partially), and 11/18 (61%) fully satisfied  
4 criterion #15 (an adequate investigation of publication bias, small study bias). Full details are  
5 available in Appendix 4.  
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## 8 Climate Impacts and Health Outcomes 9

10 For both the climate impacts and health outcomes, systematic reviews could have a general or  
11 a specific focus. A general focus consisted of investigating the general impacts of climate  
12 change or multiple impacts simultaneously, whereas a specific focus targeted specifically only  
13 one climate impact or health outcome. When combining the climate impact to the health  
14 outcome, four combinations became apparent. Table 1 shows these four combinations with  
15 sample titles of systematic reviews within that combination. The most frequent combination (n =  
16 52; 55%) consisted of studies investigating a specific climate impact on a specific health  
17 outcome (e.g., the impact of floods on mental health) and the least frequent combination (n = 5;  
18 5%) consisted of studies exploring general or multiple climate impacts' effects on multiple health  
19 outcomes (e.g., health impacts of climate change.)  
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23 **Table 1. Summary of the four scenarios possible when combining climate impact and**  
24 **health outcome categories with frequencies and examples of paper titles.**  
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Frequency (%) and Example Titles		Health Outcome	
		Multiple (n = 29)	Specific (n = 65)
Climate Impact	General or multiple (n = 18)	n = 5 (5%)  E.g., "Health Impact of Climate Change in Older People: An Integrative Review and Implications for Nursing," <sup>20</sup> and, "Climate Change and Health in the Eastern Mediterranean Countries: A Systematic Review." <sup>21</sup>	n = 13 (14%)  E.g., "Global Warming and Obesity," <sup>22</sup> and, "Systematic Review of Current Efforts to Quantify the Impacts of Climate Change on Undernutrition." <sup>23</sup>
	Specific (n = 76)	n = 24 (26%)  E.g., "Floods and Human Health: A Systematic Review," <sup>3</sup> and, "Health Effects of Drought: A Systematic Review of the Evidence." <sup>24</sup>	n = 52 (55%)  E.g., "The Mental Health Outcomes of Drought: A Systematic Review and Causal Process Diagram," <sup>25</sup> and, "The Association between Ambient Temperature and Childhood Asthma: A Systematic Review." <sup>26</sup>

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53 Regarding climate impacts, we identified five mutually exclusive categories, with 13 publications  
54 targeting more than one category of climate impacts: 1) Meteorological (n = 71 papers) (e.g.,  
55 temperature, heat waves, humidity, precipitation), 2) Extreme weather (n = 24) (e.g., water-  
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3 related, floods, cyclones, hurricanes, drought), 3) Air quality (n = 7) (e.g., air pollution and  
4 wildfire smoke exposure), 4) General (n = 5), and 5) Other (n = 3). “General” climate impacts  
5 included articles that did not specify climate change impacts but stated general climate change  
6 as their focus. “Other” climate impacts included studies investigating other effects indirectly  
7 related to climate change (e.g., impact of environmental contaminants) or general environmental  
8 risk factors (e.g., environmental hazards, sanitation, and access to clean water.)  
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11 We identified ten categories to describe the health outcomes studied by the systematic reviews,  
12 and 29 publications targeted more than one category of health outcomes: 1) Infectious diseases  
13 (n = 41 papers) (vector-, food- and water-borne), 2) Mortality (n = 32), 3) Respiratory,  
14 cardiovascular, cardiopulmonary and neurological (n = 22), 4) Healthcare systems (n = 16) , 5)  
15 Mental health (n = 13), 6) Pregnancy and birth (n = 11), 7) Dietary (n = 9), 8) Skin and allergies  
16 (n = 9), 9) Occupational health and injuries (n = 6) and 10) Other health outcomes (n = 17) (e.g.,  
17 sleep, arthritis, disability-adjusted life years, non-occupational injuries, etc.)  
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21 Figure 4 depicts the combinations of climate impact and health outcome for each study, with  
22 Appendix 5 offering further details. The 5 most common combinations are studies investigating  
23 the 1) meteorological impacts on infectious diseases (n = 35), 2) mortality (n = 24) and 3)  
24 respiratory, cardiovascular, cardiopulmonary and neurological outcomes (n = 17), and 4)  
25 extreme weather events’ impacts on infectious diseases (n = 14) and 5) meteorological impacts  
26 on health systems (n = 11).  
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### 30 **Insert Figure 4 About Here**

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32 For studies investigating meteorological impacts on health, the three most common health  
33 outcomes studied were impacts on 1) infectious diseases (n = 35), 2) mortality (n = 24) and 3)  
34 respiratory, cardiovascular, cardiopulmonary and neurological outcomes (n = 17). Extreme  
35 weather event studies most commonly reported health outcomes related to 1) infectious  
36 diseases (n = 14), 2) mental health outcomes (n = 9) and 3) dietary outcomes (n = 6) and other  
37 health outcomes (e.g., injuries, sleep) (n = 6). Studies focused on the impact of air quality were  
38 less frequent and explored mostly health outcomes linked to 1) respiratory, cardiovascular,  
39 cardiopulmonary and neurological outcomes (n = 6), 2) mortality (n = 5) and 3) pregnancy and  
40 birth outcomes (n = 3).  
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44 Meteorological factors’ impact on all health outcomes are explored, although some health  
45 outcomes are more rarely explored (e.g., mental health and dietary outcomes). In contrast, the  
46 impact of extreme weather events and air quality on skin and allergies and occupational health  
47 are not explored and their impacts on respiratory, cardiovascular, cardiopulmonary and  
48 neurological outcomes, health systems and pregnancy outcomes are only rarely explored. The  
49 impacts of air quality on infectious diseases, dietary outcomes, skin and allergies, and  
50 occupational health and injuries are also not explored. Most health outcomes are most  
51 frequently explored according to the meteorological impacts, however, mental health outcomes  
52 and dietary outcomes are most frequently explored according to extreme weather events.  
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## Summary of Findings

Most reviews suggest a deleterious impact of climate change on multiple adverse health outcomes, with some associations being explored and/or supported with consistent findings more often than others (see Table 2 for a summary of findings according to health outcomes). For instance, the association between meteorological factors, such as temperature and humidity, and vector-borne diseases is quite substantially supported by multiple reviews (n = 22) conducted in multiple geographic locations. In contrast, the association between wildfire smoke exposure and adverse birth outcomes is plausible, but the evidence from included reviews is still in its infancy stage because only a few reviews (n = 3) investigated this association and the findings are currently conflicting.

Most reviews concluded by calling for more research, noting the limitations observed among the studies included in their reviews, as well as limitations in their reviews themselves. These limitations included, amongst others, some systematic reviews having a small number of publications,<sup>27,28</sup> language restrictions such as including only papers in English,<sup>20,23</sup> arriving at conflicting evidence,<sup>29</sup> difficulty concluding a strong association due to the heterogeneity in methods and measurements or the limited equipment and access to quality data in certain contexts,<sup>27,30–32</sup> and most studies included were conducted in high-income countries.<sup>33,34</sup>

Previous authors also discussed the important challenge related to exploring the relationship between climate change and health. Not only is it difficult to explore the potential causal relationship between climate change and health, mostly due to methodological challenges, but there are also a wide variety of complex causal factors that may interact to determine health outcomes. Therefore, the possible causal mechanisms underlying these associations were at times still unknown or uncertain and the impacts of some climate factors were different according to geographical location and specificities of the context. Nonetheless, some reviews offered potential explanations for the climate-health association, with the climate factor at times, having a direct impact on health (e.g., flooding causing injuries) and in other cases, having an indirect impact (e.g., flooding causing stress which in turn may cause adverse birth outcomes.)

**Table 2.** Summary of findings from systematic reviews according to health outcome and climate impact. Reviews that covered multiple climate impacts are listed in each relevant category.

Climate Impact	F	Summary of Findings
		<b>Infectious diseases (n = 41)</b>
		<i>Vector borne infectious diseases (n = 25)</i>

Meteorological	22	Systematic reviews suggest that meteorological factors, such as temperature, precipitation, humidity, and wind, are associated with diverse vector-borne infectious diseases, including malaria and dengue. <sup>6,9,20,21,30,32,35-50</sup> This association was mostly proportional (e.g., higher temperature and increased rainfall associated with vector-borne diseases), although findings were at times conflicting, with some suggesting an inversely proportional association <sup>9</sup> (e.g., decreased rainfall) or no association at all <sup>40</sup> (e.g., with the human puumala hantavirus Infection.) Geographic location, seasonality and potential interaction with other climate-related factors may partly explain these inconsistencies. <sup>9,30</sup> Temperature, humidity and rainfall were the most common and important meteorological factors reported by reviews and factors such as wind, air pressure and sunshine were reported less often.
Extreme weather	7	There are limited and conflicting findings concerning the association of extreme weather events with vector-borne diseases. Some reviews suggest water-related extreme events <sup>51</sup> and flooding <sup>3,32,52</sup> are associated with an increased risk of vector-borne diseases, while drought is associated with a reduction of dengue incidence. <sup>9</sup> Other reviews focused specifically on Puerto Rico <sup>43</sup> and Australia <sup>53</sup> did not find an association between hurricanes and/or floods and mosquito-borne disease transmission.
<i>Food and water borne infectious diseases (n = 19)</i>		
Meteorological	14	Reviews suggest that meteorological factors, such as temperature, precipitation, and humidity, are associated with diverse food- and water-borne infectious diseases, in particular, cholera, food poisoning, schistosomiasis, salmonella and E. coli. <sup>8,21,32,41,45,48,54-61</sup> Overall, higher temperatures and humidity, <sup>8,41,54,58</sup> along with lower precipitation <sup>21,61</sup> was associated with these infectious diseases (e.g., E. coli <sup>58</sup> ; bacterial gastrointestinal infections. <sup>54</sup> ) Directionality and strength of the association seemed to vary according to disease and pathogens, <sup>59</sup> seasons, and geographic region. <sup>56</sup>
Extreme weather	10	Reviews suggest a proportional association between extreme water-related events, <sup>47,51,62</sup> such as flooding <sup>3,41,52</sup> and heavy rainfall <sup>35</sup> , and food- and water-borne diseases, including diarrhea, food contamination, cholera. <sup>3,32,35,41,45,47,51,52,57,62</sup> Drought may also be proportionally associated with food- and water-borne disease, <sup>24,35</sup> but these associations are less consistent than those with water-related extreme events. <sup>57</sup>
<i>Other infectious diseases (n = 8)</i>		

Meteorological	8	Reviews suggest an association of most meteorological factors, such as temperature and humidity, with various other infectious diseases, including meningitis, <sup>27,35</sup> Ebola, <sup>27</sup> influenza, <sup>32</sup> and pediatric infectious diseases such as hand-foot-and-mouth disease. <sup>4,5,31,49,55</sup> This association was mostly proportional for meteorological factors such as temperature, <sup>4,5,49</sup> diurnal temperature range, <sup>31</sup> and humidity, <sup>4,5,32</sup> although some meteorological factors, such as air pressure <sup>5</sup> and lower temperatures <sup>32,49</sup> were inversely proportional to these diseases. Some conflicting evidence is reported concerning the association with some meteorological factors, such as sunshine with hand-foot-and-mouth disease, <sup>4,5</sup> and humidity and pediatric infectious diseases. <sup>55</sup> No association was found between some meteorological factors, such as precipitation, wind speed and sunshine with hand-foot-and-mouth disease. <sup>4,5</sup>
<b>Mortality (n = 32)</b>		
Meteorological	24	Reviews suggest that temperature (high, low, or diurnal range) was consistently associated with all-cause and cause-specific mortality. <sup>20,21,27,28,31,34,45,47,49,63–76</sup> A strong association was reported between heat (including heat waves) and mortality (all-cause), <sup>63</sup> heat-, <sup>21,68</sup> stroke-, <sup>27,69</sup> cardiovascular-, <sup>34,47</sup> and respiratory-related, <sup>20,34,70</sup> especially in rural, <sup>67</sup> very young children <sup>49</sup> and ageing populations. <sup>28</sup> Mortality seems to be the most frequent health outcome studied in association with heatwaves. <sup>64</sup> Inconsistent results are found concerning the association between heat and childhood mortality. <sup>74</sup> Due to limited evidence, this association was weaker in some geographical regions. <sup>27,71</sup> Also, heat wave intensity (compared to duration) was more strongly associated with heat-related mortality. <sup>75</sup> Finally, although less studied, low temperature was also associated with mortality, <sup>49,76</sup> specifically respiratory, <sup>63</sup> stroke, <sup>69</sup> and cardiovascular mortality. <sup>47,66,70</sup>
Extreme Weather	5	Reviews suggest an association between extreme weather events such as floods, <sup>3</sup> droughts, <sup>24</sup> cyclones <sup>77</sup> and other water-related events, <sup>20,51</sup> with direct (e.g., drowning) and indirect long-term mortality (e.g., due to malnutrition, environmental toxin exposure, armed conflict, etc.). <sup>3,24,51,77</sup>
Air quality	5	Reviews suggest an association between exposure to air pollution <sup>20,78</sup> or wildfire smoke <sup>79–81</sup> and air pollution related-mortality, such as respiratory-specific mortality. There is currently limited evidence, but reviews suggest a potential association between wildfire smoke exposure and cardiovascular-specific mortality. <sup>79–81</sup>
<b>Respiratory, neurological, cardiovascular and cardiopulmonary (n = 22)</b>		

Meteorological	17	Reviews suggest an association between meteorological factors, such as temperature and humidity, and cardiopulmonary, cardiovascular, respiratory and neurological outcomes. <sup>20,26,27,31,34,37,45,49,55,63,66,68,69,73,74,82,83</sup> Exposure to high temperatures and extreme heat are associated to cardiovascular and respiratory diseases, <sup>20,27,37,49,66</sup> stroke, <sup>69</sup> long-term neurological outcomes (due to heat strokes), <sup>68</sup> myocardial infarction, <sup>34,83</sup> and childhood asthma and pediatric respiratory diseases. <sup>26,74</sup> A review also suggests a beneficial association between heat and the shortening of a respiratory virus season. <sup>45</sup> Exposure to low temperature (cold), temperature drop, or diurnal temperature range was associated with cardiovascular and respiratory diseases, <sup>31,63,66</sup> stroke, <sup>69</sup> and myocardial infarctions. <sup>34</sup> Humidity (most often high humidity, but also lower humidity) and low temperatures were also associated with respiratory diseases in children, including childhood asthma. <sup>26,55,82</sup>
Extreme Weather	1	A previous review suggests an association between drought and respiratory, cardiovascular and cardiopulmonary outcomes, most likely due to droughts leading to increased dust in the air. <sup>24</sup>
Air quality	6	Reviews suggest a proportional association between exposure to air pollution <sup>20,21,45</sup> or wildfire smoke exposure <sup>79-81</sup> and respiratory outcomes, including asthma, chronic obstructive pulmonary disease, coughing, wheezing, and overall lung function. Although there is currently limited evidence, <sup>79</sup> reviews also suggest a potential association between air pollution or wildfire smoke exposure and cardiovascular outcomes. <sup>45,80,81</sup>
<b>Health systems (n = 16)</b>		
General	1	A previous review suggests that climate change in general puts a strain on public health resources, via population health issues and shows that using an integrated surveillance system may guide future adaptation to climate change. <sup>84</sup>
Meteorological	11	Previous reviews suggest an association between temperature change <sup>31</sup> extreme heat, aridity and cold temperatures and an increase in use of healthcare services (mostly linked to heat-related health impacts), such as an increase in emergency department visits, hospital admissions and use of ambulances. <sup>20,21,27,31,34,49,64,71,74,83,85</sup>
Extreme weather	2	Reviews suggest that extreme weather events <sup>33</sup> and flooding <sup>3</sup> are associated with an increase in use of healthcare services (e.g., increased hospitalizations) and a compromised quality of care as extreme weather events may lead to power outages. <sup>33</sup>
Air quality	2	Reviews suggest an association between wildfire smoke exposure and an increase in use of healthcare services, such as an increase in emergency department visits. <sup>79,81</sup>
<b>Mental health (n = 13)</b>		



Meteorological	3	Reviews suggest an association of most meteorological factors such as temperature increase, aridity, heat, and heat waves with mental health outcomes, including hospital admissions for mental health reasons, <sup>21</sup> suicide, <sup>86</sup> and exacerbation of pre-existing mental health conditions, difficulty sleeping, and fatigue. <sup>83</sup> No association was found between sunlight duration and suicide incidence. <sup>86</sup>
Extreme weather	9	Most reviews reported a proportional association of extreme weather events, <sup>45,51,87,88</sup> flooding, <sup>3,20,89</sup> and drought <sup>24,25</sup> with diverse mental health issues, including, psychological distress, post-traumatic stress disorder, anxiety, depression, psychotropic medication use, alcohol consumption. There was conflicting evidence regarding the association of floods with suicide, tobacco, alcohol and substance abuse. <sup>89</sup> No association was found between drought and suicide. <sup>24</sup>
Air quality	1	A previous review suggests no association between wildfire smoke exposure and mental health, as measured by physician visits and hospitalizations for mental health reasons during wildfires. <sup>80</sup>
<b>Pregnancy and birth outcomes (n = 11)</b>		
Meteorological	5	Reviews suggest that adverse birth outcomes are higher among people exposed to meteorological factors such as high temperature, heat, sunlight intensity, cold and humidity. <sup>21,90–93</sup> These outcomes include low birth weight, preterm birth, eclampsia and preeclampsia, hypertension and length of pregnancy. <sup>21,90–93</sup> The association between heat and adverse birth outcomes seems to have stronger support than the association with cold temperatures. <sup>93</sup>
Extreme Weather	2	Reviews suggest an association of extreme weather events <sup>87</sup> and flooding <sup>3</sup> with adverse birth outcomes, such as low birth weight, preterm birth and pre-eclampsia. It is suggested that extreme weather events may indirectly affect birth outcomes via the pregnant person's well-being (e.g., stress and worry during pregnancy.) <sup>3,87</sup>
Air quality	3	There is limited and inconsistent evidence concerning the association between wildfire smoke exposure and adverse birth outcomes, but reviews suggest a potential proportional association between wildfire smoke exposure and lower birth weight. <sup>79–81</sup>
Other	1	The association between environmental pollutants and adverse birth outcomes (i.e., preterm birth) remains unclear due to conflicting evidence. <sup>29</sup>
<b>Dietary (n = 9)</b>		
General	1	A review suggests an association between climate change and obesity. <sup>22</sup>
Meteorological	4	Reviews suggest an association between meteorological factors, such as changes in temperature, heat and precipitation, with diverse dietary outcomes, including undernutrition, malnutrition and child stunting. <sup>21,23,27,71</sup> This association may be

		explained by the impact of meteorological factors, such as temperature increase and precipitation decrease, on crop production and food insecurity. <sup>21,71</sup>
Extreme Weather	6	Reviews suggest an association between extreme weather events, such as flooding and droughts, <sup>24</sup> and diverse dietary outcomes, including malnutrition and undernutrition in children and adults <sup>21,23,35,45,47</sup> via, amongst others, crops production and food insecurity (e.g., low food aid following flooding <sup>21</sup> ).
Other	1	A review suggests an association between certain environmental risk factors (e.g., sanitation, cooking fuels and food-borne mycotoxins), and childhood stunting, which could be aggravated by climate change. <sup>94</sup>
<b>Skin and allergies (n = 9)</b>		
General	2	Reviews suggest a proportional association between climate change, in general, and skin and soft tissue infections (e.g., fatal vibrio vulnificus necrotizing) <sup>95</sup> and ragweed pollen allergies in Europe. <sup>96</sup>
Meteorological	7	Reviews suggest an association of meteorological factors, such as ultraviolet light exposure, temperature and humidity, with diverse skin and allergic diseases, including skin cancer, sunburn, acute urticaria, eczema and pediatric allergies and skin irritabilities. <sup>27,45,47,49,55,83,97</sup> Higher temperature and ultraviolet light exposure is proportionally associated with sunburn <sup>83</sup> and skin cancer, <sup>45,97</sup> while low humidity and low temperatures were associated with eczema and skin irritabilities in children. <sup>49,55</sup>
<b>Occupational health and injuries (n = 6)</b>		
Meteorological	6	Reviews suggest that heat is associated with adverse occupational health outcomes, including injuries, heat strain, dehydration and kidney diseases. <sup>98–103</sup> The most frequent injuries consist of 'slips, trips, falls, wounds, lacerations and amputations.' <sup>99</sup> This association was found in many occupational settings, including agriculture, construction, transport and fishing, and seems to affect both outdoor and indoor workers. <sup>98</sup> This association may be explained by a combination of direct (e.g., dehydration) and indirect factors (e.g., impaired cognitive and physical performance.) <sup>102</sup>
Other	1	A review suggests an association between environmental pollution (e.g., heavy metals, fertilizers, etc.) and occupational diseases, such as chronic kidney disease. <sup>103</sup> This association is suggested to be affected by increasing temperatures.
<b>Other (n = 17)</b>		

General	1	A review suggests an association between climate change in general and disability-adjusted life years, which is an indicator that quantifies 'the burden of disease attributable to climate change'. <sup>104</sup> Authors suggest that the cost of disability-adjusted life years could be high, especially in low to middle income countries.
Meteorological	10	Reviews suggests an association between increasing temperatures and temperature changes, <sup>31</sup> and other various health outcomes, including acute gouty arthritis, <sup>105</sup> unintentional injuries, <sup>106</sup> diabetes, <sup>63</sup> genitourinary diseases, <sup>31,63</sup> impaired sleep time and quality, <sup>107</sup> cataracts (indirectly associated via people spending more time outside and therefore increased exposure to ultraviolet light), <sup>45,47</sup> heat stress, heat exhaustion and kidney failure, <sup>83</sup> and renal diseases, fever and electrolyte imbalance in children. <sup>49,74</sup>
Extreme weather	6	Reviews suggests an association between extreme weather events, <sup>88</sup> such as flooding, <sup>3</sup> cyclones, <sup>77</sup> hurricanes, <sup>107</sup> and drought, <sup>24</sup> and other various health outcomes including injuries (e.g., debris, diving in water that is shallower than expected), <sup>3,24,77,88</sup> impaired sleep, <sup>107</sup> esophageal cancer (likely linked to high salinity of water due to droughts), <sup>24</sup> and exacerbation of chronic illnesses. <sup>3,87</sup>
Air quality	1	There is limited evidence, but a systematic review suggests an association between wildfire smoke exposure and ophthalmic outcomes, such as eye irritation and cataracts. <sup>79</sup>

## Discussion

### Principal results

In this overview of systematic reviews, we aimed to develop an overview of systematic reviews of health impacts of climate change by mapping the characteristics and findings of studies exploring the relationship between climate change and health. We identified four key findings.

First, the most common climate impact studied by included publications consists of meteorological impacts (e.g., temperature, heat, precipitation and humidity), which aligns with findings from a previous scoping review on the health impacts of climate change in the Philippines.<sup>7</sup> Although this may not be surprising given that a key implication of climate change is the rise in temperature, this finding suggests we also need to undertake research focused on other climate impacts on health, such as the impact of droughts and wildfire smoke, to better prepare for the health crises that arise from these multiple climate-related impacts.

Second, systematic reviews primarily focus on physical health outcomes, such as infectious diseases, mortality, and respiratory, cardiopulmonary, cardiovascular and neurological outcomes, which also aligns with the country-specific previous scoping review.<sup>7</sup> Regarding mortality, we support Campbell and colleagues'<sup>64</sup> suggestion that we should expand our focus

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3 to include other types of health outcomes. This will allow us to better mitigate and adapt to the  
4 full range of threats of climate change.  
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7 It is unclear whether the distribution of frequencies of health outcomes reflects the actual burden  
8 of health impacts of climate change, or if the most frequently reported outcomes reflect a bias of  
9 Western definitions of health. The most commonly-studied health outcomes do not necessarily  
10 reflect the definition of health presented by the WHO as, "a state of complete physical, mental  
11 and social well-being and not merely the absence of disease or infirmity."<sup>17</sup> This suggests that  
12 future studies should investigate in greater depth the impacts of climate change on mental and  
13 broader social well-being. Indeed, some reviews suggested that climate change impacts  
14 psychological and social well-being, via broader consequences, such as political instability,  
15 health system capacity, migration, and crime,<sup>83,87</sup> thus illustrating how our personal health is  
16 determined not only by biological and environmental factors but also by social and health  
17 systems.  
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21 Interestingly, the reviews that explored the mental health impacts of climate change were  
22 focused mostly on the direct impacts of experiencing extreme weather events. However,  
23 psychologists are also warning about indirect mental health impacts of climate change, which  
24 are becoming more prevalent for children and adults alike.<sup>108,109</sup> Even people who do not  
25 experience direct climate impacts, such as extreme weather events, report experiencing  
26 disruptive negative emotions when thinking of the destruction of our environment or when  
27 worrying about one's uncertain future and the lack of actions being taken. To foster emotional  
28 resilience in the face of climate change, these mental health impacts of climate change need to  
29 be further explored. Humanity's ability to adapt to and mitigate climate change ultimately  
30 depends on our emotional capacity to face this threat.  
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35 Third, there is a notable geographic difference in the country affiliations of first authors, with  
36 three quarters of systematic reviews having been led by first authors affiliated to institutions in  
37 Europe, Australia, or North America. While perhaps unsurprising given the inequalities in  
38 research funding and institutions concentrated in Western countries, this is of critical importance  
39 given the significant health impacts that will be faced in other parts of the world. Research  
40 funding organizations should seek to provide more resources to authors in low- to middle-  
41 income countries to ensure their expertise and perspectives are better represented in the  
42 literature.  
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46 Fourth, overall, most reviews suggest an association between climate change and the  
47 deterioration of health in various ways, thus illustrating the interdependence of our health and  
48 well-being with the well-being of our environment. At times, climate change and its related  
49 environmental events may impact health directly (e.g., heat's impact on dehydration and  
50 exhaustion) and other times, it may impact it indirectly (e.g., via behaviour change due to heat.)  
51 The climate-health link has been the target of more research in recent years and it is also  
52 receiving increasing attention in both public health and climate communication literature.<sup>110,111</sup>  
53 The health framing of climate communication also has implications for healthcare  
54 professionals<sup>112</sup> and policymakers, as these actors could play a key part in climate  
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3 communication, adaptation, and mitigation. These key stakeholders' perspectives on the  
4 climate-health link, as well as their perceived role in climate adaptation and mitigation could be  
5 explored,<sup>113</sup> since research suggests that health professionals are important voices in climate  
6 communications<sup>112</sup> and especially since, ultimately, these adverse health outcomes will  
7 engender pressure on and cost to our health systems and health workers.  
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## 10 Strengths and Limitations

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12 To the best of our knowledge, the current study provides the first broad overview of previous  
13 systematic reviews exploring the health impacts of climate change. Our review has three main  
14 strengths. First, by targeting systematic reviews, we achieve a higher-order summary of findings  
15 than what would have been possible by consulting individual original studies. Second, by  
16 synthesizing findings across all included studies and according to the combination of climate  
17 impact and health outcome, we offer a clear, detailed, and unique summary of the current state  
18 of evidence and knowledge gaps about how climate change may influence human health. This  
19 summary may be of use to researchers, policymakers, and communities. Third, we included  
20 studies published in all languages about any climate impact and any health outcome. In doing  
21 so, we provide a comprehensive and robust overview.  
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26 Our work has three main limitations. First, we were unable to access some full texts and  
27 therefore some studies were excluded, even though we deemed them potentially relevant after  
28 title and abstract inspection. Other potentially relevant systematic reviews may be missing due  
29 to unseen flaws in our systematic search. Second, due to the heterogeneity of the included  
30 systematic reviews and the relatively small proportion of studies reporting meta-analytic  
31 findings, we could not conduct meta-meta-analyses of findings across reviews. Future research  
32 is needed to quantify the climate and health links described in this review, as well as to  
33 investigate the causal relationship and other interacting factors. Third, due to limited resources,  
34 we did not assess overlap between the included reviews concerning the studies they included.  
35 Frequencies and findings should be interpreted with potential overlap in mind.  
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## 39 Conclusions

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41 Overall, systematic reviews of the health impacts of climate change suggest an association  
42 between climate change and the deterioration of health in multiple ways, generally in the  
43 direction that climate change is associated with adverse human health outcomes. This is  
44 worrisome since these outcomes are predicted to rise in the near future, due to the temperature  
45 rise and increase in climate-change-related events such as extreme weather events and  
46 worsened air quality. Most studies included in this review focused on meteorological impacts of  
47 climate change on adverse physical health outcomes. Future studies could fill knowledge gaps  
48 by exploring other climate-related impacts and broader psychosocial health outcomes.  
49 Moreover, studies on health impacts of climate change have mostly been conducted by first  
50 authors affiliated with institutions in high-income countries. This inequity needs to be addressed,  
51 considering that the impacts of climate change are and will continue to predominantly impact  
52 lower-income countries. Finally, although most reviews also recommend more research to  
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3 better understand and quantify these associations, to adapt to and mitigate climate change's  
4 impacts on health, it will also be important to unpack the 'what, how, and where' of these  
5 effects. Health effects of climate change are unlikely to be distributed equally or randomly  
6 through populations. It will be important to mitigate the changing climate's potential to  
7 exacerbate health inequities.  
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## Ethics Committee Approval

Since this is a systematic review of previous systematic reviews, no ethics approval was required, as we did not collect original data.

## Authors' Contributions

RN, CF, ACT, HOW contributed to the design of the study. CB, RN, LPB, RAPR and HOW contributed to the systematic search of the literature and selection of studies. RR, HOW, LC conducted data analysis and interpretation. RR and HOW drafted the first version of the article with early revision by CB, LC and RN. All authors critically revised the article and approved the final version for submission for publication. RR and HOW had full access to all the data in the study and had final responsibility for the decision to submit for publication.

## Conflict of Interest Statement

The authors have no conflict of interest to declare.

## Data Sharing Statement

No additional data available.

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# Figure Legends

**Figure 1. The flow chart for included articles in this review.**

**Figure 2. Number of included systematic reviews by year of publication.**

**Figure 3. Number of publications according to geographic affiliation of the first author.**

\*Countries of origin within continents in frequency order (highest to lowest frequency) and alphabetical: **Europe:** United-Kingdom (9), Germany (6), Italy (4), Sweden (4), Denmark (2), France (2), Georgia (1), Greece (1) and Finland (1). **Australia:** All Australia. **Asia:** China (11), Iran (4), India (1), Jordan (1), Korea (1), Nepal (1), Philippines (1), Taiwan (1). **North America:** United-States (15), Canada (1). **Africa:** Ethiopia (1), Ghana (1). **South America:** Brazil (1).

**Figure 4. Summary of the combination of climate impact and health outcome**

**(frequencies).** *Note:* The total frequency for one category of health outcome could exceed the number of publications included in this health outcome, since one publication could explore the health impact according to more than one climate factor (e.g., one publication could explore both the impact of extreme weather events and temperature on mental health.)



**PRISMA 2009 Flow Diagram**

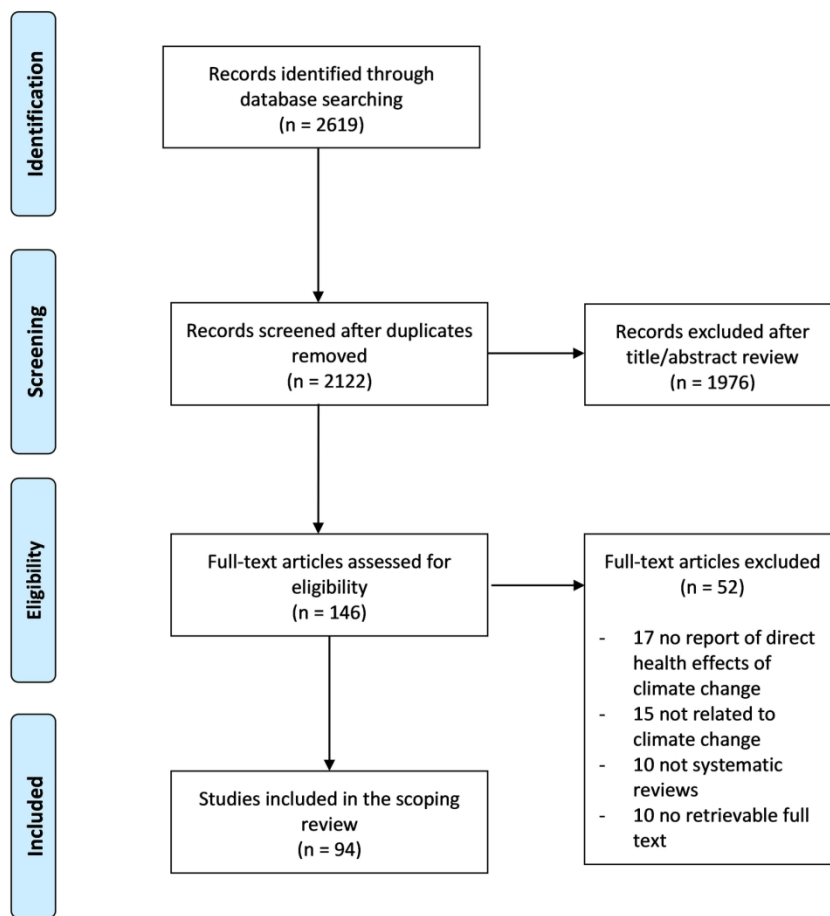


Figure 1. The flow chart for included articles in this review.

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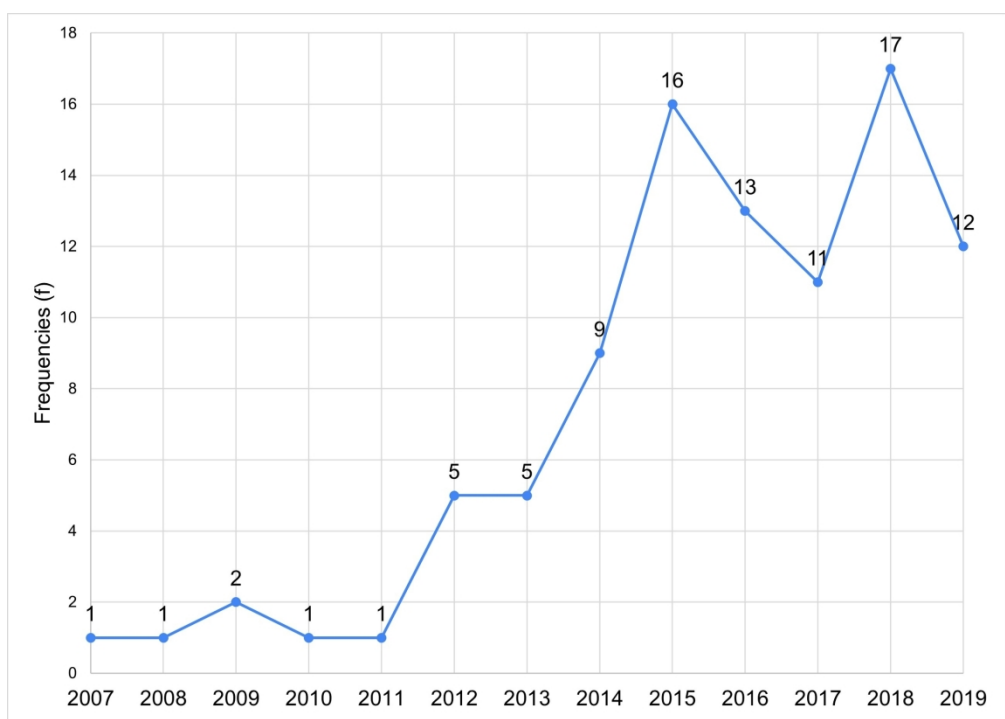


Figure 2. Number of included systematic reviews by year of publication.

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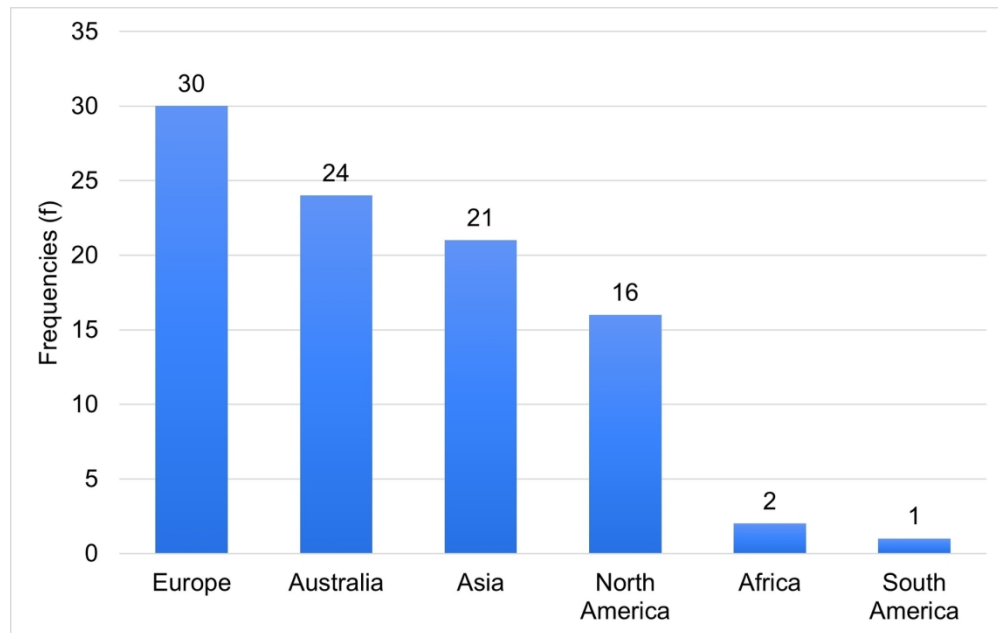


Figure 3. Number of publications according to geographic affiliation of the first author.

\*Countries of origin within continents in frequency order (highest to lowest frequency) and alphabetical: Europe: United-Kingdom (9), Germany (6), Italy (4), Sweden (4), Denmark (2), France (2), Georgia (1), Greece (1) and Finland (1). Australia: All Australia. Asia: China (11), Iran (4), India (1), Jordan (1), Korea (1), Nepal (1), Philippines (1), Taiwan (1). North America: United-States (15), Canada (1). Africa: Ethiopia (1), Ghana (1). South America: Brazil (1).

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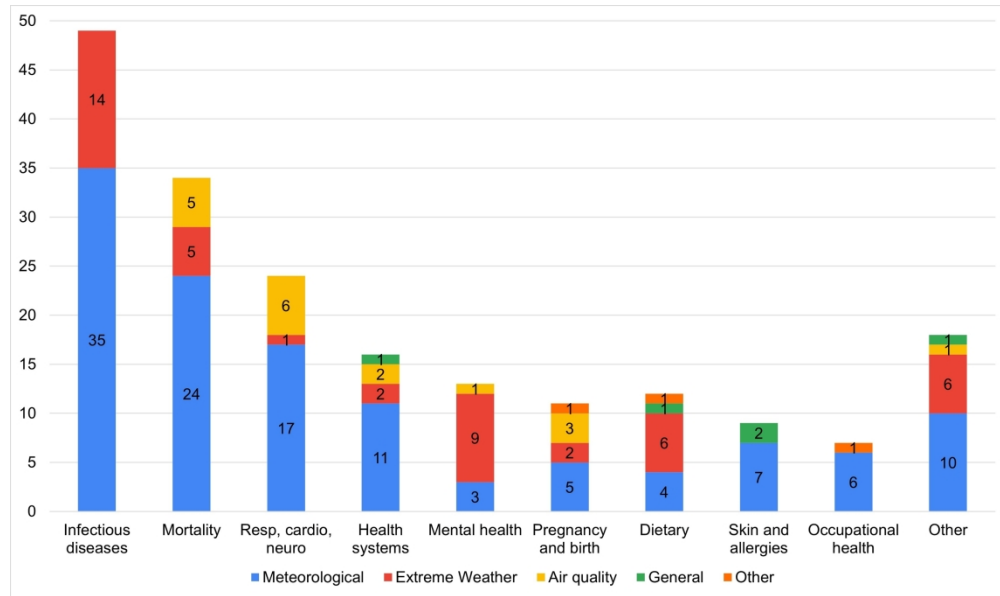


Figure 4. Summary of the combination of climate impact and health outcome (frequencies). Note: The total frequency for one category of health outcome could exceed the number of publications included in this health outcome, since one publication could explore the health impact according to more than one climate factor (e.g., one publication could explore both the impact of extreme weather events and temperature on mental health.)

270x160mm (300 x 300 DPI)

## Appendix 1. Search Strategy

Database: **MEDLINE (OVID)**

No database limit

Concepts	#	Search strategy
Global Warming	1	exp Climate Change/
	2	"Global warming".ti,ab,kw
	3	"Climate Change?".ti,ab,kw
Global Warming combined	4	or/1-3
Systematic review and meta-analysis	5	exp Meta-Analysis as Topic/
	6	"Meta-Analysis"/
	7	Meta-Analysis.ti,ab,kw
	8	"meta analy*".ti,ab,kw
	9	metaanaly*.ti,ab,kw
	10	"Systematic Review"/
	11	"Systematic Reviews as Topic"/
	12	(systematic adj2 review).ti,ab,kw
	13	(review adj1 ("selection criteria" OR "data extraction")).ti,ab
Systematic review and meta-analysis combined	14	or/5-13
Combination of concepts	15	4 AND 14

Database: **Embase.com**

No database limit

Concepts	#	Search strategy
Global Warming	1	'climate change'/de
	2	'greenhouse effect'/de
	3	"Global warming":ti,ab,kw
	4	"Climate Change*":ti,ab,kw
Global Warming combined	5	#1 OR #2 OR #3 OR #4
Systematic review and meta-analysis	6	'meta analysis'/exp
	7	'meta analysis (topic)'/de
	8	Meta-Analysis:ti,ab,kw
	9	"meta analy*":ti,ab,kw
	10	metaanaly*:ti,ab,kw
	11	'systematic review'/de
	12	(systematic NEAR/2 review):ti,ab,kw
	13	(review NEAR/2 ("selection criteria" OR "data extraction")):ti,ab
Systematic review and meta-analysis combined	14	#7 OR #8 OR #9 OR #10 OR #11 OR #12 OR #13 OR #14

Combination of concepts	15	#14 AND #5
Embase database only	16	AND [embase]/lim NOT ([embase]/lim AND [medline]/lim)

Database: **Web of Science**

Limit to: Science Citation Index Expanded (SCI-EXPANDED) and Emerging Sources Citation Index (ESCI) index only

Concepts	#	Search strategy
Global Warming	1	TS=("Global warming" OR "Climate Change\$")
Systematic review and meta-analysis	2	TS=(Meta-Analysis)
	3	TS=("meta analy*")
	4	TS=(metaanaly*)
	5	TS=(systematic NEAR/2 review)
	6	TS=(review NEAR/1 ("selection criteria" OR "data extraction"))
Systematic review and meta-analysis combined	7	#6 OR #5 OR #4 OR #3 OR #2
Combination of concepts	8	#7 AND #1

Database: **CINAHL**

No database limit

Concepts	#	Search strategy
Global Warming	1	MH "Climate Change"



	2	MH "Greenhouse Effect"
	3	TI "Global warming"
	4	TI "Climate Change?"
	5	AB "Global warming"
	6	AB "Climate Change?"
Global Warming combined	7	S1 OR S2 OR S3 OR S4 OR S5 OR S6
Systematic review and meta-analysis	8	MH "Meta Analysis"
	9	TI "Meta-Analysis"
	10	AB "Meta-Analysis"
	11	TI "meta analy**"
	12	AB "meta analy**"
	13	TI metaanaly*
	14	AB metaanaly*
	15	MH "Systematic Review"
	16	TI (systematic N2 review)
	17	AB (systematic N2 review)
	18	TI (review N1 ("selection criteria" OR "data extraction"))
	19	AB (review N1 ("selection criteria" OR "data extraction"))

Systematic review and meta-analysis combined	20	S8 OR S9 OR S10 OR S11 OR S12 OR S13 OR S14 OR S15 OR S16 OR S17 OR S18 OR S19
Combination of concepts	21	S7 AND S20

For peer review only

**Appendix 2.** Summary of AMSTAR-2 items and modified AMSTAR-2 items.

Item #	AMSTAR-2 Original Item	AMSTAR-2 Modifications
1	<p>Did the research questions and inclusion criteria for the review include components of PICO?</p> <ul style="list-style-type: none"> <li>- Population</li> <li>- Intervention</li> <li>- Comparator group</li> <li>- Outcome</li> <li>- Timeframe for follow-up (optional)</li> </ul>	<p>“Population” became “Population and/or location”.</p> <p>“Intervention” became “Exposure”.</p> <p>The “Comparator group” category was taken out.</p> <p>A new section (#1.b)) was created, it includes “Definition of the exposure”, “Definition of the outcome” and “Timeframe for follow up”.</p>
2	<p>Did the report of the review contain an explicit statement that the review methods were established prior to the conduct of the review and did the report justify any significant deviations from the protocol?</p>	<p>To score “yes”, a protocol must have been established before the review. There are no sub-criterias, you can only score yes or no.</p>
3	<p>Did the review authors explain their selection of the study designs for inclusion in the review?</p>	<p>If the study designs are specified, you score “partial yes”. They must be explained to score “yes”. No specific study design is required.</p>
4	<p>Did the review authors use a comprehensive literature search strategy?</p>	<p>The “searched trial/study registries” category was taken out.</p> <p>Justified publication restrictions (e.g. language) moved from (partial yes) to (yes)</p>
5	<p>Did the review authors perform study selection in duplicate?</p>	<p>No modifications.</p>
6	<p>Did the review authors perform data extraction in duplicate?</p>	<p>No modifications.</p>
7	<p>Did the review authors provide a list of excluded studies and justify the exclusion?</p>	<p>The explanation of the inclusion and exclusion criteria is evaluated.</p> <p>If there is only one out of the two, you score “partial yes”. The two must be explained to score “yes”.</p>
8	<p>Did the review authors describe the included studies in adequate detail?</p>	<p>“Populations” became “Populations and/or locations”.</p> <p>“Interventions” became “Exposures”.</p> <p>“Comparator groups” became “Comparator groups (if applicable)”.</p> <p>“Populations and/or locations”, “Exposures” and “Outcomes” must be described in details to score “yes”</p>
9	<p>Did the review authors use a satisfactory technique for assessing the risk of bias (RoB) in individual studies that were included in the review?</p>	<p>“RoB” became “limitations”. Instead of assessing the RoB, the review authors must have used a satisfactory technique for assessing the limitations in individual studies that were included in the review.</p>

10	Did the review authors report on the sources of funding for the studies included in the review?	No modifications.
11	If meta-analysis was performed did the review authors use appropriate methods for statistical combination of results?	No modifications.
12	If meta-analysis was performed, did the review authors assess the potential impact of RoBin individual studies on the results of the meta-analysis or other evidence synthesis	No modifications.
13	Did the review authors account for RoB in individual studies when interpreting/discussing the results of the review?	“RoB” became “limitations”. Instead of accounting for RoB in individual studies, the review authors must have accounted for limitations when interpreting/ discussing the results of the review.
14	Did the review authors provide a satisfactory explanation for, and discussion of, any heterogeneity observed in the results of the review?	No modifications.
15	If they performed quantitative synthesis did the review authors carry out an adequate investigation of publication bias (small study bias) and discuss its likely impact on the results of the review?	No modifications.
16	Did the review authors report any potential sources of conflict of interest, including any funding they received for conducting the review?	No modifications.

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**Appendix 3.** Overview of included studies (N=94) according to study characteristics and summary of climate impacts on health outcomes. Studies are presented in alphabetical order according to the first author's last name.

	First Author	Year	Country	Years of included publications	Years of the studies included in the reviews	# of articles	Meta-analysis	Specific Area of focus	Specific Population of interest	Climate Impact	Health Outcome	Summary of findings
1	Alderman	2012	Australia	2004-2011	1931-2007	35	No			Extreme weather	Infectious diseases Mortality Health systems Mental health Pregnancy and birth Other	Floods are associated with infectious diseases (water- and vector-borne diseases), mortality (e.g., drowning), exacerbation of chronic illnesses, mental health issues (e.g., PTSD), hospital admissions, pregnancy outcomes and injuries.
2	Amegah	2016	Ghana	1995-2014	1960-2010	23	No	Sub-saharan Africa		Meteorological	Infectious diseases Mortality Respiratory, cardiovascular and pulmonary, and neurological outcomes Health systems Dietary Skin and allergies	Temperature and temperature variability are suggested to be associated with infectious diseases, such as Ebola, cardiovascular diseases, mortality, cholera outbreaks, meningitis, undernutrition in children, respiratory outcomes, such as asthma, and skin diseases.
3	An	2018	United States	2002-2017	2002-2016	50	No			General	Dietary	Climate change is associated with obesity. This association can be explained in 4 ways, such that climate change may impact obesity, obesity may impact climate change, both

												factors may be associated with common causes, or both factors may influence each other.
4	Augustin	2008	Germany	1996-2006	NS	320	No	Germany		Meteorological	Skin and allergies	Although skin and allergic diseases are climate sensitive, there is not sufficient evidence to suggest a prediction concerning skin and allergic diseases linked to climate change in Germany.
5	Babaie	2018	Iran	2007-2017	1970-2015	14	No	Iran		Meteorological	Infectious diseases	Temperature, precipitation and humidity are associated with the risk of transmission of Malaria.
6	Bai	2013	China	1995-2011	1951-2010	57	No	China		Meteorological	Infectious diseases	Variability in temperature, precipitation and wind are associated with the risk of transmission of mosquito-borne diseases.
7	Benevolenza	2019	United States	2006-2017	2005-2015	13	No		Vulnerable populations	Extreme weather	Mental health Pregnancy and birth Other	Extreme weather events are associated with an exacerbation of pre-existing chronic health conditions, mental health issues (e.g., PTSD, isolation) and adverse birth outcomes.
8	Berhane	2016	Ethiopia	NS	NS	23	No	Ethiopia		Meteorological Extreme weather	Infectious diseases Dietary	Meteorological factors and extreme weather events are associated with under- and mal- nutrition and the increased risk of climate sensitive infectious diseases (e.g., malaria, diarrhea, zoonotic infections, etc.).
9	Bernhardt	2019	Germany	1997-2017	NS	464	No			Meteorological	Infectious diseases	Rising temperatures are predicted to be associated with myiasis in the future.
10	Binazzi	2019	Italy	NS	1994-2013	8	Yes		Workers	Meteorological	Occupational health and injuries	High temperatures are positively associated with occupational injuries.
11	Bonafede	2016	Italy	2000-2014	1985-2010	8	No		Workers	Meteorological	Occupational health and injuries	Extreme temperature (particularly heat) is associated with occupational injuries.

12	Brown	2013	United Kingdom	2004-2012	1975-2012	38	No	Europe		Extreme weather	Infectious diseases	Floods are associated with infectious diseases, including water-, rodent- and vector-borne diseases (from weeks to months after flooding).
13	Bunker	2016	Germany	1995-2015	1974-2013	61	Yes		Elderly	Meteorological	Mortality Respiratory, cardiovascular and pulmonary, and neurological outcomes Other	Higher and lower temperatures are associated with cardiovascular and respiratory morbidity and mortality. Heat is also associated with diabetes and genitourinary infections.
14	Campbell	2018	Australia	1964-2017	NS	188	No			Meteorological	Mortality Health systems	Most studies exploring the heat impacts on health focus on mortality outcomes, followed by hospital admissions and ambulance call outs.
15	Cann	2013	United Kingdom	1973-2010	NS	83	No			Extreme weather	Infectious diseases	Extreme water-related events are associated with outbreaks of water-related infectious diseases.
16	Carolan-Olah	2014	Australia	1997-2012	1988-2009	7	No			Meteorological	Pregnancy and birth	High temperatures are associated with preterm birth.
17	Cheng	2014	China	1990-2013	1941-2012	25	No		Adults, Elderly, Children	Meteorological	Infectious diseases Mortality Respiratory, cardiovascular and pulmonary, and neurological outcomes Health systems Other	Diurnal temperature range is associated with mortality and cardiovascular and respiratory outcomes, hospital admissions, and Hand Foot Mouth disease in children and genitourinary outcomes among the elderly.
18	Coates	2019	Denmark	2003-2018	NS	72	No			Meteorological	Infectious diseases	Some meteorological factors (temperature, humidity) are positively associated with Hand Foot Mouth

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												disease (HFMD). Precipitation, wind speed and sunshine are not associated with HFMD.
19	Cong	2017	China	1994-2015	1982-2013	26	Yes			Meteorological	Respiratory, cardiovascular and pulmonary, and neurological outcomes	Temperature drop is associated with asthma.
20	Cunrui	2011	Australia	1997-2010	1961-2100	14	No			Meteorological	Mortality	Higher temperature is associated with heat-related mortality.
21	deSousa	2018	Brazil	1976-2016	NS	106	No			Meteorological	Infectious diseases Respiratory, cardiovascular and pulmonary, and neurological outcomes	Meteorological factors (e.g., temperature, precipitation) are associated with infectious diseases (e.g., dengue, malaria) and cardiovascular and respiratory outcomes.
22	Dhimal	2015	Nepal	1956-2014	1948-2098	50	No	Nepal		Meteorological	Infectious diseases	Higher temperatures are associated with the distribution of vector-borne diseases.
23	Doocy	2013	United States	1975-2011	1974-2008	60	No			Extreme weather	Mortality Other	Cyclones are associated with mortality (e.g., drowning) and injuries.
24	Duan	2019	China	2010-2018	2000-2016	51	Yes	Southeast and East Asia		Meteorological	Infectious diseases	Some meteorological factors (mean maximum temperature, rainfall, humidity and sunshine) are positively associated with Hand Foot Mouth disease (HFMD), whereas air pressure is negatively associated with this disease and wind speed is not associated with HFMD.
25	Fan	2015	China	2004-2013	1985-2012	33	Yes			Meteorological	Infectious diseases	Temperature is positively associated with transmission and incidence of Dengue.



26	Fernandez	2015	Australia	1995-2014	NS	83	No			Extreme weather	Mental health	Floods are associated with negative mental health outcomes (e.g., PTSD, increased anxiety, depression, use of psychotropic medication). Conflicting evidence concerning suicide, tobacco, alcohol and substance abuse.
27	Flouris	2018	Greece	1954-2018	NS	111	Yes		Workers	Meteorological	Occupational health and injuries	High temperatures are positively associated with occupational heat strains, dehydration, kidney diseases and injuries.
28	Gao	2019	China	1994-2018	1969-2015	16	Yes			Meteorological	Mental health	Temperature increase is associated with suicide. No association between sunlight duration and suicide.
29	Gao	2014	China	1996-2012	1971-2010	37	No		Children	Meteorological	Infectious diseases Respiratory, cardiovascular and pulmonary, and neurological outcomes Skin and allergies	Ambient humidity is associated with gastrointestinal, respiratory and allergic diseases in children.
30	Ghanizadeh	2017	Iran	2009-2016	1990-2015	13	No			Meteorological	Mortality Respiratory, cardiovascular and pulmonary, and neurological outcomes	Meteorological factors, such as temperature and humidity, are associated with cardiopulmonary health. Cold temperatures are also associated with mortality from heart diseases.
31	Ghazani	2018	Australia	2006-2017	1991-2011	11	No			Meteorological	Infectious diseases	Higher temperature is associated with bacterial gastrointestinal infections. Humidity and rainfall may influence this association.
32	Gracia	2015	Sweden	2003-2011	1959-2008	9	No	Europe		Meteorological	Infectious diseases	Temperature is positively associated with Human Puumala Hantavirus in some regions of Europe. Results

												concerning precipitation and humidity are contradictory or null.
33	Hajat	2010	United Kingdom	1994-2008	1973-2003	11	No			Meteorological	Mortality	Ambient heat is associated with mortality.
34	Hedlund	2014	Sweden	1970-2012	1750-2009	29	No	Arctic, sub-Arctic	Vulnerable populations	Meteorological Extreme weather	Infectious diseases	Higher temperatures and flooding are associated with food- and water-borne diseases. This association is weaker for vector- and rodent-borne diseases. Air temperature and humidity seem to be associated with air-borne diseases.
35	Hii	2016	Sweden	2007-2015	2003-2012	9	No	Malaysia		Meteorological	Infectious diseases	Some meteorological factors (temperature, rainfall and humidity) are associated with Dengue, although these associations are inconsistent at times.
36	Huang	2016	Taiwan	1990-2014	1978-2011	19	Yes			General	Skin and allergies	Climate change, in general, may be associated with skin and soft-tissue infections.
37	Kampe	2016	United Kingdom	1998-2015	1971-2010	13	No	High-income countries		Meteorological	Other	Higher temperature is associated with unintentional injuries.
38	Khader	2015	Jordan	2003-2014	1991-2012	78	No	Eastern Mediterranean	Vulnerable countries	Meteorological Extreme weather Air quality	Infectious diseases Mortality Respiratory, cardiovascular and pulmonary, and neurological outcomes Health systems Mental health Pregnancy and birth	High temperature is associated with mortality. Temperature, humidity and precipitation are associated with vector-, food- and water-borne diseases. Air pollution is associated with respiratory outcomes, although some findings are inconsistent. Higher temperature is associated with mental health outcomes and hospital admissions. Higher temperature may also be associated with adverse birth outcomes. Meteorological and extreme weather events are associated with food insecurity.

											Dietary	
39	Klinger	2014	United Kingdom	2011-2013	NS	20	No			Extreme weather	Health systems	Extreme weather events may lead to power outages which may pose challenges to healthcare quality.
40	Kuehn	2017	United States	2002-2017	NS	28	No		Pregnant people	Meteorological	Pregnancy and birth	Extreme heat exposure is associated with adverse birth outcomes (e.g. stillbirth, birth weight).
41	Lake	2017	United Kingdom	NS	NS	66	No	Europe		General	Skin and allergies	Climate change may be associated with ragweed pollen allergy.
42	Lal	2019	Australia	1982-2011	NS	36	Yes		Children	Meteorological	Infectious diseases	Rainfall is associated with childhood diarrhea, although this association differed according to season and latitude.
43	Lal	2015	Australia	NS	NS	16	No	New Zealand		Meteorological	Infectious diseases	Temperature variability, higher temperature and rainfall are associated with enteric diseases.
44	Lawton	2019	Australia	2000-2015	NS	71	No			Meteorological	Mortality Respiratory, cardiovascular and pulmonary, and neurological outcomes	Heat exposure is associated with heat stroke, long-term neurological outcomes (e.g., cerebellar injury) and heat-related mortality.
45	Levi	2018	Italy	2003-2017	1977-2014	184	No		Workers	Meteorological	Occupational health and injuries	Heat exposure is associated with occupational injuries.
46	Levy	2016	United States	1972-2013	1948-2010	208	No			Meteorological Extreme weather	Infectious diseases	Temperature is associated with bacterial diarrhea and drought is associated with all-cause diarrhea, although few studies explored the association between drought and diarrhea.
47	Leyva	2017	Asia	2009-2017	NS	30	No		Elderly	Meteorological	Infectious diseases Mortality	Meteorological factors, extreme weather events (e.g. typhoon, floods) and air pollution are associated with

										Extreme weather Air quality	Respiratory, cardiovascular and pulmonary, and neurological outcomes Health systems Mental health	mortality and morbidity, especially cardiovascular- and respiratory-specific. Higher temperature is associated with vector-borne diseases. Heat and cold temperatures are associated with hospital admissions. Flooding is associated with mental health outcomes (e.g. PTSD, depression).
48	Li	2018	China	1988-2017	NS	81	No	China		Meteorological Extreme weather	Infectious diseases	Meteorological factors (temperature, precipitation, humidity, air pressure) and extreme weather events (floods, typhoons) are associated with Dengue fever in China.
49	Lian	2015	China	2003-2014	NS	20	Yes			Meteorological	Mortality Respiratory, cardiovascular and pulmonary, and neurological outcomes	Higher and lower temperatures are associated with stroke-related mortality and low temperatures are also associated with stroke-related morbidities.
50	Liu	2015	United States	1990-2014	NS	61	No			Air quality	Mortality Respiratory, cardiovascular and pulmonary, and neurological outcomes Health systems Pregnancy and birth Other	Wildfire smoke exposure is associated with mortality, respiratory outcomes and hospital admissions. Wildfire smoke exposure could also be associated with cardiovascular, ophthalmic and pregnancy outcomes, although more research is needed.
51	Madaniyazi	2015	Australia	2004-2013	1961-2100	15	No			Air quality	Mortality	Air pollution is associated with future mortality.

52	Matysiak	2017	Puerto Rico	2001-2005	NS	26	No	Puerto Rico (United-States)		Meteorological Extreme weather	Infectious diseases	Meteorological factors (higher temperature and increased rainfall) are associated with vector-borne diseases, such as Dengue and Zika. Extreme weather events are less researched, but the few studies investigating this association suggest no association between hurricanes and floods and vector-borne diseases.
53	Moghaddamnia	2017	Iran	2011-2016	1979-2013	26	Yes			Meteorological	Mortality	Higher and lower temperature are associated with cardiovascular mortality.
54	Naish	2014	Australia	NS	1931-2010	16	No			Meteorological	Infectious diseases	Meteorological factors (especially temperature, rainfall and humidity) are associated with Dengue.
55	Nichols	2009	United Kingdom	1999-2008	NS	36	No			Meteorological Extreme weather Air quality	Infectious diseases Mortality Respiratory, cardiovascular and pulmonary, and neurological outcomes Mental health Dietary Skin and allergies Other	Meteorological factors (e.g., higher temperature) are associated with mortality and various infectious diseases. Increased UV exposure is associated with skin cancer and cataracts. Extreme weather events are associated with mortality, injury, mental health outcomes, malnutrition, and food- and water-borne diseases. Air pollution is associated with cardio-respiratory outcomes.
56	Odame	2018	United States	2006-2017	1893-2013	14	Yes		Rural populations	Meteorological	Mortality	Higher temperature is associated with all-cause mortality and cardiovascular specific mortality.
57	Park	2017	Korea	1920-2015	1961-2013	10	Yes			Meteorological	Other	Higher temperature is associated with acute gouty arthritis.
58	Phalkey	2015	Germany	1989-2012	1982-2008	15	No	Low to middle-income	Children	Meteorological	Dietary	Meteorological factors (rainfall, temperature) and extreme weather

								countri es		Extreme weather		events are associated with childhood undernutrition.
59	Philipsborn	2016	Georgi a	NS	1973- 2010	28	Yes			Meteorolo gical	Infectious diseases	Higher temperature is associated with Diarrheagenic Escherichia coli. No significant relationship between rainfall and E. coli.
60	Phung	2015	Australi a	2004- 2013	NS	13	No	Southe ast Asia		Meteorolo gical Extreme weather	Infectious diseases	Meteorological factors (temperature, humidity) and extreme weather events (flooding) are associated with vector- and water-borne infectious diseases.
61	Porpora	2019	Italy	1964- 2019	NS	78	No			Other	Pregnancy and birth	Environmental pollutants may be associated with preterm birth, however this association remains unclear due to conflicting evidence.
62	Poursafa	2015	Iran	2001- 2013	NS	15	No			Meteorolo gical	Pregnancy and birth	Meteorological factors (higher temperature, lower temperature, humidity, sunlight intensity) are associated with adverse birth outcomes (low birth weight, preterm birth, hypertension, eclampsia).
63	Racloz	2012	Australi a	NS	NS	63	No			Meteorolo gical	Infectious diseases	Higher temperature, increased precipitation and humidity are associated with Dengue.
64	Rataj	2016	Germa ny	1981- 2012	1978- 2008	17	No	Low to middle income countri es		Extreme weather	Mental health Other	Extreme weather events are associated with mental health outcomes (e.g., PTSD, anxiety, depression) and injuries.
65	Reid	2016	United States	1990- 2015	NS	53	No		Susceptibl e population s	Air quality	Mortality Respiratory, cardiovascular and pulmonary, and neurological outcomes Mental health	Wildfire smoke exposure is associated with respiratory outcomes (e.g., asthma) and mortality. Wildfire smoke exposure may be associated with cardiovascular, birth, and mental health outcomes, but more research is needed.

											Pregnancy and birth	
66	Rifkin	2018	United States	1995-2017	1992-2016	16	No			Meteorological Extreme weather	Other	Temperature and extreme weather events (hurricanes) are associated with sleep quality.
67	Salve	2018	India	NS	NS	11	No	India		Meteorological	Mortality Health systems Dietary	Increase in temperature is associated with all-cause mortality, cause-specific mortality (e.g., myocardial infarctions, stroke, heart diseases), hospitalizations (e.g., heat-related admissions, neonatal intensive unit admissions), and food insecurity and malnutrition, via agricultural issues.
68	Sanderson	2017	United Kingdom	1988-2017	1900-2101	63	No			Meteorological	Mortality	Higher temperatures and heat waves are associated with mortality and heat-related mortality is likely to increase with increased temperatures.
69	Sawatzky	2018	Canada	2005-2016	NS	85	No	Arctic and Subarctic		General	Health systems	Climate change, in general, is associated with a strain in public health resources, via population health issues and surveillance systems may guide future adaptation to climate change.
70	Semenza	2012	Sweden	1998-2009	1995-2007	722	No			Meteorological	Infectious diseases	Meteorological factors (temperature, rainfall) are associated with some food- and water-borne diseases.
71	Stanke	2013	United Kingdom	1967-2011	1876-1879 and 1961-2010	87	No			Extreme weather	Infectious diseases Mortality Respiratory, cardiovascular and pulmonary, and neurological outcomes Mental health	Droughts are associated with malnutrition, mortality, infectious diseases, cardiovascular and respiratory outcomes, mental health (e.g., increased worry, anxiety), injuries, and cancer.

											Dietary Other	
72	Stensgaard	2019	Denmark	1995-2017	NS	20	No			Meteorological	Infectious diseases	Meteorological factors (temperature, precipitation, humidity) are associated with schistosomiasis and increasing temperatures are likely to affect the geographic range of this parasite.
73	Sun	2018	China	1999-2017	1974-2014	30 (review) 23 meta-analysis	Yes			Meteorological	Mortality Respiratory, cardiovascular and pulmonary, and neurological outcomes Health systems	Heat and cold exposure are associated with myocardial infarctions (MI) and hospitalization for MI. Heat exposure is associated with MI-specific mortality.
74	Swynghedauw	2009	France	NS	NS	NS	No			Meteorological Extreme weather	Infectious diseases Mortality Skin and allergies Other	Heat and cold exposure are associated with mortality and more specifically, respiratory- and cardiovascular-specific mortality. Exposure to UV is associated with skin cancer and cataracts. Higher temperatures are associated with infectious diseases (mosquito- and food-borne diseases) and extreme weather events are associated with undernutrition and food-borne diseases.
75	Tall	2014	Australia	1946-2009	1886-2006	22	No	Australia		Extreme weather	Infectious diseases	There is no strong evidence for the association between flooding and the Ross River Virus.
76	Varghese	2018	Australia	1983-2017	1922-2017	26	No		Workers	Meteorological	Occupational health and injuries	Heat is associated with occupational injuries in many contexts of work (e.g., agriculture, transport, construction, fishing).
77	Veenema	2017	United States	2006-2016	NS	47	No			Extreme weather	Infectious diseases Mortality	Extreme water-related weather events are associated with mortality, water- and vector-borne infectious diseases,



											Mental health	mental health issues (e.g., PTSD, depression, anxiety).
78	Vilcins	2018	Australia	NS	NS	72	No		Children	Other	Dietary	Certain environmental risk factors (e.g., sanitation, cooking fuels), which could be aggravated by climate change, may be associated with childhood stunting.
79	Vins	2015	United States	1995-2005	NS	82	No			Extreme weather	Mental health	Drought is likely associated with adverse mental health outcomes.
80	Waits	2018	Finland	1970-2017	NS	43	No	Arctic		Meteorological	Infectious diseases	Meteorological factors (especially higher temperature and precipitation) are associated with infectious diseases (e.g. tick borne diseases, tularemia) in the Arctic.
81	Wald	2019	United States	2009-2018	NS	17	No	United States		Meteorological	Health systems	Higher temperature is associated with emergency department (heat-related visits) visits and costs for healthcare systems.
82	Welch	2019	United States	NS	NS	91	No			Meteorological	Infectious diseases	Meteorological factors (temperature, precipitation) are associated with Salmonella.
83	Wimalawansa	2016	United States	NS	NS	NS	No	Tropical Countries	Workers	Meteorological Other	Occupational health and injuries	Increasing temperatures and environmental pollution (e.g., heavy metals, fertilizers) are associated with occupational health outcomes, such as chronic kidney disease of multifactorial origin.
84	Witt	2015	Germany	NS	NS	33	Yes		Chronic lung disease patients	Meteorological	Mortality Respiratory, cardiovascular and pulmonary, and neurological outcomes	Heat is associated with lung disease outcomes and mortality in patients with chronic lung diseases.
85	Xu	2018	Australia	2004-2016	1978-2013	19	No		Children	Meteorological	Respiratory, cardiovascular	Heat and cold temperatures are associated with childhood asthma.

											and pulmonary, and neurological outcomes	
86	Xu	2012	Australia	2000-2012	1983-2010	33	No		Children	Meteorological	Infectious diseases Mortality Respiratory, cardiovascular and pulmonary, and neurological outcomes Health systems Skin and allergies Other	Heat and cold are associated with hospital admissions and mortality in children. Temperature is also associated with various infectious diseases (e.g., HFMD, malaria), respiratory diseases (e.g., asthma) and skin outcomes (e.g., eczema). For example, high temperature is associated with Hand Foot Mouth Disease and renal diseases and low temperature is associated with eczema.
87	Xu	2016	Australia	2001-2015	NS	60	Yes			Meteorological	Mortality	Heat waves are associated with mortality and it seems that the intensity of heatwaves is particularly important compared to length of heatwave.
88	Xu	2014	Australia	1998-2012	1983-2009	12	No		Children	Meteorological	Mortality Respiratory, cardiovascular and pulmonary, and neurological outcomes Health systems Other	Heat waves are associated with hospital admissions, respiratory diseases, renal diseases, fever and electrolyte imbalances. Evidence concerning the association between heatwaves and children mortality is inconsistent.
89	Youssouf	2014	France	1990-2011	1987-2008	94	No			Air quality	Mortality	Wildfire smoke exposure is associated with mortality, respiratory and

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											Respiratory, cardiovascular and pulmonary, and neurological outcomes Health systems Pregnancy and birth	cardiovascular outcomes, hospital admissions. Wildfire smoke exposure may also be associated with adverse birth outcomes (low birth weight).
90	Yu	2015	Australia	1998-2012	1961-1990 et 2020-2100	20	No			Meteorological	Infectious diseases	Meteorological factors (temperature, rainfall, humidity) may be associated with future malaria transmission, although findings are inconsistent, partly according to geographical focus.
91	Yu	2012	Australia	1997-2008	1973-2006	15	Yes		Elderly	Meteorological	Mortality	Heat and cold temperatures are associated with mortality for the elderly, although heat-related associations seem stronger than cold-related associations.
92	Zhang	2007	Australia	NS	NS	NS	No		People with disabilities	General	Other	Climate change, in general, may be associated with disability-adjusted life years (DALY), and the cost of DALY could be particularly important in low to middle income countries.
93	Zhang	2017	China	1997-2016	1981-2012	36	No		Pregnant people	Meteorological	Pregnancy and birth	High temperature is associated with adverse birth outcomes, such as preterm birth, low birth weight and stillbirth. Low temperature is also associated with some adverse birth outcomes, including preterm birth and low birth, although the evidence is stronger for high temperature than for low temperatures.
94	Zuo	2015	Australia	NS	NS	173	No			Meteorological	Mortality Respiratory, cardiovascular	Heat waves are associated with mortality, hospital admissions, sunburn, heat exhaustion,

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												and pulmonary, and neurological outcomes Health systems Mental health Skin and allergies Other	cardiovascular outcomes (e.g., heart attacks) and mental health outcomes.
--	--	--	--	--	--	--	--	--	--	--	--	--	--

\*NS = non-specified

For peer review only

**Appendix 4.** Summary of quality assessment according to revised AMSTAR-2 items. (Y = yes, PY = partial yes, N = no, NA = non-applicable).

First author	Year	AMSTAR-2 Items																
		1	1b	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Alderman	2012	Y	N	N	PY	PY	N	N	PY	PY	N	N	NA	NA	Y	N	NA	N
Amegah	2016	Y	N	N	Y	PY	N	N	PY	Y	Y	N	NA	NA	Y	Y	NA	Y
An	2018	N	Y	N	N	PY	Y	N	Y	N	Y	N	NA	NA	Y	N	NA	Y
Augustin	2008	Y	Y	N	N	PY	N	N	PY	N	PY	N	NA	NA	Y	N	NA	Y
Babaie	2018	Y	Y	N	N	PY	Y	N	Y	PY	N	N	NA	NA	N	N	NA	N
Bai	2013	Y	Y	N	PY	PY	N	N	PY	PY	Y	N	NA	NA	Y	N	NA	Y
Benevolenza	2019	Y	Y	N	PY	N	N	N	Y	PY	PY	N	NA	NA	Y	N	NA	N
Berhane	2016	Y	N	Y	N	N	N	N	N	PY	PY	N	NA	NA	Y	N	NA	N
Bernhardt	2019	Y	N	N	N	N	N	N	PY	PY	PY	N	NA	NA	PY	N	NA	Y
Binazzi	2019	Y	Y	N	Y	PY	Y	N	Y	Y	Y	N	Y	Y	Y	Y	Y	Y
Bonafede	2016	Y	N	N	PY	PY	Y	N	Y	Y	Y	N	NA	NA	Y	Y	NA	Y
Brown	2013	Y	Y	N	PY	PY	N	N	Y	Y	PY	N	NA	NA	Y	Y	NA	Y
Bunker	2016	Y	Y	N	Y	N	Y	PY	Y	Y	PY	N	Y	Y	Y	Y	Y	Y
Campbell	2018	Y	N	N	N	PY	N	N	Y	PY	N	N	NA	NA	Y	PY	NA	Y
Cann	2013	Y	Y	Y	PY	PY	N	N	Y	PY	PY	N	NA	NA	Y	Y	NA	Y
Carolan-Olah	2014	Y	Y	N	N	PY	N	N	Y	PY	Y	N	NA	NA	PY	PY	NA	N
Cheng	2014	Y	N	N	PY	PY	N	N	Y	Y	Y	N	NA	NA	Y	PY	NA	N
Coates	2019	N	N	N	N	N	N	N	PY	PY	Y	N	NA	NA	Y	PY	NA	N
Cong	2017	N	Y	N	N	PY	N	Y	Y	Y	Y	N	Y	N	Y	Y	Y	Y
Cunrui	2011	Y	N	N	PY	PY	N	N	Y	PY	N	N	NA	NA	Y	N	NA	Y
deSousa	2018	Y	N	N	PY	PY	N	N	Y	N	N	N	NA	NA	Y	N	NA	Y
Dhimal	2015	Y	Y	N	PY	PY	N	N	Y	Y	N	N	NA	NA	N	N	NA	N
Doocy	2013	Y	N	N	N	PY	Y	N	Y	Y	N	N	NA	NA	Y	PY	NA	Y
Duan	2019	Y	N	N	N	PY	N	N	Y	PY	Y	N	Y	Y	Y	Y	Y	Y
Fan	2015	N	Y	N	N	PY	Y	Y	PY	PY	Y	N	Y	Y	Y	Y	Y	Y
Fernandez	2015	Y	Y	N	PY	PY	Y	N	Y	PY	PY	N	NA	NA	Y	N	NA	N
Flouris	2018	Y	N	Y	PY	PY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Gao	2019	N	Y	N	PY	PY	Y	N	Y	Y	Y	N	Y	Y	Y	Y	Y	Y
Gao	2014	Y	N	N	PY	PY	N	PY	Y	Y	Y	N	NA	NA	Y	Y	NA	Y
Ghanizadeh	2017	N	Y	N	PY	N	Y	PY	Y	PY	Y	N	NA	NA	N	N	NA	Y
Ghazani	2018	N	N	N	N	PY	Y	N	Y	Y	PY	N	NA	NA	Y	PY	NA	Y
Gracia	2015	Y	Y	N	PY	PY	Y	N	Y	PY	Y	N	NA	NA	Y	N	NA	Y
Hajat	2010	Y	N	N	Y	PY	N	N	Y	PY	N	N	NA	NA	N	PY	NA	Y
Hedlund	2014	Y	N	N	PY	N	Y	Y	Y	PY	Y	N	NA	NA	Y	N	NA	Y
Hii	2016	Y	N	N	PY	PY	N	N	PY	PY	N	N	NA	NA	N	N	NA	Y
Huang	2016	N	N	N	N	PY	Y	N	PY	Y	Y	N	Y	Y	Y	PY	N	Y
Kampe	2016	Y	N	N	PY	PY	Y	N	Y	Y	PY	N	NA	NA	Y	N	NA	Y
Khader	2015	Y	N	N	PY	PY	Y	N	Y	Y	N	N	NA	NA	Y	PY	NA	Y
Klinger	2014	N	N	N	N	PY	Y	N	Y	N	Y	N	NA	NA	Y	N	NA	Y
Kuehn	2017	Y	N	N	N	PY	N	N	Y	Y	PY	N	NA	NA	Y	N	NA	Y
Lake	2017	Y	Y	N	N	PY	Y	Y	PY	PY	N	N	NA	NA	N	N	NA	Y
Lal	2019	Y	N	Y	N	PY	N	Y	Y	PY	Y	N	Y	Y	Y	Y	N	Y
Lal	2015	Y	Y	N	N	PY	N	N	Y	PY	PY	N	NA	NA	Y	PY	NA	Y
Lawton	2019	Y	N	N	PY	PY	N	N	Y	Y	N	N	NA	NA	Y	N	NA	Y
Levi	2018	Y	Y	N	PY	PY	Y	N	Y	Y	N	N	NA	NA	Y	PY	NA	Y
Levy	2016	N	N	N	PY	PY	Y	PY	Y	Y	Y	N	NA	NA	Y	Y	NA	Y
Leyva	2017	Y	Y	N	PY	PY	N	N	Y	N	Y	N	NA	NA	Y	N	NA	N
Li	2018	Y	N	N	N	PY	N	N	N	PY	N	N	NA	NA	N	N	NA	Y
Lian	2015	Y	N	N	PY	PY	Y	Y	Y	N	Y	N	Y	Y	Y	Y	Y	Y
Liu	2015	Y	Y	N	Y	PY	N	N	Y	Y	PY	N	NA	NA	Y	PY	NA	Y
Madaniyazi	2015	N	N	N	PY	PY	N	N	Y	PY	N	N	NA	NA	Y	N	NA	Y
Matysiak	2017	Y	Y	N	PY	PY	N	N	Y	PY	Y	N	NA	NA	Y	N	NA	Y
Moghadamnia	2017	Y	N	N	PY	PY	Y	N	Y	Y	Y	N	Y	N	Y	Y	N	Y
Naish	2014	Y	Y	N	PY	PY	N	N	PY	PY	PY	N	NA	NA	Y	N	NA	Y
Nichols	2009	Y	N	N	PY	PY	Y	Y	Y	Y	N	N	NA	NA	N	N	NA	Y
Odame	2018	Y	N	N	PY	PY	N	N	PY	PY	N	N	Y	N	Y	Y	Y	Y
Park	2017	Y	N	N	N	PY	Y	Y	N	PY	Y	N	Y	PY	Y	Y	N	Y
Phalkey	2015	Y	Y	N	PY	PY	Y	Y	Y	PY	PY	N	NA	NA	Y	N	NA	Y

Philipsborn	2016	Y	Y	N	PY	N	N	N	Y	PY	N	N	Y	Y	N	Y	N	Y
Phung	2015	Y	Y	N	N	PY	N	N	Y	Y	PY	Y	NA	NA	N	N	NA	Y
Porpora	2019	Y	Y	Y	PY	PY	N	N	Y	PY	N	N	NA	NA	N	Y	NA	Y
Poursafa	2015	Y	N	N	PY	PY	Y	Y	PY	Y	PY	N	NA	NA	Y	Y	NA	Y
Racloz	2012	Y	N	N	N	PY	N	N	N	PY	N	N	NA	NA	Y	Y	NA	Y
Rataj	2016	Y	Y	Y	PY	PY	Y	Y	PY	PY	Y	N	NA	NA	Y	Y	NA	Y
Reid	2016	Y	N	N	PY	PY	N	N	N	PY	PY	N	NA	NA	Y	PY	NA	Y
Rifkin	2018	Y	Y	Y	PY	PY	Y	Y	Y	PY	N	N	NA	NA	Y	N	NA	Y
Salve	2018	Y	Y	N	N	PY	Y	Y	PY	PY	N	N	NA	NA	Y	N	NA	Y
Sanderson	2017	Y	Y	N	N	PY	Y	N	Y	PY	PY	N	NA	NA	Y	N	NA	Y
Sawatzky	2018	Y	Y	N	N	PY	Y	N	Y	N	N	N	NA	NA	N	N	NA	Y
Semenza	2012	N	N	N	N	N	N	N	N	N	Y	N	NA	NA	N	N	NA	N
Stanke	2013	Y	N	N	PY	PY	N	N	Y	PY	N	N	NA	NA	Y	N	NA	Y
Stensgaard	2019	Y	Y	N	N	PY	N	Y	N	PY	N	N	NA	NA	N	N	NA	Y
Sun	2018	Y	Y	N	PY	PY	N	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y
Swynghedauw	2009	Y	Y	N	N	N	N	N	N	N	N	N	NA	NA	N	N	NA	Y
Tall	2014	Y	N	N	N	PY	N	N	Y	Y	PY	N	NA	NA	Y	N	NA	Y
Varghese	2018	Y	N	N	N	PY	N	N	Y	Y	N	N	NA	NA	Y	N	NA	Y
Veenema	2017	Y	N	Y	N	PY	N	N	Y	N	PY	N	NA	NA	N	N	NA	N
Vilcins	2018	Y	N	Y	N	PY	N	N	Y	N	Y	N	NA	NA	Y	N	NA	Y
Vins	2015	Y	Y	N	N	PY	N	N	Y	N	N	N	NA	NA	Y	PY	NA	Y
Waits	2018	Y	Y	N	N	PY	N	N	Y	N	N	N	NA	NA	N	N	NA	Y
Wald	2019	Y	N	N	N	PY	N	N	Y	Y	N	N	NA	NA	Y	N	NA	N
Welch	2019	Y	Y	N	N	N	N	N	PY	PY	N	N	NA	NA	N	N	NA	N
Wimalawansa	2016	Y	N	N	N	N	N	N	N	N	N	N	NA	NA	N	N	NA	Y
Witt	2015	Y	N	N	N	PY	N	N	Y	N	N	N	N	Y	Y	N	N	Y
Xu	2018	Y	N	N	PY	PY	N	N	PY	PY	N	N	NA	NA	Y	N	NA	Y
Xu	2012	Y	N	N	PY	PY	N	N	PY	Y	PY	N	NA	NA	N	N	NA	Y
Xu	2016	Y	N	N	PY	PY	N	N	Y	Y	N	N	Y	N	Y	Y	N	Y
Xu	2014	Y	Y	N	N	PY	N	N	Y	Y	N	N	NA	NA	N	Y	NA	N
Youssef	2014	Y	Y	N	PY	PY	N	N	Y	Y	N	N	NA	NA	Y	N	NA	Y

Yu	2015	N	N	N	PY	PY	N	N	Y	Y	N	N	NA	NA	Y	PY	NA	Y
Yu	2012	Y	Y	N	PY	N	N	Y	Y	Y	N	N	Y	N	Y	Y	Y	Y
Zhang	2007	Y	N	N	N	N	N	N	N	N	N	N	NA	NA	Y	N	NA	N
Zhang	2017	Y	Y	N	PY	PY	N	N	PY	Y	Y	N	NA	NA	Y	Y	NA	Y
Zuo	2015	Y	Y	N	N	PY	N	N	N	N	N	N	NA	NA	N	N	NA	Y
TOTAL	Yes	81	44	9	5	0	32	17	64	36	31	2	17	12	70	28	11	78
	Partial Yes	0	0	0	47	80	0	4	19	41	22	0	0	1	2	15	0	0
	No	13	50	85	42	14	62	73	11	17	41	92	1	5	22	51	7	16
	Not- Applic able	0	0	0	0	0	0	0	0	0	0	0	0	76	76	0	0	76



**Appendix 5.** Summary table of publications according to climate impact and health outcome according to frequencies and references. References with a \* explore only this specific combination of climate impact and health outcome and therefore appear only once in this table. Number of studies and references (according to alphabetical order) for each combination of categories are presented in the cells. Empty cells in this Table indicate an absence of studies at this combination of categories.

Health Outcome	Climate Impact				
	Meteorological (71)	Extreme weather (24)	Air quality (7)	General (5)	Other (3)
Infectious diseases (41)	<p><b>35</b></p> <p>Amegah, Babaie*, Bai*, Berhane, Bernhardt*, Cheng, Coates*, de Sousa, Dhimal*, Duan*, Fan*, Gao 2014, Ghazani*, Gracia*, Hedlund, Hii*, Khader, Lal 2015*, Lal 2019*, Levy, Leyva, Li, Matysiak, Naish*, Nichols, Philipsborn*, Phung, Racloz*, Semenza*, Stensgaard, Swynghedau, Waits*, Welch*, Xu 2012, Yu 2015*</p>	<p><b>14</b></p> <p>Alderman, Berhane, Brown*, Cann*, Hedlund, Levy, Li, Matysiak, Nichols, Phung, Stanke, Swynghedau, Tall*, Veenema</p>			
Mortality (32)	<p><b>24</b></p> <p>Amegah, Bunker, Campbell, Cheng, Cunrui*, Ghanizadeh, Hajat*, Khader, Lawton, Leyva, Lian, Moghdamnia*, Nichols, Odame*, Salve, Sanderson*, Sun, Swynghedauw, Witt, Xu 2012, Xu 2014, Xu 2016*, Yu 2012*, Zuo</p>	<p><b>5</b></p> <p>Alderman, Doocy, Leyva, Stanke, Veenema</p>	<p><b>5</b></p> <p>Leyva, Liu, Madniyazi*, Reid, Youssouf</p>		
Respiratory, cardio-vascular, cardio-pulmonary and neurological (22)	<p><b>17</b></p> <p>Amegah, Bunker, Cheng, Cong*, de Sousa, Gao 2014, Ghanizadeh, Lawton, Leyva, Lian, Nichols, Sun, Witt, Xu 2012, Xu 2014, Xu 2018*, Zuo</p>	<p><b>1</b></p> <p>Stanke</p>	<p><b>6</b></p> <p>Khader, Leyva, Liu, Nichols, Reid, Youssouf</p>		

1 2 3 4 5 6 7	Health systems (16)	<b>11</b> Amegah, Campbell, Cheng, Khader, Leyva, Salve, Sun, Wald*, Xu 2012, Xu 2014, Zuo	<b>2</b> Alderman, Klinger*	<b>2</b> Liu, Youssouf	<b>1</b> Sawatzky*	
8 9 10 11 12 13	Mental Health (13)	<b>3</b> Gao 2019*, Khader, Zuo	<b>9</b> Alderman, Benevolenza, Fernandez*, Leyva, Nichols, Rataj, Stanke, Veenema, Vins*	<b>1</b> Reid		
14 15 16 17 18 19	Pregnancy and birth outcomes (11)	<b>5</b> Carolan-Olah*, Kuehn*, Poursafa*, Khader, Zhang 2017*	<b>2</b> Alderman, Benevolenza	<b>3</b> Liu, Reid, Youssouf		<b>1</b> Porpora*
20 21 22 23 24	Dietary (9)	<b>4</b> Amegah, Khader, Phalkey, Salve	<b>6</b> Berhane, Khader, Nichols, Phalkey, Stanke, Swynghedauw		<b>1</b> An*	<b>1</b> Vilcins*
25 26 27 28 29	Skin and allergies (9)	<b>7</b> Amegah, Augustin*, Nichols, Gao 2014, Swynghedauw, Xu 2012, Zuo			<b>2</b> Huang*, Lake*	
30 31 32 33 34 35	Occupational health and injuries (6)	<b>6</b> Binazzi*, Bonafede*, Flouris*, Levi*, Varghese*, Wimalawans				<b>1</b> Wimalawans
36 37 38 39 40 41 42 43 44 45 46 47	Other (17)	<b>10</b> Bunker, Cheng, Kampe*, Nichols, Park*, Rifkin, Swynghedauw, Xu 2012, Xu 2014, Zuo	<b>6</b> Alderman, Benevolenza, Doocy, Rataj, Rifkin, Stanke	<b>1</b> Liu	<b>1</b> Zhang 2007*	

# BMJ Open

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# The Health Effects of Climate Change: An Overview of Systematic Reviews

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## Abstract

**Objectives:** We aimed to develop a systematic synthesis of systematic reviews of health impacts of climate change, by synthesizing studies' characteristics, climate impacts, health outcomes, and key findings.

**Design:** We conducted an overview of systematic reviews of health impacts of climate change. We registered our review in PROSPERO (CRD42019145972). No ethical approval was required since we used secondary data. Additional data is not available.

**Data Sources:** On June 22, 2019, we searched Medline, CINAHL, Embase, Cochrane, and Web of Science.

**Eligibility Criteria:** We included systematic reviews that explored at least one health impact of climate change.

**Data Extraction and Synthesis:** We organized systematic reviews according to their key characteristics, including geographical regions, year of publication and authors' affiliations. We mapped the climate effects and health outcomes being studied and synthesized major findings. We used a modified version of AMSTAR-2 to assess the quality of studies.

1  
2  
3 38 Results: We included ninety-four systematic reviews. Most were published after 2015 and  
4 39 approximately one fifth contained meta-analyses. Reviews synthesized evidence about five  
5 40 categories of climate impacts; the two most common were meteorological and extreme weather  
6 41 events. Reviews covered ten health outcome categories; the three most common were 1)  
7 42 infectious diseases, 2) mortality, and 3) respiratory, cardiovascular, or neurological outcomes.  
8 43 Most reviews suggested a deleterious impact of climate change on multiple adverse health  
9 44 outcomes, although the majority also called for more research.

12 45 Conclusions: Most systematic reviews suggest that climate change is associated with worse  
13 46 human health. This study provides a comprehensive higher-order summary of research on  
14 47 health impacts of climate change. Study limitations include the date of the systematic search  
15 48 and that we did not assess for overlap. Future research could explore the potential explanations  
16 49 between these associations to propose adaptation and mitigation strategies and could include  
17 50 broader socio-psychological health impacts of climate change.

## 21 51 Keywords

22 52 Health; Climate Change; Overview of Systematic Reviews; Extreme Weather Events; Air  
23 53 Quality; Global Warming  
24 54

## 28 55 Strengths and limitations of this study

- 31 56
- 32 57 • A strength of this study is that it provides the first broad overview of previous systematic  
33 58 reviews exploring the health impacts of climate change. By targeting systematic reviews,  
34 59 we achieve a higher-order summary of findings than what would have been possible by  
35 60 consulting individual original studies.
  - 36 61 • By synthesizing findings across all included studies and according to the combination of  
37 62 climate impact and health outcome, we offer a clear, detailed, and unique summary of  
38 63 the current state of evidence and knowledge gaps about how climate change may  
39 64 influence human health.
  - 40 65 • A limitation of this study is that we were unable to access some full texts and therefore  
41 66 some studies were excluded, even though we deemed them potentially relevant after  
42 67 title and abstract inspection.
  - 43 68 • Another limitation is that we could not conduct meta-meta-analyses of findings across  
44 69 reviews, due to the heterogeneity of the included systematic reviews and the relatively  
45 70 small proportion of studies reporting meta-analytic findings.
  - 46 71 • Finally, the date of the systematic search is a limitation, as we conducted the search in  
47 72 June 2019.
- 48 71  
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50  
51

## 52 72 Introduction

53 73 The environmental consequences of climate change such as sea-level rise, increasing  
54 74 temperatures, more extreme weather events, increased droughts, flooding, and wildfires are

1  
2  
3 75 impacting human health and lives.<sup>1,2</sup> Previous studies and reviews have documented the  
4 76 multiple health impacts of climate change, including an increase in infectious diseases,  
5 77 respiratory disorders, heat-related morbidity and mortality, undernutrition due to food insecurity,  
6 78 and adverse health outcomes ensuing from increased socio-political tension and conflicts.<sup>2-5</sup>  
7 79 Indeed, the most recent Lancet Countdown report,<sup>2</sup> which investigates 43 indicators of the  
8 80 relationship between climate change and human health, arrived at their most worrisome findings  
9 81 since the beginning of their on-going annual work. This report underlines that the health impacts  
10 82 of climate change continue to worsen and are being felt on every continent, although they are  
11 83 having a disproportionate and unequal impact on populations.<sup>2</sup> Authors caution that these  
12 84 health impacts will continue to worsen unless we see an immediate international response to  
13 85 limiting climate change.  
14 86

15 87 To guide future research and action to mitigate and adapt to the health impacts of climate  
16 88 change and its environmental consequences, we need a complete and thorough overview of the  
17 89 research already conducted regarding the health impacts of climate change. Although the  
18 90 number of original studies researching the health impacts of climate change has greatly  
19 91 increased in the recent decade,<sup>2</sup> these do not allow for an in-depth overview of the current  
20 92 literature on the topic. Systematic reviews, on the other hand, allow a higher-order overview of  
21 93 the literature. Although previous systematic reviews have been conducted on the health impacts  
22 94 of climate change, these tend to focus on specific climate effects (e.g., impact of wildfires on  
23 95 health),<sup>6,7</sup> health impacts (e.g., occupational health outcomes),<sup>8,9</sup> countries,<sup>10-12</sup> or are no longer  
24 96 up to date,<sup>13,14</sup> thus limiting our global understanding of what is currently known about the  
25 97 multiple health impacts of climate change across the world.  
26 98

27 99 In this study, we aimed to develop such a complete overview by synthesizing systematic  
28 100 reviews of health impacts of climate change. This higher-order overview of the literature will  
29 101 allow us to better prepare for the worsening health impacts of climate change, by identifying and  
30 102 describing the diversity and range of health impacts studied, as well as by identifying gaps in  
31 103 previous research. Our research objectives were to synthesize studies' characteristics such as  
32 104 geographical regions, years of publication, and authors' affiliations, to map the climate impacts,  
33 105 health outcomes, and combinations of these that have been studied, and to synthesize key  
34 106 findings.  
35

## 36 107 **Methods**

37 108 We applied the Cochrane method for overviews of reviews.<sup>15</sup> This method is designed to  
38 109 systematically map the themes of studies on a topic and synthesize findings to achieve a  
39 110 broader overview of the available literature on the topic.  
40

## 41 111 **Research questions**

42 112 Our research questions were the following: 1) What is known about the relationship between  
43 113 climate change and health, as shown in previous systematic reviews? 2) What are the  
44 114 characteristics of these studies? We registered our plan (CRD42019145972<sup>16</sup>) in PROSPERO,  
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3 115 an international prospective register of systematic reviews and followed PRISMA 2020<sup>17</sup> to  
4 116 report our findings, as a reporting guideline for overviews is still in development.<sup>18</sup>  
5  
6

## 7 117 Search strategy and selection criteria

8  
9 118 To identify relevant studies, we used a systematic search strategy. There were two inclusion  
10 119 criteria. We included studies in this review if they 1) were systematic reviews of original  
11 120 research and 2) reported at least one health impact as it related (directly or indirectly) to climate  
12 121 change.  
13

14 122  
15 123 We defined a systematic review, based on Cochrane's definition, as a review of the literature in  
16 124 which one "attempts to identify, appraise and synthesize all the empirical evidence that meets  
17 125 pre-specified eligibility criteria to answer a specific research question [by] us[ing] explicit,  
18 126 systematic methods that are selected with a view aimed at minimizing bias, to produce more  
19 127 reliable findings to inform decision making."<sup>19</sup> We included systematic reviews of original  
20 128 research, with or without meta-analyses. We excluded narrative reviews, non-systematic  
21 129 literature reviews and systematic reviews of materials that were not original research (e.g.,  
22 130 systematic reviews of guidelines.)  
23

24 131  
25 132 We based our definition of health impacts on the World Health Organization's (WHO) definition  
26 133 of health as, "a state of complete physical, mental and social well-being and not merely the  
27 134 absence of disease or infirmity."<sup>20</sup> Therefore, health impacts included, among others, morbidity,  
28 135 mortality, new conditions, worsening/improving conditions, injuries, and psychological well-  
29 136 being. Included studies could refer to climate change or global warming directly or indirectly, for  
30 137 instance, by synthesizing the direct or indirect health effects of temperature rises or of natural  
31 138 conditions/disasters made more likely by climate change (e.g., floods, wildfires, temperature  
32 139 variability, droughts.) Although climate change and global warming are not equivalent terms, in  
33 140 an effort to avoid missing relevant literature, we included studies using either term. We included  
34 141 systematic reviews whose main focus was not the health impacts of climate change, providing  
35 142 they reported at least one result regarding health effects related to climate change (or  
36 143 consequences of climate change.) We excluded studies if they did not report at least one health  
37 144 effect of climate change. For instance, we excluded studies which reported on existing  
38 145 measures of health impacts of climate change (and not the health impact itself) and studies  
39 146 which reported on certain health impacts without a mention of climate change, global warming  
40 147 or environmental consequences made more likely by climate change.  
41

42 148  
43 149 On June 22, 2019, we retrieved systematic reviews regarding the health effects of climate  
44 150 change by searching from inception the electronic databases Medline, CINAHL, Embase,  
45 151 Cochrane, Web of Science using a structured search (see Appendix 1 for final search strategy  
46 152 developed by a librarian.) We did not apply language restrictions. After removing duplicates, we  
47 153 imported references into Covidence.<sup>21</sup>  
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## 154 Screening process and data extraction

155 To select studies, two trained analysts first screened independently titles and abstracts to  
156 eliminate articles that did not meet our inclusion criteria. Next, the two analysts independently  
157 screened the full text of each article. A senior analyst resolved any conflict or disagreement.

158  
159 Next, we decided on key information that needed to be extracted from studies. We extracted the  
160 first author's name, year of publication, number of studies included, time frame (in years) of the  
161 studies included in the article, first author's institution's country affiliation, whether the  
162 systematic review included a meta-analysis, geographical focus, population focus, the climate  
163 impact(s) and the health outcome(s) as well as the main findings and limitations of each  
164 systematic review.

165  
166 Two or more trained analysts (RR, CB, RN, LC, LPB, RAPR) independently extracted data,  
167 using Covidence and spreadsheet software (Google Sheets). An additional trained analyst from  
168 the group or senior research team member resolved disagreements between individual  
169 judgments.

## 171 Coding and Data Mapping

172 To summarize findings from previous reviews, we first mapped articles according to climate  
173 impacts and health outcomes. To develop the categories of climate impacts and health  
174 outcomes, two researchers (RR and LC) consulted the titles and abstracts of each article. We  
175 started by identifying categories directly based on our data and finalized our categories by  
176 consulting previous conceptual frameworks of climate impacts and health outcomes.<sup>1,22,23</sup> The  
177 same two researchers independently coded each article according to their climate impact and  
178 health outcome. We then compared coding and resolved disagreements through discussion.

179  
180 Next, using spreadsheet software, we created a matrix to map articles according to their  
181 combination of climate impacts and health outcomes. Each health outcome occupied one row,  
182 whereas climate impacts each occupied one column. We placed each article in the matrix  
183 according to the combination(s) of their climate impact(s) and health outcome(s). For instance, if  
184 we coded an article as 'extreme weather' for climate and 'mental health' for health impact, we  
185 noted the reference of this article in the cell at the intersection of these two codes. We  
186 calculated frequencies for each cell to identify frequent combinations and gaps in literature.  
187 Because one study could investigate more than one climate impact and health outcome, the  
188 frequency counts for each category could exceed the number of studies included in this review.

189  
190 Finally, we re-read the Results and Discussion sections of each article to summarize findings of  
191 the studies. We first wrote an individual summary for each study, then we collated the  
192 summaries of all studies exploring the same combination of categories to develop an overall  
193 summary of findings for each combination of categories.

## 194 Quality assessment

195 We used a modified version of AMSTAR-2 to assess the quality of the included systematic  
196 reviews (Appendix 2). Since AMSTAR-2 was developed for syntheses of systematic reviews of  
197 randomized controlled trials, working with a team member with expertise in knowledge synthesis  
198 (AT), we adapted it to suit a research context that is not amenable to randomized controlled  
199 trials. For instance, we changed assessing and accounting for risk of bias in studies' included  
200 randomized controlled trials to assessing and accounting for limitations in studies' included  
201 articles. Complete modifications are presented in Appendix 2.

## 202 Patient and Public Involvement

203 Patients and members of the public were not involved in this study.

## 204 Results

### 205 Articles identified

206 As shown in the PRISMA diagram in Figure 1, from an initial set of 2619 references, we retained  
207 94 for inclusion. More precisely, following screening of titles and abstracts, 146 studies  
208 remained for full text inspection. During full text inspection, we excluded 52 studies, as they did  
209 not report a direct health effect of climate change (n = 17), did not relate to climate change (n =  
210 15), were not systematic reviews (n = 10), or we could not retrieve the full text (n = 10).

211  
212 **Insert Figure 1 About Here**

### 213 Study Descriptions

214 A detailed table of all articles and their characteristics can be found in Appendix 3. Publication  
215 years ranged from 2007 to 2019 (year of data extraction), with the great majority of included  
216 articles (n = 69; 73%) published since 2015 (Figure 2). A median of 30 studies had been  
217 included in the systematic reviews (mean = 60; SD = 49; range 7 to 722). Approximately one  
218 fifth of the systematic reviews included meta-analyses of their included studies (n = 18; 19%).  
219 The majority of included systematic reviews' first authors had affiliations in high-income  
220 countries, with the largest representations by continent in Europe (n = 30) and Australia (n = 24)  
221 (Figure 3).

222  
223 **Insert Figure 2 About Here**

224  
225 **Insert Figure 3 About Here**

226  
227 Regarding the geographical focus of systematic reviews, most of the included studies (n = 68;  
228 72%) had a global focus or no specified geographical limitations and therefore included studies  
229 published anywhere in the world. The remaining systematic reviews either targeted certain  
230 countries (n = 12) (1 for each Australia, Germany, Iran, India, Ethiopia, Malaysia, Nepal, New

231 Zealand and 2 reviews focused on China and the United States), continents (n = 5) (3 focused  
232 on Europe and 2 on Asia), or regions according to geographical location (n = 6) (1 focused on  
233 Sub-Saharan Africa, 1 on Eastern Mediterranean countries, 1 on Tropical countries, and 3  
234 focused on the Arctic), or according to the country's level of income (n = 3) (2 on low to middle  
235 income countries, 1 on high income countries).

236  
237 Regarding specific populations of interest, most of the systematic reviews did not define a  
238 specific population of interest (n = 69; 73%). For the studies that specified a population of  
239 interest (n = 25; 26.6%), the most frequent populations were children (n = 7) and workers (n =  
240 6), followed by vulnerable or susceptible populations more generally (n = 4), the elderly (n = 3),  
241 pregnant people (n = 2), people with disabilities or chronic illnesses (n = 2) and rural populations  
242 (n = 1).

## 243 Quality assessment

244 We assessed studies for quality according to our revised AMSTAR-2. The purpose of this  
245 assessment was to evaluate the quality of the included studies as a whole to get a sense of the  
246 overall quality of evidence in this field. Therefore, individual quality scores were not compiled for  
247 each article, but scores were aggregated according to items. Complete scores for each article  
248 and each item are available in Appendix 4. Out of 94 systematic reviews, the most commonly  
249 fully satisfied criterion was #1 (PICO components) with 81/94 (86%) of included systematic  
250 reviews fully satisfying this criterion. The next most commonly-satisfied criteria were #16  
251 (potential sources of conflict of interest reported) (78/94 = 83% fully), #13 (account for  
252 limitations in individual studies) (70/94 = 75% fully and 2/94 = 2% partially), #7 (explain both  
253 inclusion and exclusion criteria) (64/94 = 68% fully and 19/94 = 20% partially), #8 (description of  
254 included studies in adequate detail) (36/94 = 38% fully and 41/94 = 44% partially), and #4 (use  
255 of a comprehensive literature search strategy) (0/94 = 0% fully and 80/94 = 85% partially). For  
256 criteria #11, #12, and #15, which only applied to reviews including meta-analyses, 17/18 (94%)  
257 fully satisfied criterion #11 (use of an appropriate methods for statistical combination of results),  
258 12/18 (67%) fully satisfied criterion #12 (assessment of the potential impact of RoB in individual  
259 studies) (1/18 = 6% partially), and 11/18 (61%) fully satisfied criterion #15 (an adequate  
260 investigation of publication bias, small study bias).

## 261 Climate Impacts and Health Outcomes

262 Regarding climate impacts, we identified five mutually exclusive categories, with 13 publications  
263 targeting more than one category of climate impacts: 1) Meteorological (n = 71 papers) (e.g.,  
264 temperature, heat waves, humidity, precipitation), 2) Extreme weather (n = 24) (e.g., water-  
265 related, floods, cyclones, hurricanes, drought), 3) Air quality (n = 7) (e.g., air pollution and  
266 wildfire smoke exposure), 4) General (n = 5), and 5) Other (n = 3). "General" climate impacts  
267 included articles that did not specify climate change impacts but stated general climate change  
268 as their focus. "Other" climate impacts included studies investigating other effects indirectly  
269 related to climate change (e.g., impact of environmental contaminants) or general environmental  
270 risk factors (e.g., environmental hazards, sanitation and access to clean water.)  
271

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2  
3 272 We identified ten categories to describe the health outcomes studied by the systematic reviews,  
4 273 and 29 publications targeted more than one category of health outcomes: 1) Infectious diseases  
5 274 (n = 41 papers) (vector-, food- and water-borne), 2) Mortality (n = 32), 3) Respiratory,  
6 275 cardiovascular, and neurological (n = 23), 4) Healthcare systems (n = 16), 5) Mental health (n =  
7 276 13), 6) Pregnancy and birth (n = 11), 7) Nutritional (n = 9), 8) Skin diseases and allergies (n =  
8 277 8), 9) Occupational health and injuries (n = 6) and 10) Other health outcomes (n = 17) (e.g.,  
9 278 sleep, arthritis, disability-adjusted life years, non-occupational injuries, etc.)  
10  
11 279

12  
13 280 Figure 4 depicts the combinations of climate impact and health outcome for each study, with  
14 281 Appendix 5 offering further details. The 5 most common combinations are studies investigating  
15 282 the 1) meteorological impacts on infectious diseases (n = 35), 2) mortality (n = 24) and 3)  
16 283 respiratory, cardiovascular, and neurological outcomes (n = 17), 4) extreme weather events'  
17 284 impacts on infectious diseases (n = 14), and 5) meteorological impacts on health systems (n =  
18 285 11).  
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20 286

### 21 287 **Insert Figure 4 About Here**

22 288

23  
24 289 For studies investigating meteorological impacts on health, the three most common health  
25 290 outcomes studied were impacts on 1) infectious diseases (n = 35), 2) mortality (n = 24) and 3)  
26 291 respiratory, cardiovascular, and neurological outcomes (n = 17). Extreme weather event studies  
27 292 most commonly reported health outcomes related to 1) infectious diseases (n = 14), 2) mental  
28 293 health outcomes (n = 9) and 3) nutritional outcomes (n = 6) and other health outcomes (e.g.,  
29 294 injuries, sleep) (n = 6). Studies focused on the impact of air quality were less frequent and  
30 295 explored mostly health outcomes linked to 1) respiratory, cardiovascular, and neurological  
31 296 outcomes (n = 6), 2) mortality (n = 5) and 3) pregnancy and birth outcomes (n = 3).  
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## 35 297 **Summary of Findings**

36 298 Most reviews suggest a deleterious impact of climate change on multiple adverse health  
37 299 outcomes, with some associations being explored and/or supported with consistent findings  
38 300 more often than others. Some reviews also report conflicting findings or an absence of  
39 301 association between the climate impact and health outcome studied (see Table 1 for a detailed  
40 302 summary of findings according to health outcomes).  
41  
42 303

43  
44 304 Notable findings of health outcomes according to climate impact include the following. For  
45 305 meteorological factors (n = 71), temperature and humidity are the variables most often studied  
46 306 and report the most consistent associations with infectious diseases and respiratory,  
47 307 cardiovascular, and neurological outcomes. Temperature is also consistently associated with  
48 308 mortality and healthcare service use. Some associations are less frequently studied, but remain  
49 309 consistent, including the association between some meteorological factors (e.g., temperature  
50 310 and heat) and some adverse mental health outcomes (e.g., hospital admissions for mental  
51 311 health reasons, suicide, exacerbation of previous mental health conditions), and the association  
52 312 between heat and adverse occupational outcomes and some adverse birth outcomes.  
53  
54 313 Temperature is also associated with adverse nutritional outcomes (likely via crop production and  
55 314 food insecurity) and temperature and humidity are associated with some skin diseases and  
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3 315 allergies. Some health outcomes are less frequently studied, but studies suggest an association  
4 316 between temperature and diabetes, impaired sleep, cataracts, heat stress, heat exhaustion and  
5 317 renal diseases.  
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7 318  
8 319 Extreme weather events (n = 24) are consistently associated with mortality, some mental health  
9 320 outcomes (e.g., distress, anxiety, depression) and adverse nutritional outcomes (likely via crop  
10 321 production and food insecurity). Some associations are explored less frequently, but these  
11 322 studies suggest an association between drought and respiratory and cardiovascular outcomes  
12 323 (likely via air quality), between extreme weather events and an increased use of healthcare  
13 324 services and some adverse birth outcomes (likely due to indirect causes, such as experiencing  
14 325 stress). Some health outcomes are less frequently studied, but studies suggest an association  
15 326 between extreme weather events and injuries, impaired sleep, esophageal cancer and  
16 327 exacerbation of chronic illnesses. There are limited and conflicting findings for the association  
17 328 between extreme weather events and infectious diseases, as well as for certain mental health  
18 329 outcomes (e.g., suicide and substance abuse). At times, different types of extreme weather  
19 330 events (e.g., drought vs flood) led to conflicting findings for some health outcomes (e.g., mental  
20 331 health outcomes, infectious diseases), but for other health outcomes, the association was  
21 332 consistent independently of the extreme weather event studied (e.g., mortality, healthcare  
22 333 service use and nutritional outcomes).  
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27 334  
28 335 The impact of air quality on health (n = 7) was less frequently studied, but the few studies  
29 336 exploring this association report consistent findings regarding an association with respiratory-  
30 337 specific mortality, adverse respiratory outcomes and an increase in healthcare service use.  
31 338 There is limited evidence regarding the association between air quality and cardiovascular  
32 339 outcomes, limited and inconsistent evidence between wildfire smoke exposure and adverse  
33 340 birth outcomes, and no association is found between exposure to wildfire smoke and increase in  
34 341 use of health services for mental health reasons. Only one review explored the impact of wildfire  
35 342 smoke exposure on ophthalmic outcomes, and it suggests that it may be associated with eye  
36 343 irritation and cataracts.  
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39 344  
40 345 Reviews investigating the general impacts of climate change on health are less frequent (n = 5),  
41 346 but they suggest an association between climate change generally and pollen allergies in  
42 347 Europe, increased use of healthcare services, obesity, skin diseases and allergies and an  
43 348 association with disability-adjusted life years. Reviews investigating the impact of other climate-  
44 349 related factors (n = 3) show inconsistent findings concerning the association between  
45 350 environmental pollutant and adverse birth outcomes, and two reviews suggest an association  
46 351 between environmental risk factors and pollutants and childhood stunting and occupational  
47 352 diseases.  
48

49 353  
50 354 Most reviews concluded by calling for more research, noting the limitations observed among the  
51 355 studies included in their reviews, as well as limitations in their reviews themselves. These  
52 356 limitations included, amongst others, some systematic reviews having a small number of  
53 357 publications,<sup>24,25</sup> language restrictions such as including only papers in English,<sup>26,27</sup> arriving at  
54 358 conflicting evidence,<sup>28</sup> difficulty concluding a strong association due to the heterogeneity in  
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359 methods and measurements or the limited equipment and access to quality data in certain  
 360 contexts,<sup>24,29–31</sup> and most studies included were conducted in high-income countries.<sup>32,33</sup>

361  
 362 Previous authors also discussed the important challenge related to exploring the relationship  
 363 between climate change and health. Not only is it difficult to explore the potential causal  
 364 relationship between climate change and health, mostly due to methodological challenges, but  
 365 there are also a wide variety of complex causal factors that may interact to determine health  
 366 outcomes. Therefore, the possible causal mechanisms underlying these associations were at  
 367 times still unknown or uncertain and the impacts of some climate factors were different  
 368 according to geographical location and specificities of the context. Nonetheless, some reviews  
 369 offered potential explanations for the climate-health association, with the climate factor at times,  
 370 having a direct impact on health (e.g., flooding causing injuries, heat causing dehydration) and  
 371 in other cases, having an indirect impact (e.g., flooding causing stress which in turn may cause  
 372 adverse birth outcomes, heat causing difficulty concentrating leading to occupational injuries.)

373  
 374 **Table 1.** Summary of findings from systematic reviews according to health outcome and climate  
 375 impact. Reviews that covered multiple climate impacts are listed in each relevant category.

Climate Impact	F	Summary of Findings
<b>Infectious diseases (n = 41)</b>		
<i>Vector borne infectious diseases (n = 25)</i>		
Meteorological	22	Systematic reviews suggest that meteorological factors, such as temperature, precipitation, humidity, and wind, are associated with diverse vector-borne infectious diseases, including malaria and dengue. <sup>9,12,26,29,31,34–50</sup> This association was mostly proportional (e.g., higher temperature and increased rainfall associated with vector-borne diseases), although findings were at times conflicting, with some suggesting an inversely proportional association <sup>12</sup> (e.g., decreased rainfall) or no association at all <sup>39</sup> (e.g., with the human puumala hantavirus Infection.) Geographic location, seasonality and potential interaction with other climate-related factors may partly explain these inconsistencies. <sup>12,29</sup> Temperature, humidity and rainfall were the most common and important meteorological factors reported by reviews and factors such as wind, air pressure and sunshine were reported less often.
Extreme weather	7	There are limited and conflicting findings concerning the association of extreme weather events with vector-borne diseases. Some reviews suggest water-related extreme events <sup>51</sup> and flooding <sup>6,31,52</sup> are associated with an increased risk of vector-borne diseases, while drought is associated with a reduction of dengue incidence. <sup>12</sup> Other reviews focused specifically on Puerto Rico <sup>43</sup> and Australia <sup>53</sup> did not find an association between hurricanes and/or floods and mosquito-borne disease transmission.

<i>Food and water borne infectious diseases (n = 19)</i>		
Meteorological	14	Reviews suggest that meteorological factors, such as temperature, precipitation, and humidity, are associated with diverse food- and water-borne infectious diseases, in particular, cholera, schistosomiasis, salmonella and E. coli gastroenteritis. <sup>11,31,40,42,45,48,54–61</sup> Overall, higher temperatures and humidity, <sup>11,40,54,58</sup> along with lower precipitation <sup>42,61</sup> was associated with these infectious diseases. Directionality and strength of the association seemed to vary according to disease and pathogens, <sup>59</sup> seasons, and geographic region. <sup>56</sup>
Extreme weather	10	Reviews suggest a proportional association between extreme water-related events, <sup>47,51,62</sup> such as flooding <sup>6,40,52</sup> and heavy rainfall <sup>34</sup> , and food- and water-borne diseases, including diarrhea, food contamination, cholera. <sup>6,31,34,40,45,47,51,52,57,62</sup> Drought may also be proportionally associated with food- and water-borne disease, <sup>34,63</sup> but these associations are less consistent than those with water-related extreme events. <sup>57</sup>
<i>Other infectious diseases (n = 8)</i>		
Meteorological	8	Reviews suggest an association of most meteorological factors, such as temperature and humidity, with various other infectious diseases, including meningitis, <sup>24,34</sup> Ebola, <sup>24</sup> influenza, <sup>31</sup> and pediatric infectious diseases such as hand-foot-and-mouth disease. <sup>7,8,30,49,55</sup> This association was mostly proportional for meteorological factors such as temperature, <sup>7,8,49</sup> diurnal temperature range, <sup>30</sup> and humidity, <sup>7,8,31</sup> although some meteorological factors, such as air pressure <sup>8</sup> and lower temperatures <sup>31,49</sup> were inversely proportional to these diseases. Some conflicting evidence is reported concerning the association with some meteorological factors, such as sunshine with hand-foot-and-mouth disease, <sup>7,8</sup> and humidity and pediatric infectious diseases. <sup>55</sup> No association was found between some meteorological factors, such as precipitation, wind speed and sunshine with hand-foot-and-mouth disease. <sup>7,8</sup>
<b>Mortality (n = 32)</b>		
Meteorological	24	Reviews suggest that temperature (high, low, or diurnal range) was consistently associated with all-cause and cause-specific mortality. <sup>24–26,30,33,42,45,47,49,64–77</sup> A strong association was reported between heat (including heat waves) and mortality (all-cause), <sup>64</sup> heat-, <sup>42,69</sup> stroke-, <sup>24,70</sup> cardiovascular-, <sup>33,47</sup> and respiratory-related, <sup>26,33,71</sup> especially in rural, <sup>68</sup> very young children <sup>49</sup> and ageing populations. <sup>25</sup> Mortality seems to be the most frequent health outcome studied in association with heatwaves. <sup>65</sup> Inconsistent results are found concerning the association between heat and childhood mortality. <sup>75</sup> Due to limited evidence, this association was weaker in some geographical regions. <sup>24,72</sup> Also, heat wave intensity (compared to duration) was more strongly associated with heat-related mortality. <sup>76</sup> Finally, although less studied, low temperature was also associated with mortality, <sup>49,77</sup> specifically respiratory, <sup>64</sup> stroke, <sup>70</sup> and cardiovascular mortality. <sup>47,67,71</sup>

Extreme Weather	5	Reviews suggest an association between extreme weather events such as floods, <sup>6</sup> droughts, <sup>63</sup> cyclones <sup>78</sup> and other water-related events, <sup>26,51</sup> with direct (e.g., drowning) and indirect long-term mortality (e.g., due to malnutrition, environmental toxin exposure, armed conflict, etc.). <sup>6,51,63,78</sup>
Air quality	5	Reviews suggest an association between exposure to air pollution <sup>26,79</sup> or wildfire smoke <sup>80–82</sup> and air pollution related-mortality, such as respiratory-specific mortality. There is currently limited evidence, but reviews suggest a potential association between wildfire smoke exposure and cardiovascular-specific mortality. <sup>80–82</sup>
<b>Respiratory, neurological, and cardiovascular (n = 23)</b>		
General	1	A review suggests a proportional association between climate change, in general, and ragweed pollen allergies in Europe. <sup>83</sup>
Meteorological	17	Reviews suggest an association between meteorological factors, such as temperature and humidity, and cardiovascular, respiratory and neurological outcomes. <sup>24,26,30,33,36,45,49,55,64,67,69,70,74,75,84–86</sup> Exposure to high temperatures and extreme heat are associated to cardiovascular and respiratory diseases, <sup>24,26,36,49,67</sup> stroke, <sup>70</sup> long-term neurological outcomes (due to heat strokes), <sup>69</sup> myocardial infarction, <sup>33,85</sup> and childhood asthma and pediatric respiratory diseases. <sup>75,86</sup> A review also suggests a beneficial association between heat and the shortening of a respiratory virus season. <sup>45</sup> Exposure to low temperature (cold), temperature drop, or diurnal temperature range was associated with cardiovascular and respiratory diseases, <sup>30,64,67</sup> stroke, <sup>70</sup> and myocardial infarctions. <sup>33</sup> Humidity (most often high humidity, but also lower humidity) and low temperatures were also associated with respiratory diseases in children, including childhood asthma. <sup>55,84,86</sup>
Extreme Weather	1	A previous review suggests an association between drought and respiratory and cardiovascular outcomes, most likely due to droughts leading to increased dust in the air. <sup>63</sup>
Air quality	6	Reviews suggest a proportional association between exposure to air pollution <sup>26,42,45</sup> or wildfire smoke exposure <sup>80–82</sup> and respiratory outcomes, including asthma, chronic obstructive pulmonary disease, coughing, wheezing, and overall lung function. Although there is currently limited evidence, <sup>80</sup> reviews also suggest a potential association between air pollution or wildfire smoke exposure and cardiovascular outcomes. <sup>45,81,82</sup>
<b>Health systems (n = 16)</b>		
General	1	A previous review suggests that climate change in general puts a strain on public health resources, via population health issues and shows that using an integrated surveillance system may guide future adaptation to climate change. <sup>87</sup>
Meteorological	11	Previous reviews suggest an association between temperature change <sup>30</sup> extreme heat, aridity and cold temperatures and an increase in use of healthcare services (mostly linked to heat-related health impacts), such as an increase in emergency



		department visits, hospital admissions and use of ambulances. <sup>24,26,30,33,42,49,65,72,75,85,88</sup>
Extreme weather	2	Reviews suggest that extreme weather events <sup>32</sup> and flooding <sup>6</sup> may be associated with an increase in use of healthcare services (e.g., increased hospitalizations) and a compromised quality of care as extreme weather events may lead to power outages. <sup>32</sup>
Air quality	2	Reviews suggest an association between wildfire smoke exposure and an increase in use of healthcare services, such as an increase in emergency department visits. <sup>80,82</sup>
<b>Mental health (n = 13)</b>		
Meteorological	3	Reviews suggest an association of most meteorological factors such as temperature increase, aridity, heat, and heat waves with mental health outcomes, including hospital admissions for mental health reasons, <sup>42</sup> suicide, <sup>89</sup> and exacerbation of pre-existing mental health conditions, difficulty sleeping, and fatigue. <sup>85</sup> No association was found between sunlight duration and suicide incidence. <sup>89</sup>
Extreme weather	9	Most reviews reported a proportional association of extreme weather events, <sup>45,51,90,91</sup> flooding, <sup>6,26,92</sup> and drought <sup>63,93</sup> with diverse mental health issues, including, psychological distress, post-traumatic stress disorder, anxiety, depression, psychotropic medication use, alcohol consumption. There was conflicting evidence regarding the association of floods with suicide, tobacco, alcohol and substance abuse. <sup>92</sup> No association was found between drought and suicide. <sup>63</sup>
Air quality	1	A previous review suggests no association between wildfire smoke exposure and mental health, as measured by physician visits and hospitalizations for mental health reasons during wildfires. <sup>81</sup>
<b>Pregnancy and birth outcomes (n = 11)</b>		
Meteorological	5	Reviews suggest that adverse birth outcomes may be higher among people exposed to meteorological factors such as high temperature, heat, sunlight intensity, cold and humidity. <sup>42,94–97</sup> These outcomes include low birth weight, preterm birth, eclampsia and preeclampsia, hypertension and length of pregnancy. <sup>42,94–97</sup> The association between heat and adverse birth outcomes seems to have stronger support than the association with cold temperatures. <sup>97</sup>
Extreme Weather	2	Reviews suggest a potential association of extreme weather events <sup>90</sup> and flooding <sup>6</sup> with adverse birth outcomes, such as low birth weight, preterm birth and pre-eclampsia. It is suggested that extreme weather events may indirectly affect birth outcomes via the pregnant person's well-being (e.g., stress and worry during pregnancy.) <sup>6,90</sup>

Air quality	3	There is limited and inconsistent evidence concerning the association between wildfire smoke exposure and adverse birth outcomes, but reviews suggest a potential proportional association between wildfire smoke exposure and lower birth weight. <sup>80–82</sup>
Other	1	The association between environmental pollutants and adverse birth outcomes (i.e., preterm birth) remains unclear due to conflicting evidence. <sup>28</sup>
<b>Nutritional (n = 9)</b>		
General	1	A review suggests an association between climate change and obesity. <sup>98</sup>
Meteorological	4	Reviews suggest an association between meteorological factors, such as changes in temperature, heat and precipitation, with diverse nutritional outcomes, including undernutrition, malnutrition and child stunting. <sup>24,27,42,72</sup> This association may be explained by the impact of meteorological factors, such as temperature increase and precipitation decrease, on crop production and food insecurity. <sup>42,72</sup>
Extreme Weather	6	Reviews suggest an association between extreme weather events, such as flooding and droughts, <sup>63</sup> and diverse nutritional outcomes, including malnutrition and undernutrition in children and adults <sup>27,34,42,45,47</sup> via, amongst others, crops production and food insecurity (e.g., low food aid following flooding <sup>42</sup> ).
Other	1	A review suggests a potential association between certain environmental risk factors (e.g., sanitation, cooking fuels and food-borne mycotoxins), and childhood stunting, which could be aggravated by climate change. <sup>99</sup>
<b>Skin diseases and allergies (n = 8)</b>		
General	1	A review suggests a potential proportional association between climate change, in general, and skin and soft tissue infections (e.g., fatal vibrio vulnificus necrotizing). <sup>100</sup>
Meteorological	7	Reviews suggest an association of meteorological factors, such as ultraviolet light exposure, temperature and humidity, with diverse skin diseases and allergies, including skin cancer, sunburn, acute urticaria, eczema and pediatric skin irritabilities. <sup>24,45,47,49,55,85,101</sup> Higher temperature and ultraviolet light exposure is proportionally associated with sunburn <sup>85</sup> and skin cancer, <sup>45,101</sup> while low humidity and low temperatures were associated with eczema and skin irritabilities in children. <sup>49,55</sup>
<b>Occupational health and injuries (n = 6)</b>		

Meteorological	6	Reviews suggest that heat is associated with adverse occupational health outcomes, including injuries (e.g., slips, trips, falls, wounds, lacerations and amputations), heat strain, dehydration and kidney diseases. <sup>102-107 103</sup> This association was found in many occupational settings, including agriculture, construction, transport and fishing, and seems to affect both outdoor and indoor workers. <sup>102</sup> This association may be explained by a combination of direct (e.g., dehydration) and indirect factors (e.g., impaired cognitive and physical performance.) <sup>106</sup>
Other	1	A review suggests a potential association between environmental pollution (e.g., heavy metals, fertilizers, etc.) and occupational diseases, such as chronic kidney disease. <sup>107</sup> This association is suggested to be affected by increasing temperatures.
<b>Other (n = 17)</b>		
General	1	A review suggests a potential association between climate change in general and disability-adjusted life years, which is an indicator that quantifies 'the burden of disease attributable to climate change'. <sup>108</sup> Authors suggest that the cost of disability-adjusted life years could be high, especially in low to middle income countries.
Meteorological	10	Reviews suggests an association between increasing temperatures and temperature changes, <sup>30</sup> and other various health outcomes, including acute gouty arthritis, <sup>109</sup> unintentional injuries, <sup>110</sup> diabetes, <sup>64</sup> genitourinary diseases, <sup>30,64</sup> impaired sleep time and quality, <sup>111</sup> cataracts (indirectly associated via people spending more time outside and therefore increased exposure to ultraviolet light), <sup>45,47</sup> heat stress, heat exhaustion and kidney failure, <sup>85</sup> and renal diseases, fever and electrolyte imbalance in children. <sup>49,75</sup>
Extreme weather	6	Reviews suggests an association between extreme weather events, <sup>91</sup> such as flooding, <sup>6</sup> cyclones, <sup>78</sup> hurricanes, <sup>111</sup> and drought, <sup>63</sup> and other various health outcomes including injuries (e.g., debris, diving in water that is shallower than expected), <sup>6,63,78,91</sup> impaired sleep, <sup>111</sup> esophageal cancer (likely linked to high salinity of water due to droughts), <sup>63</sup> and exacerbation of chronic illnesses. <sup>6,90</sup>
Air quality	1	There is limited evidence, but a systematic review suggests a potential association between wildfire smoke exposure and ophthalmic outcomes, such as eye irritation and cataracts. <sup>80</sup>

## 376 Discussion

### 377 Principal results

378 In this overview of systematic reviews, we aimed to develop a synthesis of systematic reviews  
379 of health impacts of climate change by mapping the characteristics and findings of studies  
380 exploring the relationship between climate change and health. We identified four key findings.

381  
382 First, the most common climate impact studied by included publications consists of  
383 meteorological impacts, mostly related to temperature and humidity, which aligns with findings  
384 from a previous scoping review on the health impacts of climate change in the Philippines.<sup>10</sup>  
385 Indeed, meteorological factors' impact on all health outcomes are explored, although some  
386 health outcomes are more rarely explored (e.g., mental health and nutritional outcomes).  
387 Although this may not be surprising given that a key implication of climate change is the rise in  
388 temperature, this finding suggests we also need to undertake research focused on other climate  
389 impacts on health, such as the impact of droughts and wildfire smoke, to better prepare for the  
390 health crises that arise from these ever-increasing climate-related impacts. For instance, the  
391 impacts of extreme weather events and air quality on certain health outcomes are not explored  
392 (e.g., skin diseases and allergies, occupational health) or only rarely explored (e.g., pregnancy  
393 outcomes).

394  
395 Second, systematic reviews primarily focus on physical health outcomes, such as infectious  
396 diseases, mortality, and respiratory, cardiovascular and neurological outcomes, which also  
397 aligns with the country-specific previous scoping review.<sup>10</sup> Regarding mortality, we support  
398 Campbell and colleagues<sup>65</sup> suggestion that we should expand our focus to include other types  
399 of health outcomes. This will allow us to better mitigate and adapt to the full range of threats of  
400 climate change.

401  
402 Moreover, it is unclear whether the distribution of frequencies of health outcomes reflects the  
403 actual burden of health impacts of climate change, or if the most frequently-reported outcomes  
404 reflect a bias of Western definitions of health. The most commonly-studied health outcomes do  
405 not necessarily reflect the definition of health presented by the WHO as, "a state of complete  
406 physical, mental and social well-being and not merely the absence of disease or infirmity."<sup>20</sup>  
407 This suggests that future studies should investigate in greater depth the impacts of climate  
408 change on mental and broader social well-being. Indeed, some reviews suggested that climate  
409 change impacts psychological and social well-being, via broader consequences, such as  
410 political instability, health system capacity, migration, and crime,<sup>3,4,85,90</sup> thus illustrating how our  
411 personal health is determined not only by biological and environmental factors but also by social  
412 and health systems. The importance of expanding our scope of health in this field is also  
413 recognized in the most recent Lancet report, which states that future reports will include a new  
414 mental health indicator.<sup>2</sup>

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416 Interestingly, the reviews that explored the mental health impacts of climate change were  
417 focused mostly on the direct and immediate impacts of experiencing extreme weather events.

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3 418 However, psychologists are also warning about the long-term indirect mental health impacts of  
4 419 climate change, which are becoming more prevalent for children and adults alike (e.g., eco-  
5 420 anxiety, climate depression).<sup>112,113</sup> Even people who do not experience direct climate impacts,  
6 421 such as extreme weather events, report experiencing distressing emotions when thinking of the  
7 422 destruction of our environment or when worrying about one's uncertain future and the lack of  
8 423 actions being taken. To foster emotional resilience in the face of climate change, these mental  
9 424 health impacts of climate change need to be further explored. Humanity's ability to adapt to and  
10 425 mitigate climate change ultimately depends on our emotional capacity to face this threat.  
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14 427 Third, there is a notable geographic difference in the country affiliations of first authors, with  
15 428 three quarters of systematic reviews having been led by first authors affiliated to institutions in  
16 429 Europe, Australia, or North America, which aligns with the findings of the most recent Lancet  
17 430 report.<sup>2</sup> While perhaps unsurprising given the inequalities in research funding and institutions  
18 431 concentrated in Western countries, this is of critical importance given the significant health  
19 432 impacts that are currently faced (and will remain) in other parts of the world. Research funding  
20 433 organizations should seek to provide more resources to authors in low- to middle-income  
21 434 countries to ensure their expertise and perspectives are better represented in the literature.  
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25 436 Fourth, overall, most reviews suggest an association between climate change and the  
26 437 deterioration of health in various ways, thus illustrating the interdependence of our health and  
27 438 well-being with the well-being of our environment. At times, climate change and its related  
28 439 environmental events may impact health directly (e.g., heat's impact on dehydration and  
29 440 exhaustion) and other times, it may impact it indirectly (e.g., via behavior change due to heat.)  
30 441 The most frequently explored and consistently supported associations include an association  
31 442 between temperature and humidity with infectious diseases, mortality, and adverse respiratory,  
32 443 cardiovascular and neurological outcomes. Other less frequently studied but consistent  
33 444 associations include associations between climate impacts and increased use of healthcare  
34 445 services, some adverse mental health outcomes, adverse nutritional outcomes, and adverse  
35 446 occupational health outcomes. These associations align with key findings of the most recent  
36 447 Lancet report, in which authors report, amongst others, increasing heat exposure being  
37 448 associated with increasing morbidities and mortality, climate change leading to food insecurity  
38 449 and undernutrition, and to an increase in infectious disease transmission.<sup>2</sup>  
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42 451 That said, a number of reviews included in this study reported limited, conflicting and/or an  
43 452 absence of evidence regarding the association between the climate impact and health outcome.  
44 453 For instance, there was conflicting or limited evidence concerning the association between  
45 454 extreme weather events and infectious diseases, cardiorespiratory outcomes and some mental  
46 455 health outcomes and the association between air quality and cardiovascular-specific mortality  
47 456 and adverse birth outcomes. Finally, most reviews, whether they reported consistent evidence  
48 457 or not, concluded with the need for further research, as these associations are complex and  
49 458 likely determined by multiple interacting factors.  
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53 460 The climate-health link has been the target of more research in recent years and it is also  
54 461 receiving increasing attention from the public and in both public health and climate  
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3 462 communication literature.<sup>2,114–116</sup> However, the health framing of climate change information is  
4 463 still underused in climate communications, and researchers suggest we should be doing more  
5 464 to make the link between human health and climate change more explicit to increase  
6 465 engagement with the climate crisis.<sup>2,116–118</sup> The health framing of climate communication also  
7 466 has implications for healthcare professionals<sup>119</sup> and policymakers, as these actors could play a  
8 467 key part in climate communication, adaptation, and mitigation.<sup>116,117,120</sup> These key stakeholders'  
9 468 perspectives on the climate-health link, as well as their perceived role in climate adaptation and  
10 469 mitigation could be explored,<sup>121</sup> since research suggests that health professionals are important  
11 470 voices in climate communications<sup>119</sup> and especially since, ultimately, these adverse health  
12 471 outcomes will engender pressure on and cost to our health systems and health workers.

## 16 17 472 Strengths and Limitations

18 473 To the best of our knowledge, the current study provides the first broad overview of previous  
19 474 systematic reviews exploring the health impacts of climate change. Our review has three main  
20 475 strengths. First, by targeting systematic reviews, we achieve a higher-order summary of findings  
21 476 than what would have been possible by consulting individual original studies. Second, by  
22 477 synthesizing findings across all included studies and according to the combination of climate  
23 478 impact and health outcome, we offer a clear, detailed, and unique summary of the current state  
24 479 of evidence and knowledge gaps about how climate change may influence human health. This  
25 480 summary may be of use to researchers, policymakers, and communities. Third, we included  
26 481 studies published in all languages about any climate impact and any health outcome. In doing  
27 482 so, we provide a comprehensive and robust overview.

28 483  
29 484 Our work has four main limitations. First, we were unable to access some full texts and  
30 485 therefore some studies were excluded, even though we deemed them potentially relevant after  
31 486 title and abstract inspection. Other potentially relevant systematic reviews may be missing due  
32 487 to unseen flaws in our systematic search. Second, due to the heterogeneity of the included  
33 488 systematic reviews and the relatively small proportion of studies reporting meta-analytic  
34 489 findings, we could not conduct meta-meta-analyses of findings across reviews. Future research  
35 490 is needed to quantify the climate and health links described in this review, as well as to  
36 491 investigate the causal relationship and other interacting factors. Third, due to limited resources,  
37 492 we did not assess overlap between the included reviews concerning the studies they included.  
38 493 Frequencies and findings should be interpreted with potential overlap in mind. Fourth, we  
39 494 conducted the systematic search of the literature in June 2019, and it is therefore likely that  
40 495 some recent systematic reviews are not included in this study.

## 47 48 496 Conclusions

49  
50 497 Overall, most systematic reviews of the health impacts of climate change suggest an  
51 498 association between climate change and the deterioration of health in multiple ways, generally  
52 499 in the direction that climate change is associated with adverse human health outcomes. This is  
53 500 worrisome since these outcomes are predicted to rise in the near future, due to the rise in  
54 501 temperature and increase in climate-change-related events such as extreme weather events

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3 502 and worsened air quality. Most studies included in this review focused on meteorological  
4 503 impacts of climate change on adverse physical health outcomes. Future studies could fill  
5 504 knowledge gaps by exploring other climate-related impacts and broader psychosocial health  
6 505 outcomes. Moreover, studies on health impacts of climate change have mostly been conducted  
7 506 by first authors affiliated with institutions in high-income countries. This inequity needs to be  
8 507 addressed, considering that the impacts of climate change are and will continue to  
9 508 predominantly impact lower-income countries. Finally, although most reviews also recommend  
10 509 more research to better understand and quantify these associations, to adapt to and mitigate  
11 510 climate change's impacts on health, it will also be important to unpack the 'what, how, and  
12 511 where' of these effects. Health effects of climate change are unlikely to be distributed equally or  
13 512 randomly through populations. It will be important to mitigate the changing climate's potential to  
14 513 exacerbate health inequities.  
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## 527 Ethics Committee Approval

528 Since this is a systematic review of previous systematic reviews, no ethics approval was  
529 required, as we did not collect original data.

## 530 Authors' Contributions

531 RN, CF, ACT, HOW contributed to the design of the study. CB, RN, LPB, RAPR and HOW  
532 contributed to the systematic search of the literature and selection of studies. RR, HOW, LC  
533 conducted data analysis and interpretation. RR and HOW drafted the first version of the article  
534 with early revision by CB, LC and RN. All authors critically revised the article and approved the  
535 final version for submission for publication. RR and HOW had full access to all the data in the  
536 study and had final responsibility for the decision to submit for publication.

## 537 Conflict of Interest Statement

538 The authors have no conflict of interest to declare.

## 539 Data Sharing Statement

540 No additional data available.

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## 868 Figure Legends

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870 **Figure 1. The flow chart for included articles in this review.**

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872 **Figure 2. Number of included systematic reviews by year of publication.**

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874 **Figure 3. Number of publications according to geographic affiliation of the first author.**

875 \*Countries of origin within continents in frequency order (highest to lowest frequency) and

876 alphabetical: **Europe:** United-Kingdom (9), Germany (6), Italy (4), Sweden (4), Denmark (2),

877 France (2), Georgia (1), Greece (1) and Finland (1). **Australia:** All Australia. **Asia:** China (11),

878 Iran (4), India (1), Jordan (1), Korea (1), Nepal (1), Philippines (1), Taiwan (1). **North America:**

879 United-States (15), Canada (1). **Africa:** Ethiopia (1), Ghana (1). **South America:** Brazil (1).

880

881 **Figure 4. Summary of the combination of climate impact and health outcome**

882 **(frequencies).** *Note:* The total frequency for one category of health outcome could exceed the

883 number of publications included in this health outcome, since one publication could explore the

884 health impact according to more than one climate factor (e.g., one publication could explore

885 both the impact of extreme weather events and temperature on mental health.



### PRISMA 2009 Flow Diagram

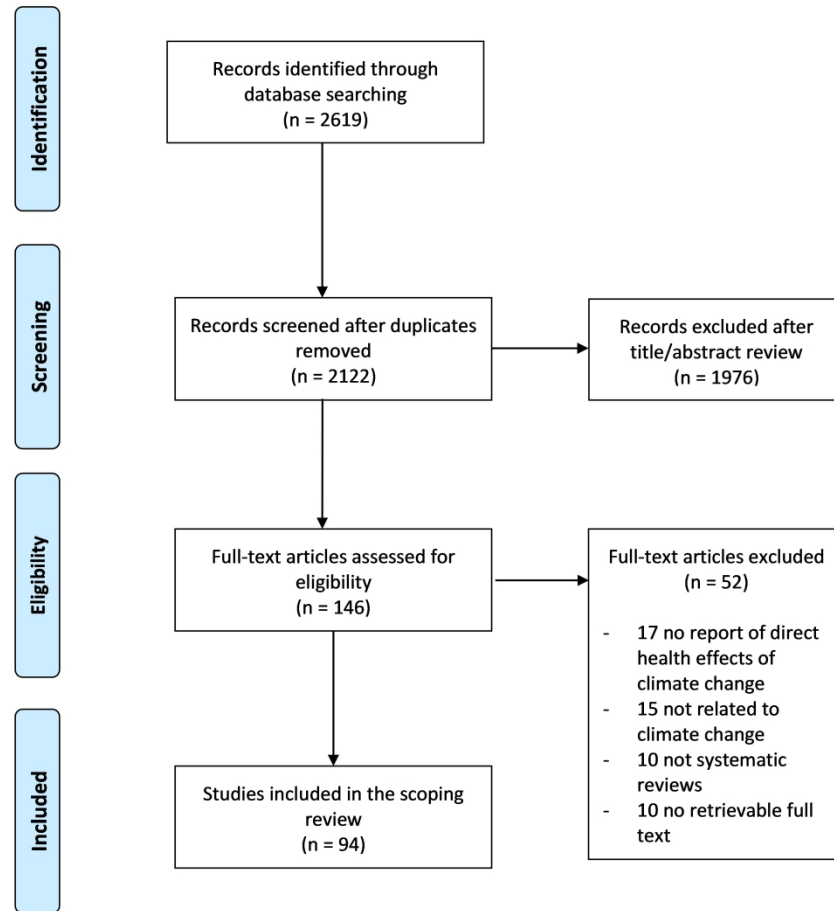


Figure 1. The flow chart for included articles in this review.

165x174mm (600 x 600 DPI)

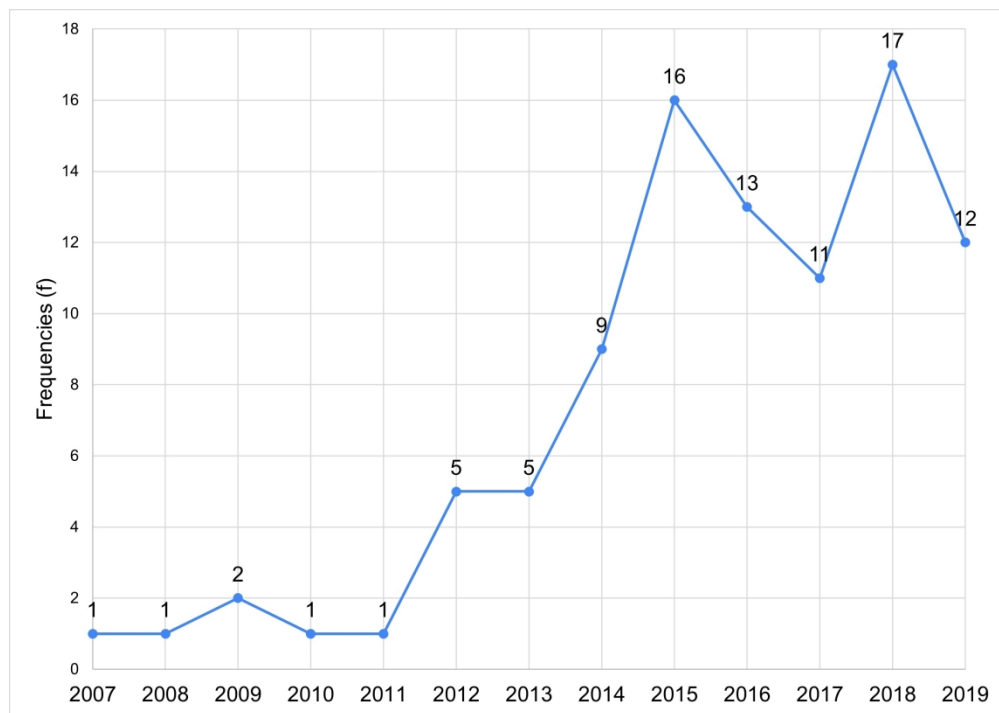


Figure 2. Number of included systematic reviews by year of publication.

199x141mm (330 x 330 DPI)

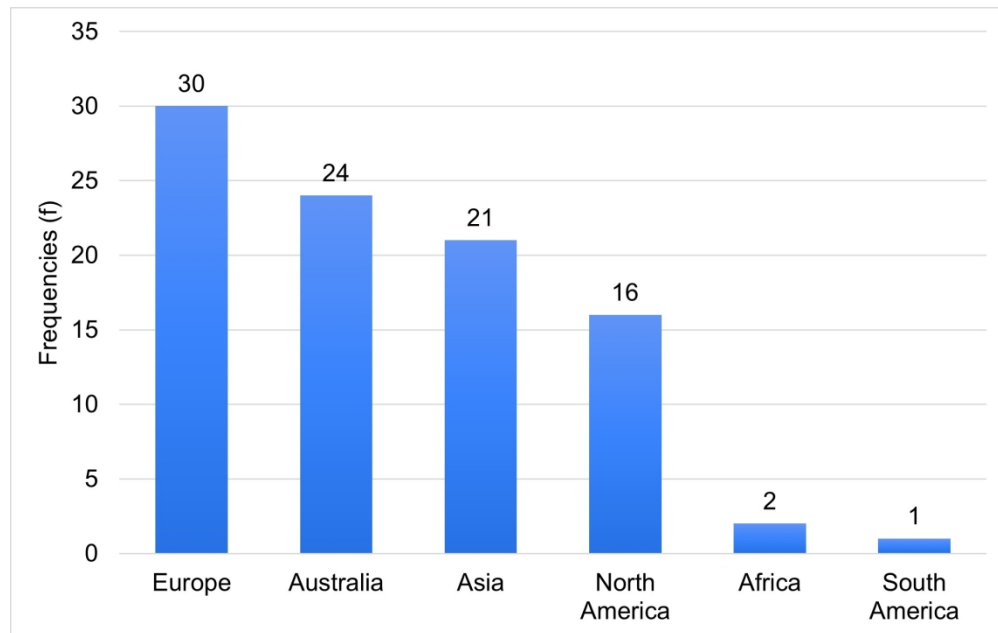
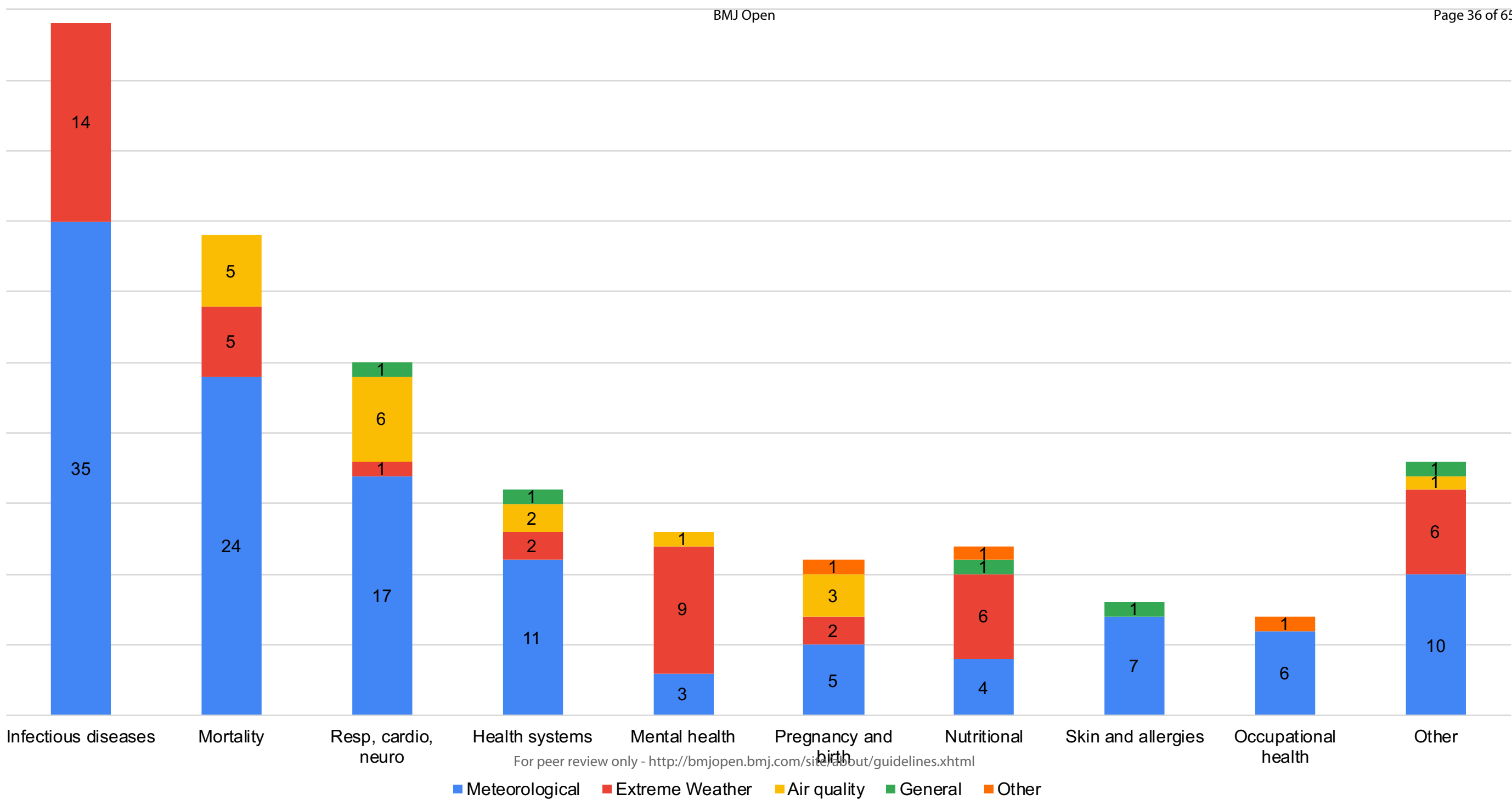


Figure 3. Number of publications according to geographic affiliation of the first author.

\*Countries of origin within continents in frequency order (highest to lowest frequency) and alphabetical: Europe: United-Kingdom (9), Germany (6), Italy (4), Sweden (4), Denmark (2), France (2), Georgia (1), Greece (1) and Finland (1). Australia: All Australia. Asia: China (11), Iran (4), India (1), Jordan (1), Korea (1), Nepal (1), Philippines (1), Taiwan (1). North America: United-States (15), Canada (1). Africa: Ethiopia (1), Ghana (1). South America: Brazil (1).

172x108mm (330 x 330 DPI)



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■ Meteorological ■ Extreme Weather ■ Air quality ■ General ■ Other

## Appendix 1. Search Strategy

Database: **MEDLINE (OVID)**

No database limit

Concepts	#	Search strategy
Global Warming	1	exp Climate Change/
	2	"Global warming".ti,ab,kw
	3	"Climate Change?".ti,ab,kw
Global Warming combined	4	or/1-3
Systematic review and meta-analysis	5	exp Meta-Analysis as Topic/
	6	"Meta-Analysis"/
	7	Meta-Analysis.ti,ab,kw
	8	"meta analy*".ti,ab,kw
	9	metaanaly*.ti,ab,kw
	10	"Systematic Review"/
	11	"Systematic Reviews as Topic"/
	12	(systematic adj2 review).ti,ab,kw
	13	(review adj1 ("selection criteria" OR "data extraction")).ti,ab
Systematic review and meta-analysis combined	14	or/5-13
Combination of concepts	15	4 AND 14



Database: **Embase.com**

No database limit

Concepts	#	Search strategy
Global Warming	1	'climate change'/de
	2	'greenhouse effect'/de
	3	"Global warming":ti,ab,kw
	4	"Climate Change*":ti,ab,kw
Global Warming combined	5	#1 OR #2 OR #3 OR #4
Systematic review and meta-analysis	6	'meta analysis'/exp
	7	'meta analysis (topic)'/de
	8	Meta-Analysis:ti,ab,kw
	9	"meta analy*":ti,ab,kw
	10	metaanaly*:ti,ab,kw
	11	'systematic review'/de
	12	(systematic NEAR/2 review):ti,ab,kw
	13	(review NEAR/2 ("selection criteria" OR "data extraction")):ti,ab
Systematic review and meta-analysis combined	14	#7 OR #8 OR #9 OR #10 OR #11 OR #12 OR #13 OR #14

Combination of concepts	15	#14 AND #5
Embase database only	16	AND [embase]/lim NOT ([embase]/lim AND [medline]/lim)

Database: **Web of Science**

Limit to: Science Citation Index Expanded (SCI-EXPANDED) and Emerging Sources Citation Index (ESCI) index only

Concepts	#	Search strategy
Global Warming	1	TS=("Global warming" OR "Climate Change\$")
Systematic review and meta-analysis	2	TS=(Meta-Analysis)
	3	TS=("meta analy*")
	4	TS=(metaanaly*)
	5	TS=(systematic NEAR/2 review)
	6	TS=(review NEAR/1 ("selection criteria" OR "data extraction"))
Systematic review and meta-analysis combined	7	#6 OR #5 OR #4 OR #3 OR #2
Combination of concepts	8	#7 AND #1

Database: **CINAHL**

No database limit

Concepts	#	Search strategy
Global Warming	1	MH "Climate Change"

	2	MH "Greenhouse Effect"
	3	TI "Global warming"
	4	TI "Climate Change?"
	5	AB "Global warming"
	6	AB "Climate Change?"
Global Warming combined	7	S1 OR S2 OR S3 OR S4 OR S5 OR S6
Systematic review and meta-analysis	8	MH "Meta Analysis"
	9	TI "Meta-Analysis"
	10	AB "Meta-Analysis"
	11	TI "meta analy**"
	12	AB "meta analy**"
	13	TI metaanaly*
	14	AB metaanaly*
	15	MH "Systematic Review"
	16	TI (systematic N2 review)
	17	AB (systematic N2 review)
	18	TI (review N1 ("selection criteria" OR "data extraction"))
	19	AB (review N1 ("selection criteria" OR "data extraction"))

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Systematic review and meta-analysis combined	20	S8 OR S9 OR S10 OR S11 OR S12 OR S13 OR S14 OR S15 OR S16 OR S17 OR S18 OR S19
Combination of concepts	21	S7 AND S20

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**Appendix 2.** Summary of AMSTAR-2 items and modified AMSTAR-2 items.

Topic #	AMSTAR-2 Original Items	AMSTAR-2 Modifications
1	<p>Did the research questions and inclusion criteria for the review include components of PICO?</p> <ul style="list-style-type: none"> <li>- Population</li> <li>- Intervention</li> <li>- Comparator group</li> <li>- Outcome</li> <li>- Timeframe for follow-up (optional)</li> </ul>	<p>“Population” became “Population and/or location”.</p> <p>“Intervention” became “Exposure”.</p> <p>The “Comparator group” category was taken out.</p> <p>A new section (#1.b)) was created, it includes “Definition of the exposure”, “Definition of the outcome” and “Timeframe for follow up”.</p>
2	<p>Did the report of the review contain an explicit statement that the review methods were established prior to the conduct of the review and did the report justify any significant deviations from the protocol?</p>	<p>To score “yes”, a protocol must have been established before the review. There are no sub-criteria, you can only score yes or no.</p>
3	<p>Did the review authors explain their selection of the study designs for inclusion in the review?</p>	<p>If the study designs are specified, you score “partial yes”. They must be explained to score “yes”. No specific study design is required.</p>
4	<p>Did the review authors use a comprehensive literature search strategy?</p>	<p>The “searched trial/study registries” category was taken out.</p> <p>Justified publication restrictions (e.g. language) moved from (partial yes) to (yes)</p>
5	<p>Did the review authors perform study selection in duplicate?</p>	<p>No modifications.</p>
6	<p>Did the review authors perform data extraction in duplicate?</p>	<p>No modifications.</p>
7	<p>Did the review authors provide a list of excluded studies and justify the exclusion?</p>	<p>The explanation of the inclusion and exclusion criteria is evaluated.</p> <p>If there is only one out of the two, you score “partial yes”. The two must be explained to score “yes”.</p>
8	<p>Did the review authors describe the included studies in adequate detail?</p>	<p>“Populations” became “Populations and/or locations”.</p> <p>“Interventions” became “Exposures”.</p> <p>“Comparator groups” became “Comparator groups (if applicable)”.</p> <p>“Populations and/or locations”, “Exposures” and “Outcomes” must be described in details to score “yes”</p>
9	<p>Did the review authors use a satisfactory technique for assessing the risk of bias (RoB) in individual studies that were included in the review?</p>	<p>“RoB” became “limitations”. Instead of assessing the RoB, the review authors must have used a satisfactory technique for assessing the limitations in individual studies that were included in the review.</p>

10	Did the review authors report on the sources of funding for the studies included in the review?	No modifications.
11	If meta-analysis was performed did the review authors use appropriate methods for statistical combination of results?	No modifications.
12	If meta-analysis was performed, did the review authors assess the potential impact of RoBin individual studies on the results of the meta-analysis or other evidence synthesis	No modifications.
13	Did the review authors account for RoB in individual studies when interpreting/discussing the results of the review?	“RoB” became “limitations”. Instead of accounting for RoB in individual studies, the review authors must have accounted for limitations when interpreting/ discussing the results of the review.
14	Did the review authors provide a satisfactory explanation for, and discussion of, any heterogeneity observed in the results of the review?	No modifications.
15	If they performed quantitative synthesis did the review authors carry out an adequate investigation of publication bias (small study bias) and discuss its likely impact on the results of the review?	No modifications.
16	Did the review authors report any potential sources of conflict of interest, including any funding they received for conducting the review?	No modifications.

**Appendix 3.** Overview of included studies (N=94) according to study characteristics and summary of climate impacts on health outcomes. Studies are presented in alphabetical order according to the first author's last name.

	First Author	Year	Country	Years of included publications	Years of the studies included in the reviews	# of articles	Meta-analysis	Specific Area of focus	Specific Population of interest	Climate Impact	Health Outcome	Summary of findings
1	Alderman	2012	Australia	2004-2011	1931-2007	35	No			Extreme weather	Infectious diseases Mortality Health systems Mental health Pregnancy and birth Other	Floods are associated with infectious diseases (water- and vector-borne diseases), mortality (e.g., drowning), exacerbation of chronic illnesses, mental health issues (e.g., PTSD), hospital admissions, pregnancy outcomes and injuries.
2	Amegah	2016	Ghana	1995-2014	1960-2010	23	No	Sub-saharan Africa		Meteorological	Infectious diseases Mortality Respiratory, cardiovascular, and neurological outcomes Health systems Nutritional Skin diseases and allergies	Temperature and temperature variability are suggested to be associated with infectious diseases, such as Ebola, cardiovascular diseases, mortality, cholera outbreaks, meningitis, undernutrition in children, respiratory outcomes, such as asthma, and skin diseases.
3	An	2018	United States	2002-2017	2002-2016	50	No			General	Nutritional	Climate change is associated with obesity. This association can be explained in 4 ways, such that climate change may impact obesity, obesity may impact climate change, both factors may be associated with common causes, or both factors may influence each other.

4	Augustin	2008	Germany	1996-2006	NS	320	No	Germany		Meteorological	Skin diseases and allergies	Although skin and allergic diseases are climate sensitive, there is not sufficient evidence to suggest a prediction concerning skin and allergic diseases linked to climate change in Germany.
5	Babaie	2018	Iran	2007-2017	1970-2015	14	No	Iran		Meteorological	Infectious diseases	Temperature, precipitation and humidity are associated with the risk of transmission of Malaria.
6	Bai	2013	China	1995-2011	1951-2010	57	No	China		Meteorological	Infectious diseases	Variability in temperature, precipitation and wind are associated with the risk of transmission of mosquito-borne diseases.
7	Benevolenza	2019	United States	2006-2017	2005-2015	13	No		Vulnerable populations	Extreme weather	Mental health Pregnancy and birth Other	Extreme weather events are associated with an exacerbation of pre-existing chronic health conditions, mental health issues (e.g., PTSD, isolation) and adverse birth outcomes.
8	Berhane	2016	Ethiopia	NS	NS	23	No	Ethiopia		Meteorological Extreme weather	Infectious diseases Nutritional	Meteorological factors and extreme weather events are associated with under- and mal- nutrition and the increased risk of climate sensitive infectious diseases (e.g., malaria, diarrhea, zoonotic infections, etc.).
9	Bernhardt	2019	Germany	1997-2017	NS	464	No			Meteorological	Infectious diseases	Rising temperatures are predicted to be associated with myiasis in the future.
10	Binazzi	2019	Italy	NS	1994-2013	8	Yes		Workers	Meteorological	Occupational health and injuries	High temperatures are positively associated with occupational injuries.
11	Bonafede	2016	Italy	2000-2014	1985-2010	8	No		Workers	Meteorological	Occupational health and injuries	Extreme temperature (particularly heat) is associated with occupational injuries.



12	Brown	2013	United Kingdom	2004-2012	1975-2012	38	No	Europe		Extreme weather	Infectious diseases	Floods are associated with infectious diseases, including water-, rodent- and vector-borne diseases (from weeks to months after flooding).
13	Bunker	2016	Germany	1995-2015	1974-2013	61	Yes		Elderly	Meteorological	Mortality Respiratory, cardiovascular, and neurological outcomes Other	Higher and lower temperatures are associated with cardiovascular and respiratory morbidity and mortality. Heat is also associated with diabetes and genitourinary infections.
14	Campbell	2018	Australia	1964-2017	NS	188	No			Meteorological	Mortality Health systems	Most studies exploring the heat impacts on health focus on mortality outcomes, followed by hospital admissions and ambulance call outs.
15	Cann	2013	United Kingdom	1973-2010	NS	83	No			Extreme weather	Infectious diseases	Extreme water-related events are associated with outbreaks of water-related infectious diseases.
16	Carolan-Olah	2014	Australia	1997-2012	1988-2009	7	No			Meteorological	Pregnancy and birth	High temperatures are associated with preterm birth.
17	Cheng	2014	China	1990-2013	1941-2012	25	No		Adults, Elderly, Children	Meteorological	Infectious diseases Mortality Respiratory, cardiovascular, and neurological outcomes Health systems Other	Diurnal temperature range is associated with mortality and cardiovascular and respiratory outcomes, hospital admissions, and Hand Foot Mouth disease in children and genitourinary outcomes among the elderly.
18	Coates	2019	Denmark	2003-2018	NS	72	No			Meteorological	Infectious diseases	Some meteorological factors (temperature, humidity) are positively associated with Hand Foot Mouth disease (HFMD). Precipitation, wind speed and sunshine are not associated with HFMD.

19	Cong	2017	China	1994-2015	1982-2013	26	Yes			Meteorological	Respiratory, cardiovascular, and neurological outcomes	Temperature drop is associated with asthma.
20	Cunrui	2011	Australia	1997-2010	1961-2100	14	No			Meteorological	Mortality	Higher temperature is associated with heat-related mortality.
21	deSousa	2018	Brazil	1976-2016	NS	106	No			Meteorological	Infectious diseases Respiratory, cardiovascular, and neurological outcomes	Meteorological factors (e.g., temperature, precipitation) are associated with infectious diseases (e.g., dengue, malaria) and cardiovascular and respiratory outcomes.
22	Dhimal	2015	Nepal	1956-2014	1948-2098	50	No	Nepal		Meteorological	Infectious diseases	Higher temperatures are associated with the distribution of vector-borne diseases.
23	Doocy	2013	United States	1975-2011	1974-2008	60	No			Extreme weather	Mortality Other	Cyclones are associated with mortality (e.g., drowning) and injuries.
24	Duan	2019	China	2010-2018	2000-2016	51	Yes	Southeast and East Asia		Meteorological	Infectious diseases	Some meteorological factors (mean maximum temperature, rainfall, humidity and sunshine) are positively associated with Hand Foot Mouth disease (HFMD), whereas air pressure is negatively associated with this disease and wind speed is not associated with HFMD.
25	Fan	2015	China	2004-2013	1985-2012	33	Yes			Meteorological	Infectious diseases	Temperature is positively associated with transmission and incidence of Dengue.
26	Fernandez	2015	Australia	1995-2014	NS	83	No			Extreme weather	Mental health	Floods are associated with negative mental health outcomes (e.g., PTSD, increased anxiety, depression, use of psychotropic medication). Conflicting evidence concerning suicide,

												tobacco, alcohol and substance abuse.
27	Flouris	2018	Greece	1954-2018	NS	111	Yes		Workers	Meteorological	Occupational health and injuries	High temperatures are positively associated with occupational heat strains, dehydration, kidney diseases and injuries.
28	Gao	2019	China	1994-2018	1969-2015	16	Yes			Meteorological	Mental health	Temperature increase is associated with suicide. No association between sunlight duration and suicide.
29	Gao	2014	China	1996-2012	1971-2010	37	No		Children	Meteorological	Infectious diseases Respiratory, cardiovascular, and neurological outcomes Skin diseases and allergies	Ambient humidity is associated with gastrointestinal, respiratory and allergic diseases in children.
30	Ghanizadeh	2017	Iran	2009-2016	1990-2015	13	No			Meteorological	Mortality Respiratory, cardiovascular, and neurological outcomes	Meteorological factors, such as temperature and humidity, are associated with cardiopulmonary health. Cold temperatures are also associated with mortality from heart diseases.
31	Ghazani	2018	Australia	2006-2017	1991-2011	11	No			Meteorological	Infectious diseases	Higher temperature is associated with bacterial gastrointestinal infections. Humidity and rainfall may influence this association.
32	Gracia	2015	Sweden	2003-2011	1959-2008	9	No	Europe		Meteorological	Infectious diseases	Temperature is positively associated with Human Puumala Hantavirus in some regions of Europe. Results concerning precipitation and humidity are contradictory or null.
33	Hajat	2010	United Kingdom	1994-2008	1973-2003	11	No			Meteorological	Mortality	Ambient heat is associated with mortality.

34	Hedlund	2014	Sweden	1970-2012	1750-2009	29	No	Arctic, sub-Arctic	Vulnerable populations	Meteorological Extreme weather	Infectious diseases	Higher temperatures and flooding are associated with food- and water-borne diseases. This association is weaker for vector- and rodent-borne diseases. Air temperature and humidity seem to be associated with air-borne diseases.
35	Hii	2016	Sweden	2007-2015	2003-2012	9	No	Malaysia		Meteorological	Infectious diseases	Some meteorological factors (temperature, rainfall and humidity) are associated with Dengue, although these associations are inconsistent at times.
36	Huang	2016	Taiwan	1990-2014	1978-2011	19	Yes			General	Skin diseases and allergies	Climate change, in general, may be associated with skin and soft-tissue infections.
37	Kampe	2016	United Kingdom	1998-2015	1971-2010	13	No	High-income countries		Meteorological	Other	Higher temperature is associated with unintentional injuries.
38	Khader	2015	Jordan	2003-2014	1991-2012	78	No	Eastern Mediterranean	Vulnerable countries	Meteorological Extreme weather Air quality	Infectious diseases Mortality Respiratory, cardiovascular, and neurological outcomes Health systems Mental health Pregnancy and birth Nutritional	High temperature is associated with mortality. Temperature, humidity and precipitation are associated with vector-, food- and water-borne diseases. Air pollution is associated with respiratory outcomes, although some findings are inconsistent. Higher temperature is associated with mental health outcomes and hospital admissions. Higher temperature may also be associated with adverse birth outcomes. Meteorological and extreme weather events are associated with food insecurity.
39	Klinger	2014	United Kingdom	2011-2013	NS	20	No			Extreme weather	Health systems	Extreme weather events may lead to power outages which may pose challenges to healthcare quality.

40	Kuehn	2017	United States	2002-2017	NS	28	No		Pregnant people	Meteorological	Pregnancy and birth	Extreme heat exposure is associated with adverse birth outcomes (e.g. stillbirth, birth weight).
41	Lake	2017	United Kingdom	NS	NS	66	No	Europe		General	Respiratory, cardiovascular, and neurological outcomes	Climate change may be associated with ragweed pollen allergy.
42	Lal	2019	Australia	1982-2011	NS	36	Yes		Children	Meteorological	Infectious diseases	Rainfall is associated with childhood diarrhea, although this association differed according to season and latitude.
43	Lal	2015	Australia	NS	NS	16	No	New Zealand		Meteorological	Infectious diseases	Temperature variability, higher temperature and rainfall are associated with enteric diseases.
44	Lawton	2019	Australia	2000-2015	NS	71	No			Meteorological	Mortality Respiratory, cardiovascular, and neurological outcomes	Heat exposure is associated with heat stroke, long-term neurological outcomes (e.g., cerebellar injury) and heat-related mortality.
45	Levi	2018	Italy	2003-2017	1977-2014	184	No		Workers	Meteorological	Occupational health and injuries	Heat exposure is associated with occupational injuries.
46	Levy	2016	United States	1972-2013	1948-2010	208	No			Meteorological Extreme weather	Infectious diseases	Temperature is associated with bacterial diarrhea and drought is associated with all-cause diarrhea, although few studies explored the association between drought and diarrhea.
47	Leyva	2017	Asia	2009-2017	NS	30	No		Elderly	Meteorological Extreme weather Air quality	Infectious diseases Mortality Respiratory, cardiovascular, and	Meteorological factors, extreme weather events (e.g. typhoon, floods) and air pollution are associated with mortality and morbidity, especially cardiovascular- and respiratory-specific. Higher temperature is associated with

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											neurological outcomes Health systems Mental health	vector-borne diseases. Heat and cold temperatures are associated with hospital admissions. Flooding is associated with mental health outcomes (e.g. PTSD, depression).
48	Li	2018	China	1988-2017	NS	81	No	China		Meteorological Extreme weather	Infectious diseases	Meteorological factors (temperature, precipitation, humidity, air pressure) and extreme weather events (floods, typhoons) are associated with Dengue fever in China.
49	Lian	2015	China	2003-2014	NS	20	Yes			Meteorological	Mortality Respiratory, cardiovascular, and neurological outcomes	Higher and lower temperatures are associated with stroke-related mortality and low temperatures are also associated with stroke-related morbidities.
50	Liu	2015	United States	1990-2014	NS	61	No			Air quality	Mortality Respiratory, cardiovascular, and neurological outcomes Health systems Pregnancy and birth Other	Wildfire smoke exposure is associated with mortality, respiratory outcomes and hospital admissions. Wildfire smoke exposure could also be associated with cardiovascular, ophthalmic and pregnancy outcomes, although more research is needed.
51	Madaniyazi	2015	Australia	2004-2013	1961-2100	15	No			Air quality	Mortality	Air pollution is associated with future mortality.
52	Matysiak	2017	Puerto Rico	2001-2005	NS	26	No	Puerto Rico (United-States)		Meteorological Extreme weather	Infectious diseases	Meteorological factors (higher temperature and increased rainfall) are associated with vector-borne diseases, such as Dengue and Zika. Extreme weather events are less researched, but the few studies investigating this association suggest no association between hurricanes

												and floods and vector-borne diseases.
53	Moghaddamnia	2017	Iran	2011-2016	1979-2013	26	Yes			Meteorological	Mortality	Higher and lower temperature are associated with cardiovascular mortality.
54	Naish	2014	Australia	NS	1931-2010	16	No			Meteorological	Infectious diseases	Meteorological factors (especially temperature, rainfall and humidity) are associated with Dengue.
55	Nichols	2009	United Kingdom	1999-2008	NS	36	No			Meteorological Extreme weather Air quality	Infectious diseases Mortality Respiratory, cardiovascular, and neurological outcomes Mental health Nutritional Skin diseases and allergies Other	Meteorological factors (e.g., higher temperature) are associated with mortality and various infectious diseases. Increased UV exposure is associated with skin cancer and cataracts. Extreme weather events are associated with mortality, injury, mental health outcomes, malnutrition, and food- and water-borne diseases. Air pollution is associated with cardio-respiratory outcomes.
56	Odame	2018	United States	2006-2017	1893-2013	14	Yes		Rural populations	Meteorological	Mortality	Higher temperature is associated with all-cause mortality and cardiovascular specific mortality.
57	Park	2017	Korea	1920-2015	1961-2013	10	Yes			Meteorological	Other	Higher temperature is associated with acute gouty arthritis.
58	Phalkey	2015	Germany	1989-2012	1982-2008	15	No	Low to middle-income countries	Children	Meteorological Extreme weather	Nutritional	Meteorological factors (rainfall, temperature) and extreme weather events are associated with childhood undernutrition.
59	Philipsborn	2016	Georgia	NS	1973-2010	28	Yes			Meteorological	Infectious diseases	Higher temperature is associated with Diarrheagenic Escherichia coli. No significant relationship between rainfall and E. coli.
60	Phung	2015	Australia	2004-2013	NS	13	No	Southeast Asia		Meteorological	Infectious diseases	Meteorological factors (temperature, humidity) and extreme weather

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										Extreme weather		events (flooding) are associated with vector- and water-borne infectious diseases.
61	Porpora	2019	Italy	1964-2019	NS	78	No			Other	Pregnancy and birth	Environmental pollutants may be associated with preterm birth, however this association remains unclear due to conflicting evidence.
62	Poursafa	2015	Iran	2001-2013	NS	15	No			Meteorological	Pregnancy and birth	Meteorological factors (higher temperature, lower temperature, humidity, sunlight intensity) are associated with adverse birth outcomes (low birth weight, preterm birth, hypertension, eclampsia).
63	Racloz	2012	Australia	NS	NS	63	No			Meteorological	Infectious diseases	Higher temperature, increased precipitation and humidity are associated with Dengue.
64	Rataj	2016	Germany	1981-2012	1978-2008	17	No	Low to middle income countries		Extreme weather	Mental health Other	Extreme weather events are associated with mental health outcomes (e.g., PTSD, anxiety, depression) and injuries.
65	Reid	2016	United States	1990-2015	NS	53	No		Susceptible populations	Air quality	Mortality Respiratory, cardiovascular, and neurological outcomes Mental health Pregnancy and birth	Wildfire smoke exposure is associated with respiratory outcomes (e.g., asthma) and mortality. Wildfire smoke exposure may be associated with cardiovascular, birth, and mental health outcomes, but more research is needed.
66	Rifkin	2018	United States	1995-2017	1992-2016	16	No			Meteorological Extreme weather	Other	Temperature and extreme weather events (hurricanes) are associated with sleep quality.
67	Salve	2018	India	NS	NS	11	No	India		Meteorological	Mortality Health systems Nutritional	Increase in temperature is associated with all-cause mortality, cause-specific mortality (e.g., myocardial



												infarctions, stroke, heart diseases), hospitalizations (e.g., heat-related admissions, neonatal intensive unit admissions), and food insecurity and malnutrition, via agricultural issues.
68	Sanderson	2017	United Kingdom	1988-2017	1900-2101	63	No			Meteorological	Mortality	Higher temperatures and heat waves are associated with mortality and heat-related mortality is likely to increase with increased temperatures.
69	Sawatzky	2018	Canada	2005-2016	NS	85	No	Arctic and Subarctic		General	Health systems	Climate change, in general, is associated with a strain in public health resources, via population health issues and surveillance systems may guide future adaptation to climate change.
70	Semenza	2012	Sweden	1998-2009	1995-2007	722	No			Meteorological	Infectious diseases	Meteorological factors (temperature, rainfall) are associated with some food- and water-borne diseases.
71	Stanke	2013	United Kingdom	1967-2011	1876-1879 and 1961-2010	87	No			Extreme weather	Infectious diseases Mortality Respiratory, cardiovascular, and neurological outcomes Mental health Nutritional Other	Droughts are associated with malnutrition, mortality, infectious diseases, cardiovascular and respiratory outcomes, mental health (e.g., increased worry, anxiety), injuries, and cancer.
72	Stensgaard	2019	Denmark	1995-2017	NS	20	No			Meteorological	Infectious diseases	Meteorological factors (temperature, precipitation, humidity) are associated with schistosomiasis and increasing temperatures are likely to affect the geographic range of this parasite.
73	Sun	2018	China	1999-2017	1974-2014	30(review)	Yes			Meteorological	Mortality	Heat and cold exposure are associated with myocardial

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						w)2 3m eta- anal ysis					Respiratory, cardiovascular, and neurological outcomes Health systems	infarctions (MI) and hospitalization for MI. Heat exposure is associated with MI-specific mortality.
74	Swynghe dauw	2009	France	NS	NS	NS	No			Meteorolo gical Extreme weather	Infectious diseases Mortality Skin diseases and allergies Other	Heat and cold exposure are associated with mortality and more specifically, respiratory- and cardiovascular-specific mortality. Exposure to UV is associated with skin cancer and cataracts. Higher temperatures are associated with infectious diseases (mosquito- and food-borne diseases) and extreme weather events are associated with undernutrition and food-borne diseases.
75	Tall	2014	Australi a	1946- 2009	1886- 2006	22	No	Australi a		Extreme weather	Infectious diseases	There is no strong evidence for the association between flooding and the Ross River Virus.
76	Varghese	2018	Australi a	1983- 2017	1922- 2017	26	No		Workers	Meteorolo gical	Occupational health and injuries	Heat is associated with occupational injuries in many contexts of work (e.g., agriculture, transport, construction, fishing).
77	Veenema	2017	United States	2006- 2016	NS	47	No			Extreme weather	Infectious diseases Mortality Mental health	Extreme water-related weather events are associated with mortality, water- and vector-borne infectious diseases, mental health issues (e.g., PTSD, depression, anxiety).
78	Vilcins	2018	Australi a	NS	NS	72	No		Children	Other	Nutritional	Certain environmental risk factors (e.g., sanitation, cooking fuels), which could be aggravated by climate change, may be associated with childhood stunting.
79	Vins	2015	United States	1995- 2005	NS	82	No			Extreme weather	Mental health	Drought is likely associated with adverse mental health outcomes.

80	Waits	2018	Finland	1970-2017	NS	43	No	Arctic		Meteorological	Infectious diseases	Meteorological factors (especially higher temperature and precipitation) are associated with infectious diseases (e.g. tick borne diseases, tularemia) in the Arctic.
81	Wald	2019	United States	2009-2018	NS	17	No	United States		Meteorological	Health systems	Higher temperature is associated with emergency department (heat-related visits) visits and costs for healthcare systems.
82	Welch	2019	United States	NS	NS	91	No			Meteorological	Infectious diseases	Meteorological factors (temperature, precipitation) are associated with Salmonella.
83	Wimalawansa	2016	United States	NS	NS	NS	No	Tropical Countries	Workers	Meteorological Other	Occupational health and injuries	Increasing temperatures and environmental pollution (e.g., heavy metals, fertilizers) are associated with occupational health outcomes, such as chronic kidney disease of multifactorial origin.
84	Witt	2015	Germany	NS	NS	33	Yes		Chronic lung disease patients	Meteorological	Mortality Respiratory, cardiovascular, and neurological outcomes	Heat is associated with lung disease outcomes and mortality in patients with chronic lung diseases.
85	Xu	2018	Australia	2004-2016	1978-2013	19	No		Children	Meteorological	Respiratory, cardiovascular, and neurological outcomes	Heat and cold temperatures are associated with childhood asthma.
86	Xu	2012	Australia	2000-2012	1983-2010	33	No		Children	Meteorological	Infectious diseases Mortality Respiratory, cardiovascular, and neurological outcomes Health systems	Heat and cold are associated with hospital admissions and mortality in children. Temperature is also associated with various infectious diseases (e.g., HFMD, malaria), respiratory diseases (e.g., asthma) and skin outcomes (e.g. eczema). For example, high temperature is associated with Hand Foot Mouth

											Skin diseases and allergies Other	Disease and renal diseases and low temperature is associated with eczema.
87	Xu	2016	Australia	2001-2015	NS	60	Yes			Meteorological	Mortality	Heat waves are associated with mortality and it seems that the intensity of heatwaves is particularly important compared to length of heatwave.
88	Xu	2014	Australia	1998-2012	1983-2009	12	No		Children	Meteorological	Mortality Respiratory, cardiovascular, and neurological outcomes Health systems Other	Heat waves are associated with hospital admissions, respiratory diseases, renal diseases, fever and electrolyte imbalances. Evidence concerning the association between heatwaves and children mortality is inconsistent.
89	Youssef	2014	France	1990-2011	1987-2008	94	No			Air quality	Mortality Respiratory, cardiovascular, and neurological outcomes Health systems Pregnancy and birth	Wildfire smoke exposure is associated with mortality, respiratory and cardiovascular outcomes, hospital admissions. Wildfire smoke exposure may also be associated with adverse birth outcomes (low birth weight).
90	Yu	2015	Australia	1998-2012	1961-1990 et 2020-2100	20	No			Meteorological	Infectious diseases	Meteorological factors (temperature, rainfall, humidity) may be associated with future malaria transmission, although findings are inconsistent, partly according to geographical focus.
91	Yu	2012	Australia	1997-2008	1973-2006	15	Yes		Elderly	Meteorological	Mortality	Heat and cold temperatures are associated with mortality for the elderly, although heat-related associations seem stronger than cold-related associations.

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92	Zhang	2007	Australia	NS	NS	NS	No		People with disabilities	General	Other	Climate change, in general, may be associated with disability-adjusted life years (DALY), and the cost of DALY could be particularly important in low to middle income countries.
93	Zhang	2017	China	1997-2016	1981-2012	36	No		Pregnant people	Meteorological	Pregnancy and birth	High temperature is associated with adverse birth outcomes, such as preterm birth, low birth weight and stillbirth. Low temperature is also associated with some adverse birth outcomes, including preterm birth and low birth, although the evidence is stronger for high temperature than for low temperatures.
94	Zuo	2015	Australia	NS	NS	173	No			Meteorological	Mortality Respiratory, cardiovascular, and neurological outcomes Health systems Mental health Skin diseases and allergies Other	Heat waves are associated with mortality, hospital admissions, sunburn, heat exhaustion, cardiovascular outcomes (e.g., heart attacks) and mental health outcomes.

\*NS = non-specified

**Appendix 4.** Summary of quality assessment according to revised AMSTAR-2 items. (Y = yes, PY = partial yes, N = no, NA = non-applicable).

First author	Year	AMSTAR-2 Items																
		1	1b	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Alderman	2012	Y	N	N	PY	PY	N	N	PY	PY	N	N	NA	NA	Y	N	NA	N
Amegah	2016	Y	N	N	Y	PY	N	N	PY	Y	Y	N	NA	NA	Y	Y	NA	Y
An	2018	N	Y	N	N	PY	Y	N	Y	N	Y	N	NA	NA	Y	N	NA	Y
Augustin	2008	Y	Y	N	N	PY	N	N	PY	N	PY	N	NA	NA	Y	N	NA	Y
Babaie	2018	Y	Y	N	N	PY	Y	N	Y	PY	N	N	NA	NA	N	N	NA	N
Bai	2013	Y	Y	N	PY	PY	N	N	PY	PY	Y	N	NA	NA	Y	N	NA	Y
Benevolenza	2019	Y	Y	N	PY	N	N	N	Y	PY	PY	N	NA	NA	Y	N	NA	N
Berhane	2016	Y	N	Y	N	N	N	N	N	PY	PY	N	NA	NA	Y	N	NA	N
Bernhardt	2019	Y	N	N	N	N	N	N	PY	PY	PY	N	NA	NA	PY	N	NA	Y
Binazzi	2019	Y	Y	N	Y	PY	Y	N	Y	Y	Y	N	Y	Y	Y	Y	Y	Y
Bonafede	2016	Y	N	N	PY	PY	Y	N	Y	Y	Y	N	NA	NA	Y	Y	NA	Y
Brown	2013	Y	Y	N	PY	PY	N	N	Y	Y	PY	N	NA	NA	Y	Y	NA	Y
Bunker	2016	Y	Y	N	Y	N	Y	PY	Y	Y	PY	N	Y	Y	Y	Y	Y	Y
Campbell	2018	Y	N	N	N	PY	N	N	Y	PY	N	N	NA	NA	Y	PY	NA	Y
Cann	2013	Y	Y	Y	PY	PY	N	N	Y	PY	PY	N	NA	NA	Y	Y	NA	Y
Carolan-Olah	2014	Y	Y	N	N	PY	N	N	Y	PY	Y	N	NA	NA	PY	PY	NA	N
Cheng	2014	Y	N	N	PY	PY	N	N	Y	Y	Y	N	NA	NA	Y	PY	NA	N
Coates	2019	N	N	N	N	N	N	N	PY	PY	Y	N	NA	NA	Y	PY	NA	N
Cong	2017	N	Y	N	N	PY	N	Y	Y	Y	Y	N	Y	N	Y	Y	Y	Y
Cunrui	2011	Y	N	N	PY	PY	N	N	Y	PY	N	N	NA	NA	Y	N	NA	Y
deSousa	2018	Y	N	N	PY	PY	N	N	Y	N	N	N	NA	NA	Y	N	NA	Y
Dhimal	2015	Y	Y	N	PY	PY	N	N	Y	Y	N	N	NA	NA	N	N	NA	N
Doocy	2013	Y	N	N	N	PY	Y	N	Y	Y	N	N	NA	NA	Y	PY	NA	Y
Duan	2019	Y	N	N	N	PY	N	N	Y	PY	Y	N	Y	Y	Y	Y	Y	Y
Fan	2015	N	Y	N	N	PY	Y	Y	PY	PY	Y	N	Y	Y	Y	Y	Y	Y
Fernandez	2015	Y	Y	N	PY	PY	Y	N	Y	PY	PY	N	NA	NA	Y	N	NA	N
Flouris	2018	Y	N	Y	PY	PY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Gao	2019	N	Y	N	PY	PY	Y	N	Y	Y	Y	N	Y	Y	Y	Y	Y	Y
Gao	2014	Y	N	N	PY	PY	N	PY	Y	Y	Y	N	NA	NA	Y	Y	NA	Y
Ghanizadeh	2017	N	Y	N	PY	N	Y	PY	Y	PY	Y	N	NA	NA	N	N	NA	Y
Ghazani	2018	N	N	N	N	PY	Y	N	Y	Y	PY	N	NA	NA	Y	PY	NA	Y
Gracia	2015	Y	Y	N	PY	PY	Y	N	Y	PY	Y	N	NA	NA	Y	N	NA	Y
Hajat	2010	Y	N	N	Y	PY	N	N	Y	PY	N	N	NA	NA	N	PY	NA	Y
Hedlund	2014	Y	N	N	PY	N	Y	Y	Y	PY	Y	N	NA	NA	Y	N	NA	Y
Hii	2016	Y	N	N	PY	PY	N	N	PY	PY	N	N	NA	NA	N	N	NA	Y
Huang	2016	N	N	N	N	PY	Y	N	PY	Y	Y	N	Y	Y	Y	PY	N	Y
Kampe	2016	Y	N	N	PY	PY	Y	N	Y	Y	PY	N	NA	NA	Y	N	NA	Y
Khader	2015	Y	N	N	PY	PY	Y	N	Y	Y	N	N	NA	NA	Y	PY	NA	Y
Klinger	2014	N	N	N	N	PY	Y	N	Y	N	Y	N	NA	NA	Y	N	NA	Y
Kuehn	2017	Y	N	N	N	PY	N	N	Y	Y	PY	N	NA	NA	Y	N	NA	Y
Lake	2017	Y	Y	N	N	PY	Y	Y	PY	PY	N	N	NA	NA	N	N	NA	Y
Lal	2019	Y	N	Y	N	PY	N	Y	Y	PY	Y	N	Y	Y	Y	Y	N	Y
Lal	2015	Y	Y	N	N	PY	N	N	Y	PY	PY	N	NA	NA	Y	PY	NA	Y
Lawton	2019	Y	N	N	PY	PY	N	N	Y	Y	N	N	NA	NA	Y	N	NA	Y
Levi	2018	Y	Y	N	PY	PY	Y	N	Y	Y	N	N	NA	NA	Y	PY	NA	Y
Levy	2016	N	N	N	PY	PY	Y	PY	Y	Y	Y	N	NA	NA	Y	Y	NA	Y
Leyva	2017	Y	Y	N	PY	PY	N	N	Y	N	Y	N	NA	NA	Y	N	NA	N
Li	2018	Y	N	N	N	PY	N	N	N	PY	N	N	NA	NA	N	N	NA	Y
Lian	2015	Y	N	N	PY	PY	Y	Y	Y	N	Y	N	Y	Y	Y	Y	Y	Y
Liu	2015	Y	Y	N	Y	PY	N	N	Y	Y	PY	N	NA	NA	Y	PY	NA	Y
Madaniyazi	2015	N	N	N	PY	PY	N	N	Y	PY	N	N	NA	NA	Y	N	NA	Y
Matysiak	2017	Y	Y	N	PY	PY	N	N	Y	PY	Y	N	NA	NA	Y	N	NA	Y
Moghadamnia	2017	Y	N	N	PY	PY	Y	N	Y	Y	Y	N	Y	N	Y	Y	N	Y
Naish	2014	Y	Y	N	PY	PY	N	N	PY	PY	PY	N	NA	NA	Y	N	NA	Y
Nichols	2009	Y	N	N	PY	PY	Y	Y	Y	Y	N	N	NA	NA	N	N	NA	Y
Odame	2018	Y	N	N	PY	PY	N	N	PY	PY	N	N	Y	N	Y	Y	Y	Y
Park	2017	Y	N	N	N	PY	Y	Y	N	PY	Y	N	Y	PY	Y	Y	N	Y
Phalkey	2015	Y	Y	N	PY	PY	Y	Y	Y	PY	PY	N	NA	NA	Y	N	NA	Y

Philipsborn	2016	Y	Y	N	PY	N	N	N	Y	PY	N	N	Y	Y	N	Y	N	Y
Phung	2015	Y	Y	N	N	PY	N	N	Y	Y	PY	Y	NA	NA	N	N	NA	Y
Porpora	2019	Y	Y	Y	PY	PY	N	N	Y	PY	N	N	NA	NA	N	Y	NA	Y
Poursafa	2015	Y	N	N	PY	PY	Y	Y	PY	Y	PY	N	NA	NA	Y	Y	NA	Y
Racloz	2012	Y	N	N	N	PY	N	N	N	PY	N	N	NA	NA	Y	Y	NA	Y
Rataj	2016	Y	Y	Y	PY	PY	Y	Y	PY	PY	Y	N	NA	NA	Y	Y	NA	Y
Reid	2016	Y	N	N	PY	PY	N	N	N	PY	PY	N	NA	NA	Y	PY	NA	Y
Rifkin	2018	Y	Y	Y	PY	PY	Y	Y	Y	PY	N	N	NA	NA	Y	N	NA	Y
Salve	2018	Y	Y	N	N	PY	Y	Y	PY	PY	N	N	NA	NA	Y	N	NA	Y
Sanderson	2017	Y	Y	N	N	PY	Y	N	Y	PY	PY	N	NA	NA	Y	N	NA	Y
Sawatzky	2018	Y	Y	N	N	PY	Y	N	Y	N	N	N	NA	NA	N	N	NA	Y
Semenza	2012	N	N	N	N	N	N	N	N	N	Y	N	NA	NA	N	N	NA	N
Stanke	2013	Y	N	N	PY	PY	N	N	Y	PY	N	N	NA	NA	Y	N	NA	Y
Stensgaard	2019	Y	Y	N	N	PY	N	Y	N	PY	N	N	NA	NA	N	N	NA	Y
Sun	2018	Y	Y	N	PY	PY	N	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y
Swynghedauw	2009	Y	Y	N	N	N	N	N	N	N	N	N	NA	NA	N	N	NA	Y
Tall	2014	Y	N	N	N	PY	N	N	Y	Y	PY	N	NA	NA	Y	N	NA	Y
Varghese	2018	Y	N	N	N	PY	N	N	Y	Y	N	N	NA	NA	Y	N	NA	Y
Veenema	2017	Y	N	Y	N	PY	N	N	Y	N	PY	N	NA	NA	N	N	NA	N
Vilcins	2018	Y	N	Y	N	PY	N	N	Y	N	Y	N	NA	NA	Y	N	NA	Y
Vins	2015	Y	Y	N	N	PY	N	N	Y	N	N	N	NA	NA	Y	PY	NA	Y
Waits	2018	Y	Y	N	N	PY	N	N	Y	N	N	N	NA	NA	N	N	NA	Y
Wald	2019	Y	N	N	N	PY	N	N	Y	Y	N	N	NA	NA	Y	N	NA	N
Welch	2019	Y	Y	N	N	N	N	N	PY	PY	N	N	NA	NA	N	N	NA	N
Wimalawansa	2016	Y	N	N	N	N	N	N	N	N	N	N	NA	NA	N	N	NA	Y
Witt	2015	Y	N	N	N	PY	N	N	Y	N	N	N	N	Y	Y	N	N	Y
Xu	2018	Y	N	N	PY	PY	N	N	PY	PY	N	N	NA	NA	Y	N	NA	Y
Xu	2012	Y	N	N	PY	PY	N	N	PY	Y	PY	N	NA	NA	N	N	NA	Y
Xu	2016	Y	N	N	PY	PY	N	N	Y	Y	N	N	Y	N	Y	Y	N	Y
Xu	2014	Y	Y	N	N	PY	N	N	Y	Y	N	N	NA	NA	N	Y	NA	N
Youssef	2014	Y	Y	N	PY	PY	N	N	Y	Y	N	N	NA	NA	Y	N	NA	Y



Yu	2015	N	N	N	PY	PY	N	N	Y	Y	N	N	NA	NA	Y	PY	NA	Y
Yu	2012	Y	Y	N	PY	N	N	Y	Y	Y	N	N	Y	N	Y	Y	Y	Y
Zhang	2007	Y	N	N	N	N	N	N	N	N	N	N	NA	NA	Y	N	NA	N
Zhang	2017	Y	Y	N	PY	PY	N	N	PY	Y	Y	N	NA	NA	Y	Y	NA	Y
Zuo	2015	Y	Y	N	N	PY	N	N	N	N	N	N	NA	NA	N	N	NA	Y
TOTAL	Yes	81	44	9	5	0	32	17	64	36	31	2	17	12	70	28	11	78
	Partial Yes	0	0	0	47	80	0	4	19	41	22	0	0	1	2	15	0	0
	No	13	50	85	42	14	62	73	11	17	41	92	1	5	22	51	7	16
	Not- Applic able	0	0	0	0	0	0	0	0	0	0	0	0	76	76	0	0	76

**Appendix 5.** Summary table of publications according to climate impact and health outcome according to frequencies and references. References with a \* explore only this specific combination of climate impact and health outcome and therefore appear only once in this table. Number of studies and references (according to alphabetical order) for each combination of categories are presented in the cells. Empty cells in this Table indicate an absence of studies at this combination of categories.

Health Outcome	Climate Impact				
	Meteorological (71)	Extreme weather (24)	Air quality (7)	General (5)	Other (3)
Infectious diseases (41)	<p><b>35</b></p> <p>Amegah, Babaie*, Bai*, Berhane, Bernhardt*, Cheng, Coates*, de Sousa, Dhimal*, Duan*, Fan*, Gao 2014, Ghazani*, Gracia*, Hedlund, Hii*, Khader, Lal 2015*, Lal 2019*, Levy, Leyva, Li, Matysiak, Naish*, Nichols, Philipsborn*, Phung, Racloz*, Semenza*, Stensgaard, Swynghedau, Waits*, Welch*, Xu 2012, Yu 2015*</p>	<p><b>14</b></p> <p>Alderman, Berhane, Brown*, Cann*, Hedlund, Levy, Li, Matysiak, Nichols, Phung, Stanke, Swynghedau, Tall*, Veenema</p>			
Mortality (32)	<p><b>24</b></p> <p>Amegah, Bunker, Campbell, Cheng, Cunrui*, Ghanizadeh, Hajat*, Khader, Lawton, Leyva, Lian, Moghdamnia*, Nichols, Odame*, Salve, Sanderson*, Sun, Swynghedauw, Witt, Xu 2012, Xu 2014, Xu 2016*, Yu 2012*, Zuo</p>	<p><b>5</b></p> <p>Alderman, Doocy, Leyva, Stanke, Veenema</p>	<p><b>5</b></p> <p>Leyva, Liu, Madniyazi*, Reid, Youssouf</p>		
Respiratory, cardiovascular, and neurological (23)	<p><b>17</b></p> <p>Amegah, Bunker, Cheng, Cong*, de Sousa, Gao 2014, Ghanizadeh, Lawton, Leyva, Lian, Nichols, Sun, Witt, Xu 2012, Xu 2014, Xu 2018*, Zuo</p>	<p><b>1</b></p> <p>Stanke</p>	<p><b>6</b></p> <p>Khader, Leyva, Liu, Nichols, Reid, Youssouf</p>	<p><b>1</b></p> <p>Lake*</p>	

1 2 3 4 5 6 7	Health systems (16)	<b>11</b> Amegah, Campbell, Cheng, Khader, Leyva, Salve, Sun, Wald*, Xu 2012, Xu 2014, Zuo	<b>2</b> Alderman, Klinger*	<b>2</b> Liu, Youssouf	<b>1</b> Sawatzky*	
8 9 10 11 12 13	Mental Health (13)	<b>3</b> Gao 2019*, Khader, Zuo	<b>9</b> Alderman, Benevolenza, Fernandez*, Leyva, Nichols, Rataj, Stanke, Veenema, Vins*	<b>1</b> Reid		
14 15 16 17 18 19	Pregnancy and birth outcomes (11)	<b>5</b> Carolan-Olah*, Kuehn*, Poursafa*, Khader, Zhang 2017*	<b>2</b> Alderman, Benevolenza	<b>3</b> Liu, Reid, Youssouf		<b>1</b> Porpora*
20 21 22 23 24	Nutritional (9)	<b>4</b> Amegah, Khader, Phalkey, Salve	<b>6</b> Berhane, Khader, Nichols, Phalkey, Stanke, Swynghedauw		<b>1</b> An*	<b>1</b> Vilcins*
25 26 27 28 29	Skin diseases and allergies (8)	<b>7</b> Amegah, Augustin*, Nichols, Gao 2014, Swynghedauw, Xu 2012, Zuo			<b>1</b> Huang*	
30 31 32 33 34 35	Occupational health and injuries (6)	<b>6</b> Binazzi*, Bonafede*, Flouris*, Levi*, Varghese*, Wimalawans				<b>1</b> Wimalawans
36 37 38 39 40 41 42 43 44 45 46 47	Other (17)	<b>10</b> Bunker, Cheng, Kampe*, Nichols, Park*, Rifkin, Swynghedauw, Xu 2012, Xu 2014, Zuo	<b>6</b> Alderman, Benevolenza, Doocy, Rataj, Rifkin, Stanke	<b>1</b> Liu	<b>1</b> Zhang 2007*	



# PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
<b>TITLE</b>			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
<b>ABSTRACT</b>			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	1
<b>INTRODUCTION</b>			
Rationale	3	Describe the rationale for the review in the context of what is already known.	2
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	2
<b>METHODS</b>			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	3
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	3
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	3
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	31
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	3,4
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	4
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	4
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	5
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	4
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., $I^2$ ) for each meta-analysis.	4,5



# PRISMA 2009 Checklist

Page 1 of 2

Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	5, 53-56
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	NA
<b>RESULTS</b>			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	6
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	6-8
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	8
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	38-52
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	11-17
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	8,53-56
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	NA
<b>DISCUSSION</b>			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	17-18
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	19
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	19
<b>FUNDING</b>			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	21

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(6): e1000097. doi:10.1371/journal.pmed1000097

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# BMJ Open

## The Health Effects of Climate Change: An Overview of Systematic Reviews

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Date Submitted by the Author:	22-May-2021
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<b>Primary Subject Heading</b>:	Public health
Secondary Subject Heading:	Public health, Global health
Keywords:	PUBLIC HEALTH, SOCIAL MEDICINE, Public health < INFECTIOUS DISEASES

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# The Health Effects of Climate Change: An Overview of Systematic Reviews

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## Abstract

**Objectives:** We aimed to develop a systematic synthesis of systematic reviews of health impacts of climate change, by synthesizing studies' characteristics, climate impacts, health outcomes, and key findings.

**Design:** We conducted an overview of systematic reviews of health impacts of climate change. We registered our review in PROSPERO (CRD42019145972). No ethical approval was required since we used secondary data. Additional data is not available.

**Data Sources:** On June 22, 2019, we searched Medline, CINAHL, Embase, Cochrane, and Web of Science.

**Eligibility Criteria:** We included systematic reviews that explored at least one health impact of climate change.

**Data Extraction and Synthesis:** We organized systematic reviews according to their key characteristics, including geographical regions, year of publication and authors' affiliations. We mapped the climate effects and health outcomes being studied and synthesized major findings. We used a modified version of AMSTAR-2 to assess the quality of studies.



1  
2  
3 38 Results: We included ninety-four systematic reviews. Most were published after 2015 and  
4 39 approximately one fifth contained meta-analyses. Reviews synthesized evidence about five  
5 40 categories of climate impacts; the two most common were meteorological and extreme weather  
6 41 events. Reviews covered ten health outcome categories; the three most common were 1)  
7 42 infectious diseases, 2) mortality, and 3) respiratory, cardiovascular, or neurological outcomes.  
8 43 Most reviews suggested a deleterious impact of climate change on multiple adverse health  
9 44 outcomes, although the majority also called for more research.

12 45 Conclusions: Most systematic reviews suggest that climate change is associated with worse  
13 46 human health. This study provides a comprehensive higher-order summary of research on  
14 47 health impacts of climate change. Study limitations include possible missed relevant reviews, no  
15 48 meta-meta-analyses, and no assessment of overlap. Future research could explore the potential  
16 49 explanations between these associations to propose adaptation and mitigation strategies and  
17 50 could include broader socio-psychological health impacts of climate change.

## 21 51 Keywords

22 52 Health; Climate Change; Overview of Systematic Reviews; Extreme Weather Events; Air  
23 53 Quality; Global Warming  
24 54

## 28 55 Strengths and limitations of this study

- 31 56
- 32 57 • A strength of this study is that it provides the first broad overview of previous systematic  
33 58 reviews exploring the health impacts of climate change. By targeting systematic reviews,  
34 59 we achieve a higher-order summary of findings than what would have been possible by  
35 60 consulting individual original studies.
  - 36 61 • By synthesizing findings across all included studies and according to the combination of  
37 62 climate impact and health outcome, we offer a clear, detailed, and unique summary of  
38 63 the current state of evidence and knowledge gaps about how climate change may  
39 64 influence human health.
  - 40 65 • A limitation of this study is that we were unable to access some full texts and therefore  
41 66 some studies were excluded, even though we deemed them potentially relevant after  
42 67 title and abstract inspection.
  - 43 68 • Another limitation is that we could not conduct meta-meta-analyses of findings across  
44 69 reviews, due to the heterogeneity of the included systematic reviews and the relatively  
45 70 small proportion of studies reporting meta-analytic findings.
  - 46 71 • Finally, the date of the systematic search is a limitation, as we conducted the search in  
47 72 June 2019.
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## 52 72 Introduction

53 73 The environmental consequences of climate change such as sea-level rise, increasing  
54 74 temperatures, more extreme weather events, increased droughts, flooding, and wildfires are

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3 75 impacting human health and lives.<sup>1,2</sup> Previous studies and reviews have documented the  
4 76 multiple health impacts of climate change, including an increase in infectious diseases,  
5 77 respiratory disorders, heat-related morbidity and mortality, undernutrition due to food insecurity,  
6 78 and adverse health outcomes ensuing from increased socio-political tension and conflicts.<sup>2-5</sup>  
7 79 Indeed, the most recent Lancet Countdown report,<sup>2</sup> which investigates 43 indicators of the  
8 80 relationship between climate change and human health, arrived at their most worrisome findings  
9 81 since the beginning of their on-going annual work. This report underlines that the health impacts  
10 82 of climate change continue to worsen and are being felt on every continent, although they are  
11 83 having a disproportionate and unequal impact on populations.<sup>2</sup> Authors caution that these  
12 84 health impacts will continue to worsen unless we see an immediate international response to  
13 85 limiting climate change.  
14 86

15 87 To guide future research and action to mitigate and adapt to the health impacts of climate  
16 88 change and its environmental consequences, we need a complete and thorough overview of the  
17 89 research already conducted regarding the health impacts of climate change. Although the  
18 90 number of original studies researching the health impacts of climate change has greatly  
19 91 increased in the recent decade,<sup>2</sup> these do not allow for an in-depth overview of the current  
20 92 literature on the topic. Systematic reviews, on the other hand, allow a higher-order overview of  
21 93 the literature. Although previous systematic reviews have been conducted on the health impacts  
22 94 of climate change, these tend to focus on specific climate effects (e.g., impact of wildfires on  
23 95 health),<sup>6,7</sup> health impacts (e.g., occupational health outcomes),<sup>8,9</sup> countries,<sup>10-12</sup> or are no longer  
24 96 up to date,<sup>13,14</sup> thus limiting our global understanding of what is currently known about the  
25 97 multiple health impacts of climate change across the world.  
26 98

27 99 In this study, we aimed to develop such a complete overview by synthesizing systematic  
28 100 reviews of health impacts of climate change. This higher-order overview of the literature will  
29 101 allow us to better prepare for the worsening health impacts of climate change, by identifying and  
30 102 describing the diversity and range of health impacts studied, as well as by identifying gaps in  
31 103 previous research. Our research objectives were to synthesize studies' characteristics such as  
32 104 geographical regions, years of publication, and authors' affiliations, to map the climate impacts,  
33 105 health outcomes, and combinations of these that have been studied, and to synthesize key  
34 106 findings.  
35

## 36 107 **Methods**

37 108 We applied the Cochrane method for overviews of reviews.<sup>15</sup> This method is designed to  
38 109 systematically map the themes of studies on a topic and synthesize findings to achieve a  
39 110 broader overview of the available literature on the topic.  
40

## 41 111 **Research questions**

42 112 Our research questions were the following: 1) What is known about the relationship between  
43 113 climate change and health, as shown in previous systematic reviews? 2) What are the  
44 114 characteristics of these studies? We registered our plan (CRD42019145972<sup>16</sup>) in PROSPERO,  
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3 115 an international prospective register of systematic reviews and followed PRISMA 2020<sup>17</sup> to  
4 116 report our findings, as a reporting guideline for overviews is still in development.<sup>18</sup>  
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6

## 7 117 Search strategy and selection criteria

8  
9 118 To identify relevant studies, we used a systematic search strategy. There were two inclusion  
10 119 criteria. We included studies in this review if they 1) were systematic reviews of original  
11 120 research and 2) reported at least one health impact as it related (directly or indirectly) to climate  
12 121 change.  
13

14 122  
15 123 We defined a systematic review, based on Cochrane's definition, as a review of the literature in  
16 124 which one "attempts to identify, appraise and synthesize all the empirical evidence that meets  
17 125 pre-specified eligibility criteria to answer a specific research question [by] us[ing] explicit,  
18 126 systematic methods that are selected with a view aimed at minimizing bias, to produce more  
19 127 reliable findings to inform decision making."<sup>19</sup> We included systematic reviews of original  
20 128 research, with or without meta-analyses. We excluded narrative reviews, non-systematic  
21 129 literature reviews and systematic reviews of materials that were not original research (e.g.,  
22 130 systematic reviews of guidelines.)  
23

24 131  
25 132 We based our definition of health impacts on the World Health Organization's (WHO) definition  
26 133 of health as, "a state of complete physical, mental and social well-being and not merely the  
27 134 absence of disease or infirmity."<sup>20</sup> Therefore, health impacts included, among others, morbidity,  
28 135 mortality, new conditions, worsening/improving conditions, injuries, and psychological well-  
29 136 being. Included studies could refer to climate change or global warming directly or indirectly, for  
30 137 instance, by synthesizing the direct or indirect health effects of temperature rises or of natural  
31 138 conditions/disasters made more likely by climate change (e.g., floods, wildfires, temperature  
32 139 variability, droughts.) Although climate change and global warming are not equivalent terms, in  
33 140 an effort to avoid missing relevant literature, we included studies using either term. We included  
34 141 systematic reviews whose main focus was not the health impacts of climate change, providing  
35 142 they reported at least one result regarding health effects related to climate change (or  
36 143 consequences of climate change.) We excluded studies if they did not report at least one health  
37 144 effect of climate change. For instance, we excluded studies which reported on existing  
38 145 measures of health impacts of climate change (and not the health impact itself) and studies  
39 146 which reported on certain health impacts without a mention of climate change, global warming  
40 147 or environmental consequences made more likely by climate change.  
41

42 148  
43 149 On June 22, 2019, we retrieved systematic reviews regarding the health effects of climate  
44 150 change by searching from inception the electronic databases Medline, CINAHL, Embase,  
45 151 Cochrane, Web of Science using a structured search (see Appendix 1 for final search strategy  
46 152 developed by a librarian.) We did not apply language restrictions. After removing duplicates, we  
47 153 imported references into Covidence.<sup>21</sup>  
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## 154 Screening process and data extraction

155 To select studies, two trained analysts first screened independently titles and abstracts to  
156 eliminate articles that did not meet our inclusion criteria. Next, the two analysts independently  
157 screened the full text of each article. A senior analyst resolved any conflict or disagreement.

158  
159 Next, we decided on key information that needed to be extracted from studies. We extracted the  
160 first author's name, year of publication, number of studies included, time frame (in years) of the  
161 studies included in the article, first author's institution's country affiliation, whether the  
162 systematic review included a meta-analysis, geographical focus, population focus, the climate  
163 impact(s) and the health outcome(s) as well as the main findings and limitations of each  
164 systematic review.

165  
166 Two or more trained analysts (RR, CB, RN, LC, LPB, RAPR) independently extracted data,  
167 using Covidence and spreadsheet software (Google Sheets). An additional trained analyst from  
168 the group or senior research team member resolved disagreements between individual  
169 judgments.

## 171 Coding and Data Mapping

172 To summarize findings from previous reviews, we first mapped articles according to climate  
173 impacts and health outcomes. To develop the categories of climate impacts and health  
174 outcomes, two researchers (RR and LC) consulted the titles and abstracts of each article. We  
175 started by identifying categories directly based on our data and finalized our categories by  
176 consulting previous conceptual frameworks of climate impacts and health outcomes.<sup>1,22,23</sup> The  
177 same two researchers independently coded each article according to their climate impact and  
178 health outcome. We then compared coding and resolved disagreements through discussion.

179  
180 Next, using spreadsheet software, we created a matrix to map articles according to their  
181 combination of climate impacts and health outcomes. Each health outcome occupied one row,  
182 whereas climate impacts each occupied one column. We placed each article in the matrix  
183 according to the combination(s) of their climate impact(s) and health outcome(s). For instance, if  
184 we coded an article as 'extreme weather' for climate and 'mental health' for health impact, we  
185 noted the reference of this article in the cell at the intersection of these two codes. We  
186 calculated frequencies for each cell to identify frequent combinations and gaps in literature.  
187 Because one study could investigate more than one climate impact and health outcome, the  
188 frequency counts for each category could exceed the number of studies included in this review.

189  
190 Finally, we re-read the Results and Discussion sections of each article to summarize findings of  
191 the studies. We first wrote an individual summary for each study, then we collated the  
192 summaries of all studies exploring the same combination of categories to develop an overall  
193 summary of findings for each combination of categories.

## 194 Quality assessment

195 We used a modified version of AMSTAR-2 to assess the quality of the included systematic  
196 reviews (Appendix 2). The purpose of this assessment was to evaluate the quality of the  
197 included studies as a whole to get a sense of the overall quality of evidence in this field.  
198 Therefore, individual quality scores were not compiled for each article, but scores were  
199 aggregated according to items. Since AMSTAR-2 was developed for syntheses of systematic  
200 reviews of randomized controlled trials, working with a team member with expertise in  
201 knowledge synthesis (AT), we adapted it to suit a research context that is not amenable to  
202 randomized controlled trials. For instance, we changed assessing and accounting for risk of bias  
203 in studies' included randomized controlled trials to assessing and accounting for limitations in  
204 studies' included articles. Complete modifications are presented in Appendix 2.

## 205 Patient and Public Involvement

206 Patients and members of the public were not involved in this study.

## 207 Results

### 208 Articles identified

209 As shown in the PRISMA diagram in Figure 1, from an initial set of 2619 references, we retained  
210 94 for inclusion. More precisely, following screening of titles and abstracts, 146 studies  
211 remained for full text inspection. During full text inspection, we excluded 52 studies, as they did  
212 not report a direct health effect of climate change (n = 17), did not relate to climate change (n =  
213 15), were not systematic reviews (n = 10), or we could not retrieve the full text (n = 10).

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215 **Insert Figure 1 About Here**

### 216 Study Descriptions

217 A detailed table of all articles and their characteristics can be found in Appendix 3. Publication  
218 years ranged from 2007 to 2019 (year of data extraction), with the great majority of included  
219 articles (n = 69; 73%) published since 2015 (Figure 2). A median of 30 studies had been  
220 included in the systematic reviews (mean = 60; SD = 49; range 7 to 722). Approximately one  
221 fifth of the systematic reviews included meta-analyses of their included studies (n = 18; 19%).  
222 The majority of included systematic reviews' first authors had affiliations in high-income  
223 countries, with the largest representations by continent in Europe (n = 30) and Australia (n = 24)  
224 (Figure 3). Countries of origin by continents include (from highest to lowest frequency, then by  
225 alphabetical order): Europe (30); United-Kingdom (9), Germany (6), Italy (4), Sweden (4),  
226 Denmark (2), France (2), Georgia (1), Greece (1) and Finland (1); Australia (24); Asia (21);  
227 China (11), Iran (4), India (1), Jordan (1), Korea (1), Nepal (1), Philippines (1), Taiwan (1);  
228 North America (16); United-States (15), Canada (1); Africa (2); Ethiopia (1), Ghana (1), and  
229 South America (1); Brazil (1).

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**Insert Figure 2 About Here**

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**Insert Figure 3 About Here**

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Regarding the geographical focus of systematic reviews, most of the included studies (n = 68; 72%) had a global focus or no specified geographical limitations and therefore included studies published anywhere in the world. The remaining systematic reviews either targeted certain countries (n = 12) (1 for each Australia, Germany, Iran, India, Ethiopia, Malaysia, Nepal, New Zealand and 2 reviews focused on China and the United States), continents (n = 5) (3 focused on Europe and 2 on Asia), or regions according to geographical location (n = 6) (1 focused on Sub-Saharan Africa, 1 on Eastern Mediterranean countries, 1 on Tropical countries, and 3 focused on the Arctic), or according to the country's level of income (n = 3) (2 on low to middle income countries, 1 on high income countries).

Regarding specific populations of interest, most of the systematic reviews did not define a specific population of interest (n = 69; 73%). For the studies that specified a population of interest (n = 25; 26.6%), the most frequent populations were children (n = 7) and workers (n = 6), followed by vulnerable or susceptible populations more generally (n = 4), the elderly (n = 3), pregnant people (n = 2), people with disabilities or chronic illnesses (n = 2) and rural populations (n = 1).

## 252 Quality assessment

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We assessed studies for quality according to our revised AMSTAR-2. Complete scores for each article and each item are available in Appendix 4. Out of 94 systematic reviews, the most commonly fully satisfied criterion was #1 (PICO components) with 81/94 (86%) of included systematic reviews fully satisfying this criterion. The next most commonly-satisfied criteria were #16 (potential sources of conflict of interest reported) (78/94 = 83% fully), #13 (account for limitations in individual studies) (70/94 = 75% fully and 2/94 = 2% partially), #7 (explain both inclusion and exclusion criteria) (64/94 = 68% fully and 19/94 = 20% partially), #8 (description of included studies in adequate detail) (36/94 = 38% fully and 41/94 = 44% partially), and #4 (use of a comprehensive literature search strategy) (0/94 = 0% fully and 80/94 = 85% partially). For criteria #11, #12, and #15, which only applied to reviews including meta-analyses, 17/18 (94%) fully satisfied criterion #11 (use of an appropriate methods for statistical combination of results), 12/18 (67%) fully satisfied criterion #12 (assessment of the potential impact of RoB in individual studies) (1/18 = 6% partially), and 11/18 (61%) fully satisfied criterion #15 (an adequate investigation of publication bias, small study bias).

## 267 Climate Impacts and Health Outcomes

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Regarding climate impacts, we identified five mutually exclusive categories, with 13 publications targeting more than one category of climate impacts: 1) Meteorological (n = 71 papers) (e.g., temperature, heat waves, humidity, precipitation, sunlight, wind, air pressure), 2) Extreme weather (n = 24) (e.g., water-related, floods, cyclones, hurricanes, drought), 3) Air quality (n = 7)

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3 272 (e.g., air pollution and wildfire smoke exposure), 4) General (n = 5), and 5) Other (n = 3).  
4 273 Although heat waves could be considered an extreme weather event, papers investigating heat  
5 274 waves' impact on health were classified in the meteorological impact category, since some of  
6 275 these studies treated them with high temperature. "General" climate impacts included articles  
7 276 that did not specify climate change impacts but stated general climate change as their focus.  
8 277 "Other" climate impacts included studies investigating other effects indirectly related to climate  
9 278 change (e.g., impact of environmental contaminants) or general environmental risk factors (e.g.,  
10 279 environmental hazards, sanitation and access to clean water.)  
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14 281 We identified ten categories to describe the health outcomes studied by the systematic reviews,  
15 282 and 29 publications targeted more than one category of health outcomes: 1) Infectious diseases  
16 283 (n = 41 papers) (vector-, food- and water-borne), 2) Mortality (n = 32), 3) Respiratory,  
17 284 cardiovascular, and neurological (n = 23), 4) Healthcare systems (n = 16), 5) Mental health (n =  
18 285 13), 6) Pregnancy and birth (n = 11), 7) Nutritional (n = 9), 8) Skin diseases and allergies (n =  
19 286 8), 9) Occupational health and injuries (n = 6) and 10) Other health outcomes (n = 17) (e.g.,  
20 287 sleep, arthritis, disability-adjusted life years, non-occupational injuries, etc.)  
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24 289 Figure 4 depicts the combinations of climate impact and health outcome for each study, with  
25 290 Appendix 5 offering further details. The 5 most common combinations are studies investigating  
26 291 the 1) meteorological impacts on infectious diseases (n = 35), 2) mortality (n = 24) and 3)  
27 292 respiratory, cardiovascular, and neurological outcomes (n = 17), 4) extreme weather events'  
28 293 impacts on infectious diseases (n = 14), and 5) meteorological impacts on health systems (n =  
29 294 11).  
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### 32 296 **Insert Figure 4 About Here**

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34 298 For studies investigating meteorological impacts on health, the three most common health  
35 299 outcomes studied were impacts on 1) infectious diseases (n = 35), 2) mortality (n = 24) and 3)  
36 300 respiratory, cardiovascular, and neurological outcomes (n = 17). Extreme weather event studies  
37 301 most commonly reported health outcomes related to 1) infectious diseases (n = 14), 2) mental  
38 302 health outcomes (n = 9) and 3) nutritional outcomes (n = 6) and other health outcomes (e.g.,  
39 303 injuries, sleep) (n = 6). Studies focused on the impact of air quality were less frequent and  
40 304 explored mostly health outcomes linked to 1) respiratory, cardiovascular, and neurological  
41 305 outcomes (n = 6), 2) mortality (n = 5) and 3) pregnancy and birth outcomes (n = 3).  
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## 46 306 **Summary of Findings**

47 307 Most reviews suggest a deleterious impact of climate change on multiple adverse health  
48 308 outcomes, with some associations being explored and/or supported with consistent findings  
49 309 more often than others. Some reviews also report conflicting findings or an absence of  
50 310 association between the climate impact and health outcome studied (see Table 1 for a detailed  
51 311 summary of findings according to health outcomes).  
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55 313 Notable findings of health outcomes according to climate impact include the following. For  
56 314 meteorological factors (n = 71), temperature and humidity are the variables most often studied  
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3 315 and report the most consistent associations with infectious diseases and respiratory,  
4 316 cardiovascular, and neurological outcomes. Temperature is also consistently associated with  
5 317 mortality and healthcare service use. Some associations are less frequently studied, but remain  
6 318 consistent, including the association between some meteorological factors (e.g., temperature  
7 319 and heat) and some adverse mental health outcomes (e.g., hospital admissions for mental  
8 320 health reasons, suicide, exacerbation of previous mental health conditions), and the association  
9 321 between heat and adverse occupational outcomes and some adverse birth outcomes.  
10 322 Temperature is also associated with adverse nutritional outcomes (likely via crop production and  
11 323 food insecurity) and temperature and humidity are associated with some skin diseases and  
12 324 allergies. Some health outcomes are less frequently studied, but studies suggest an association  
13 325 between temperature and diabetes, impaired sleep, cataracts, heat stress, heat exhaustion and  
14 326 renal diseases.  
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19 328 Extreme weather events (n = 24) are consistently associated with mortality, some mental health  
20 329 outcomes (e.g., distress, anxiety, depression) and adverse nutritional outcomes (likely via crop  
21 330 production and food insecurity). Some associations are explored less frequently, but these  
22 331 studies suggest an association between drought and respiratory and cardiovascular outcomes  
23 332 (likely via air quality), between extreme weather events and an increased use of healthcare  
24 333 services and some adverse birth outcomes (likely due to indirect causes, such as experiencing  
25 334 stress). Some health outcomes are less frequently studied, but studies suggest an association  
26 335 between extreme weather events and injuries, impaired sleep, esophageal cancer and  
27 336 exacerbation of chronic illnesses. There are limited and conflicting findings for the association  
28 337 between extreme weather events and infectious diseases, as well as for certain mental health  
29 338 outcomes (e.g., suicide and substance abuse). At times, different types of extreme weather  
30 339 events (e.g., drought vs flood) led to conflicting findings for some health outcomes (e.g., mental  
31 340 health outcomes, infectious diseases), but for other health outcomes, the association was  
32 341 consistent independently of the extreme weather event studied (e.g., mortality, healthcare  
33 342 service use and nutritional outcomes).  
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38 344 The impact of air quality on health (n = 7) was less frequently studied, but the few studies  
39 345 exploring this association report consistent findings regarding an association with respiratory-  
40 346 specific mortality, adverse respiratory outcomes and an increase in healthcare service use.  
41 347 There is limited evidence regarding the association between air quality and cardiovascular  
42 348 outcomes, limited and inconsistent evidence between wildfire smoke exposure and adverse  
43 349 birth outcomes, and no association is found between exposure to wildfire smoke and increase in  
44 350 use of health services for mental health reasons. Only one review explored the impact of wildfire  
45 351 smoke exposure on ophthalmic outcomes, and it suggests that it may be associated with eye  
46 352 irritation and cataracts.  
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50 354 Reviews which stated climate change as their general focus and did not specify the climate  
51 355 impact(s) under study were less frequent (n = 5), but they suggest an association between  
52 356 climate change and pollen allergies in Europe, increased use of healthcare services, obesity,  
53 357 skin diseases and allergies and an association with disability-adjusted life years. Reviews  
54 358 investigating the impact of other climate-related factors (n = 3) show inconsistent findings  
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359 concerning the association between environmental pollutant and adverse birth outcomes, and  
 360 two reviews suggest an association between environmental risk factors and pollutants and  
 361 childhood stunting and occupational diseases.

362  
 363 Most reviews concluded by calling for more research, noting the limitations observed among the  
 364 studies included in their reviews, as well as limitations in their reviews themselves. These  
 365 limitations included, amongst others, some systematic reviews having a small number of  
 366 publications,<sup>24,25</sup> language restrictions such as including only papers in English,<sup>26,27</sup> arriving at  
 367 conflicting evidence,<sup>28</sup> difficulty concluding a strong association due to the heterogeneity in  
 368 methods and measurements or the limited equipment and access to quality data in certain  
 369 contexts,<sup>24,29–31</sup> and most studies included were conducted in high-income countries.<sup>32,33</sup>

370  
 371 Previous authors also discussed the important challenge related to exploring the relationship  
 372 between climate change and health. Not only is it difficult to explore the potential causal  
 373 relationship between climate change and health, mostly due to methodological challenges, but  
 374 there are also a wide variety of complex causal factors that may interact to determine health  
 375 outcomes. Therefore, the possible causal mechanisms underlying these associations were at  
 376 times still unknown or uncertain and the impacts of some climate factors were different  
 377 according to geographical location and specificities of the context. Nonetheless, some reviews  
 378 offered potential explanations for the climate-health association, with the climate factor at times,  
 379 having a direct impact on health (e.g., flooding causing injuries, heat causing dehydration) and  
 380 in other cases, having an indirect impact (e.g., flooding causing stress which in turn may cause  
 381 adverse birth outcomes, heat causing difficulty concentrating leading to occupational injuries.)

382  
 383 **Table 1.** Summary of findings from systematic reviews according to health outcome and climate  
 384 impact. Reviews that covered multiple climate impacts are listed in each relevant category.

Climate Impact	F	Summary of Findings
<b>Infectious diseases (n = 41)</b>		
<i>Vector borne infectious diseases (n = 25)</i>		

Meteorological	22	Systematic reviews suggest that meteorological factors, such as temperature, precipitation, humidity, and wind, are associated with diverse vector-borne infectious diseases, including malaria and dengue. <sup>9,12,26,29,31,34–50</sup> This association was mostly proportional (e.g., higher temperature and increased rainfall associated with vector-borne diseases), although findings were at times conflicting, with some suggesting an inversely proportional association <sup>12</sup> (e.g., decreased rainfall) or no association at all <sup>39</sup> (e.g., with the human puumala hantavirus Infection.) Geographic location, seasonality and potential interaction with other climate-related factors may partly explain these inconsistencies. <sup>12,29</sup> Temperature, humidity and rainfall were the most common and important meteorological factors reported by reviews and factors such as wind, air pressure and sunshine were reported less often.
Extreme weather	7	There are limited and conflicting findings concerning the association of extreme weather events with vector-borne diseases. Some reviews suggest water-related extreme events <sup>51</sup> and flooding <sup>6,31,52</sup> are associated with an increased risk of vector-borne diseases, while drought is associated with a reduction of dengue incidence. <sup>12</sup> Other reviews focused specifically on Puerto Rico <sup>43</sup> and Australia <sup>53</sup> did not find an association between hurricanes and/or floods and mosquito-borne disease transmission.
<i>Food and water borne infectious diseases (n = 19)</i>		
Meteorological	14	Reviews suggest that meteorological factors, such as temperature, precipitation, and humidity, are associated with diverse food- and water-borne infectious diseases, in particular, cholera, schistosomiasis, salmonella and E. coli gastroenteritis. <sup>11,31,40,42,45,48,54–61</sup> Overall, higher temperatures and humidity, <sup>11,40,54,58</sup> along with lower precipitation <sup>42,61</sup> was associated with these infectious diseases. Directionality and strength of the association seemed to vary according to disease and pathogens, <sup>59</sup> seasons, and geographic region. <sup>56</sup>
Extreme weather	10	Reviews suggest a proportional association between extreme water-related events, <sup>47,51,62</sup> such as flooding <sup>6,40,52</sup> and heavy rainfall <sup>34</sup> , and food- and water-borne diseases, including diarrhea, food contamination, cholera. <sup>6,31,34,40,45,47,51,52,57,62</sup> Drought may also be proportionally associated with food- and water-borne disease, <sup>34,63</sup> but these associations are less consistent than those with water-related extreme events. <sup>57</sup>
<i>Other infectious diseases (n = 8)</i>		

Meteorological	8	Reviews suggest an association of most meteorological factors, such as temperature and humidity, with various other infectious diseases, including meningitis, <sup>24,34</sup> Ebola, <sup>24</sup> influenza, <sup>31</sup> and pediatric infectious diseases such as hand-foot-and-mouth disease. <sup>7,8,30,49,55</sup> This association was mostly proportional for meteorological factors such as temperature, <sup>7,8,49</sup> diurnal temperature range, <sup>30</sup> and humidity, <sup>7,8,31</sup> although some meteorological factors, such as air pressure <sup>8</sup> and lower temperatures <sup>31,49</sup> were inversely proportional to these diseases. Some conflicting evidence is reported concerning the association with some meteorological factors, such as sunshine with hand-foot-and-mouth disease, <sup>7,8</sup> and humidity and pediatric infectious diseases. <sup>55</sup> No association was found between some meteorological factors, such as precipitation, wind speed and sunshine with hand-foot-and-mouth disease. <sup>7,8</sup>
<b>Mortality (n = 32)</b>		
Meteorological	24	Reviews suggest that temperature (high, low, or diurnal range) was consistently associated with all-cause and cause-specific mortality. <sup>24–26,30,33,42,45,47,49,64–77</sup> A strong association was reported between heat (including heat waves) and mortality (all-cause), <sup>64</sup> heat-, <sup>42,69</sup> stroke-, <sup>24,70</sup> cardiovascular-, <sup>33,47</sup> and respiratory-related, <sup>26,33,71</sup> especially in rural, <sup>68</sup> very young children <sup>49</sup> and ageing populations. <sup>25</sup> Mortality seems to be the most frequent health outcome studied in association with heatwaves. <sup>65</sup> Inconsistent results are found concerning the association between heat and childhood mortality. <sup>75</sup> Due to limited evidence, this association was weaker in some geographical regions. <sup>24,72</sup> Also, heat wave intensity (compared to duration) was more strongly associated with heat-related mortality. <sup>76</sup> Finally, although less studied, low temperature was also associated with mortality, <sup>49,77</sup> specifically respiratory, <sup>64</sup> stroke, <sup>70</sup> and cardiovascular mortality. <sup>47,67,71</sup>
Extreme Weather	5	Reviews suggest an association between extreme weather events such as floods, <sup>6</sup> droughts, <sup>63</sup> cyclones <sup>78</sup> and other water-related events, <sup>26,51</sup> with direct (e.g., drowning) and indirect long-term mortality (e.g., due to malnutrition, environmental toxin exposure, armed conflict, etc.). <sup>6,51,63,78</sup>
Air quality	5	Reviews suggest an association between exposure to air pollution <sup>26,79</sup> or wildfire smoke <sup>80–82</sup> and air pollution related-mortality, such as respiratory-specific mortality. There is currently limited evidence, but reviews suggest a potential association between wildfire smoke exposure and cardiovascular-specific mortality. <sup>80–82</sup>
<b>Respiratory, neurological, and cardiovascular (n = 23)</b>		
General	1	A review suggests a proportional association between climate change, in general, and ragweed pollen allergies in Europe. <sup>83</sup>

Meteorological	17	Reviews suggest an association between meteorological factors, such as temperature and humidity, and cardiovascular, respiratory and neurological outcomes. <sup>24,26,30,33,36,45,49,55,64,67,69,70,74,75,84–86</sup> Exposure to high temperatures and extreme heat are associated to cardiovascular and respiratory diseases, <sup>24,26,36,49,67</sup> stroke, <sup>70</sup> long-term neurological outcomes (due to heat strokes), <sup>69</sup> myocardial infarction, <sup>33,85</sup> and childhood asthma and pediatric respiratory diseases. <sup>75,86</sup> A review also suggests a beneficial association between heat and the shortening of a respiratory virus season. <sup>45</sup> Exposure to low temperature (cold), temperature drop, or diurnal temperature range was associated with cardiovascular and respiratory diseases, <sup>30,64,67</sup> stroke, <sup>70</sup> and myocardial infarctions. <sup>33</sup> Humidity (most often high humidity, but also lower humidity) and low temperatures were also associated with respiratory diseases in children, including childhood asthma. <sup>55,84,86</sup>
Extreme Weather	1	A previous review suggests an association between drought and respiratory and cardiovascular outcomes, most likely due to droughts leading to increased dust in the air. <sup>63</sup>
Air quality	6	Reviews suggest a proportional association between exposure to air pollution <sup>26,42,45</sup> or wildfire smoke exposure <sup>80–82</sup> and respiratory outcomes, including asthma, chronic obstructive pulmonary disease, coughing, wheezing, and overall lung function. Although there is currently limited evidence, <sup>80</sup> reviews also suggest a potential association between air pollution or wildfire smoke exposure and cardiovascular outcomes. <sup>45,81,82</sup>
<b>Health systems (n = 16)</b>		
General	1	A previous review suggests that climate change in general puts a strain on public health resources, via population health issues and shows that using an integrated surveillance system may guide future adaptation to climate change. <sup>87</sup>
Meteorological	11	Previous reviews suggest an association between temperature change <sup>30</sup> extreme heat, aridity and cold temperatures and an increase in use of healthcare services (mostly linked to heat-related health impacts), such as an increase in emergency department visits, hospital admissions and use of ambulances. <sup>24,26,30,33,42,49,65,72,75,85,88</sup>
Extreme weather	2	Reviews suggest that extreme weather events <sup>32</sup> and flooding <sup>6</sup> may be associated with an increase in use of healthcare services (e.g., increased hospitalizations) and a compromised quality of care as extreme weather events may lead to power outages. <sup>32</sup>
Air quality	2	Reviews suggest an association between wildfire smoke exposure and an increase in use of healthcare services, such as an increase in emergency department visits. <sup>80,82</sup>
<b>Mental health (n = 13)</b>		

Meteorological	3	Reviews suggest an association of most meteorological factors such as temperature increase, aridity, heat, and heat waves with mental health outcomes, including hospital admissions for mental health reasons, <sup>42</sup> suicide, <sup>89</sup> and exacerbation of pre-existing mental health conditions, difficulty sleeping, and fatigue. <sup>85</sup> No association was found between sunlight duration and suicide incidence. <sup>89</sup>
Extreme weather	9	Most reviews reported a proportional association of extreme weather events, <sup>45,51,90,91</sup> flooding, <sup>6,26,92</sup> and drought <sup>63,93</sup> with diverse mental health issues, including, psychological distress, post-traumatic stress disorder, anxiety, depression, psychotropic medication use, alcohol consumption. There was conflicting evidence regarding the association of floods with suicide, tobacco, alcohol and substance abuse. <sup>92</sup> No association was found between drought and suicide. <sup>63</sup>
Air quality	1	A previous review suggests no association between wildfire smoke exposure and mental health, as measured by physician visits and hospitalizations for mental health reasons during wildfires. <sup>81</sup>
<b>Pregnancy and birth outcomes (n = 11)</b>		
Meteorological	5	Reviews suggest that adverse birth outcomes may be higher among people exposed to meteorological factors such as high temperature, heat, sunlight intensity, cold and humidity. <sup>42,94–97</sup> These outcomes include low birth weight, preterm birth, eclampsia and preeclampsia, hypertension and length of pregnancy. <sup>42,94–97</sup> The association between heat and adverse birth outcomes seems to have stronger support than the association with cold temperatures. <sup>97</sup>
Extreme Weather	2	Reviews suggest a potential association of extreme weather events <sup>90</sup> and flooding <sup>6</sup> with adverse birth outcomes, such as low birth weight, preterm birth and pre-eclampsia. It is suggested that extreme weather events may indirectly affect birth outcomes via the pregnant person's well-being (e.g., stress and worry during pregnancy.) <sup>6,90</sup>
Air quality	3	There is limited and inconsistent evidence concerning the association between wildfire smoke exposure and adverse birth outcomes, but reviews suggest a potential proportional association between wildfire smoke exposure and lower birth weight. <sup>80–82</sup>
Other	1	The association between environmental pollutants and adverse birth outcomes (i.e., preterm birth) remains unclear due to conflicting evidence. <sup>28</sup>
<b>Nutritional (n = 9)</b>		
General	1	A review suggests an association between climate change and obesity. <sup>98</sup>
Meteorological	4	Reviews suggest an association between meteorological factors, such as changes in temperature, heat and precipitation, with diverse nutritional outcomes, including undernutrition, malnutrition and child stunting. <sup>24,27,42,72</sup> This association may be

		explained by the impact of meteorological factors, such as temperature increase and precipitation decrease, on crop production and food insecurity. <sup>42,72</sup>
Extreme Weather	6	Reviews suggest an association between extreme weather events, such as flooding and droughts, <sup>63</sup> and diverse nutritional outcomes, including malnutrition and undernutrition in children and adults <sup>27,34,42,45,47</sup> via, amongst others, crops production and food insecurity (e.g., low food aid following flooding <sup>42</sup> ).
Other	1	A review suggests a potential association between certain environmental risk factors (e.g., sanitation, cooking fuels and food-borne mycotoxins), and childhood stunting, which could be aggravated by climate change. <sup>99</sup>
<b>Skin diseases and allergies (n = 8)</b>		
General	1	A review suggests a potential proportional association between climate change, in general, and skin and soft tissue infections (e.g., fatal vibrio vulnificus necrotizing). <sup>100</sup>
Meteorological	7	Reviews suggest an association of meteorological factors, such as ultraviolet light exposure, temperature and humidity, with diverse skin diseases and allergies, including skin cancer, sunburn, acute urticaria, eczema and pediatric skin irritabilities. <sup>24,45,47,49,55,85,101</sup> Higher temperature and ultraviolet light exposure is proportionally associated with sunburn <sup>85</sup> and skin cancer, <sup>45,101</sup> while low humidity and low temperatures were associated with eczema and skin irritabilities in children. <sup>49,55</sup>
<b>Occupational health and injuries (n = 6)</b>		
Meteorological	6	Reviews suggest that heat is associated with adverse occupational health outcomes, including injuries (e.g., slips, trips, falls, wounds, lacerations and amputations), heat strain, dehydration and kidney diseases. <sup>102-107 103</sup> This association was found in many occupational settings, including agriculture, construction, transport and fishing, and seems to affect both outdoor and indoor workers. <sup>102</sup> This association may be explained by a combination of direct (e.g., dehydration) and indirect factors (e.g., impaired cognitive and physical performance.) <sup>106</sup>
Other	1	A review suggests a potential association between environmental pollution (e.g., heavy metals, fertilizers, etc.) and occupational diseases, such as chronic kidney disease. <sup>107</sup> This association is suggested to be affected by increasing temperatures.
<b>Other (n = 17)</b>		

General	1	A review suggests a potential association between climate change in general and disability-adjusted life years, which is an indicator that quantifies 'the burden of disease attributable to climate change'. <sup>108</sup> Authors suggest that the cost of disability-adjusted life years could be high, especially in low to middle income countries.
Meteorological	10	Reviews suggests an association between increasing temperatures and temperature changes, <sup>30</sup> and other various health outcomes, including acute gouty arthritis, <sup>109</sup> unintentional injuries, <sup>110</sup> diabetes, <sup>64</sup> genitourinary diseases, <sup>30,64</sup> impaired sleep time and quality, <sup>111</sup> cataracts (indirectly associated via people spending more time outside and therefore increased exposure to ultraviolet light), <sup>45,47</sup> heat stress, heat exhaustion and kidney failure, <sup>85</sup> and renal diseases, fever and electrolyte imbalance in children. <sup>49,75</sup>
Extreme weather	6	Reviews suggests an association between extreme weather events, <sup>91</sup> such as flooding, <sup>6</sup> cyclones, <sup>78</sup> hurricanes, <sup>111</sup> and drought, <sup>63</sup> and other various health outcomes including injuries (e.g., debris, diving in water that is shallower than expected), <sup>6,63,78,91</sup> impaired sleep, <sup>111</sup> esophageal cancer (likely linked to high salinity of water due to droughts), <sup>63</sup> and exacerbation of chronic illnesses. <sup>6,90</sup>
Air quality	1	There is limited evidence, but a systematic review suggests a potential association between wildfire smoke exposure and ophthalmic outcomes, such as eye irritation and cataracts. <sup>80</sup>

## 385 Discussion

### 386 Principal results

387 In this overview of systematic reviews, we aimed to develop a synthesis of systematic reviews  
 388 of health impacts of climate change by mapping the characteristics and findings of studies  
 389 exploring the relationship between climate change and health. We identified four key findings.

390  
 391 First, meteorological impacts, mostly related to temperature and humidity, were the most  
 392 common impacts studied by included publications, which aligns with findings from a previous  
 393 scoping review on the health impacts of climate change in the Philippines.<sup>10</sup> Indeed,  
 394 meteorological factors' impact on all health outcomes identified in this review are explored,  
 395 although some health outcomes are more rarely explored (e.g., mental health and nutritional  
 396 outcomes). Although this may not be surprising given that a key implication of climate change is  
 397 the long-term meteorological impact of temperature rise, this finding suggests we also need to  
 398 undertake research focused on other climate impacts on health, including potential direct and  
 399 indirect effects of temperature rise, such as the impact of droughts and wildfire smoke. This will  
 400 allow us to better prepare for the health crises that arise from these ever-increasing climate-  
 401 related impacts. For instance, the impacts of extreme weather events and air quality on certain  
 402 health outcomes are not explored (e.g., skin diseases and allergies, occupational health) or only  
 403 rarely explored (e.g., pregnancy outcomes).

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4 405 Second, systematic reviews primarily focus on physical health outcomes, such as infectious  
5 406 diseases, mortality, and respiratory, cardiovascular and neurological outcomes, which also  
6 407 aligns with the country-specific previous scoping review.<sup>10</sup> Regarding mortality, we support  
7 408 Campbell and colleagues'<sup>65</sup> suggestion that we should expand our focus to include other types  
8 409 of health outcomes. This will provide better support for mitigation policies and allow us to adapt  
9 410 to the full range of threats of climate change.  
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12 412 Moreover, it is unclear whether the distribution of frequencies of health outcomes reflects the  
13 413 actual burden of health impacts of climate change. The most commonly-studied health  
14 414 outcomes do not necessarily reflect the definition of health presented by the WHO as, "a state of  
15 415 complete physical, mental and social well-being and not merely the absence of disease or  
16 416 infirmity."<sup>20</sup> This suggests that future studies should investigate in greater depth the impacts of  
17 417 climate change on mental and broader social well-being. Indeed, some reviews suggested that  
18 418 climate change impacts psychological and social well-being, via broader consequences, such  
19 419 as political instability, health system capacity, migration, and crime,<sup>3,4,85,90</sup> thus illustrating how  
20 420 our personal health is determined not only by biological and environmental factors but also by  
21 421 social and health systems. The importance of expanding our scope of health in this field is also  
22 422 recognized in the most recent Lancet report, which states that future reports will include a new  
23 423 mental health indicator.<sup>2</sup>  
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25 425 Interestingly, the reviews that explored the mental health impacts of climate change were  
26 426 focused mostly on the direct and immediate impacts of experiencing extreme weather events.  
27 427 However, psychologists are also warning about the long-term indirect mental health impacts of  
28 428 climate change, which are becoming more prevalent for children and adults alike (e.g., eco-  
29 429 anxiety, climate depression).<sup>112,113</sup> Even people who do not experience direct climate impacts,  
30 430 such as extreme weather events, report experiencing distressing emotions when thinking of the  
31 431 destruction of our environment or when worrying about one's uncertain future and the lack of  
32 432 actions being taken. To foster emotional resilience in the face of climate change, these mental  
33 433 health impacts of climate change need to be further explored. Humanity's ability to adapt to and  
34 434 mitigate climate change ultimately depends on our emotional capacity to face this threat.  
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36 436 Third, there is a notable geographic difference in the country affiliations of first authors, with  
37 437 three quarters of systematic reviews having been led by first authors affiliated to institutions in  
38 438 Europe, Australia, or North America, which aligns with the findings of the most recent Lancet  
39 439 report.<sup>2</sup> While perhaps unsurprising given the inequalities in research funding and institutions  
40 440 concentrated in Western countries, this is of critical importance given the significant health  
41 441 impacts that are currently faced (and will remain) in other parts of the world. Research funding  
42 442 organizations should seek to provide more resources to authors in low- to middle-income  
43 443 countries to ensure their expertise and perspectives are better represented in the literature.  
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45 445 Fourth, overall, most reviews suggest an association between climate change and the  
46 446 deterioration of health in various ways, illustrating the interdependence of our health and well-  
47 447 being with the well-being of our environment. This interdependence may be direct (e.g., heat's  
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3 448 impact on dehydration and exhaustion) or indirect (e.g., via behavior change due to heat.) The  
4 449 most frequently-explored and consistently-supported associations include an association  
5 450 between temperature and humidity with infectious diseases, mortality, and adverse respiratory,  
6 451 cardiovascular and neurological outcomes. Other less frequently studied but consistent  
7 452 associations include associations between climate impacts and increased use of healthcare  
8 453 services, some adverse mental health outcomes, adverse nutritional outcomes, and adverse  
9 454 occupational health outcomes. These associations support key findings of the most recent  
10 455 Lancet report, in which authors report, amongst others, increasing heat exposure being  
11 456 associated with increasing morbidities and mortality, climate change leading to food insecurity  
12 457 and undernutrition, and to an increase in infectious disease transmission.<sup>2</sup>  
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14 459 That said, a number of reviews included in this study reported limited, conflicting and/or an  
15 460 absence of evidence regarding the association between the climate impact and health outcome.  
16 461 For instance, there was conflicting or limited evidence concerning the association between  
17 462 extreme weather events and infectious diseases, cardiorespiratory outcomes and some mental  
18 463 health outcomes and the association between air quality and cardiovascular-specific mortality  
19 464 and adverse birth outcomes. These conflicting and limited findings highlight the need for further  
20 465 research. These associations are complex and there exist important methodological challenges  
21 466 inherent to exploring the causal relationship between climate change and health outcomes. This  
22 467 relationship may at times be indirect and likely determined by multiple interacting factors.  
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24 469 The climate-health link has been the target of more research in recent years and it is also  
25 470 receiving increasing attention from the public and in both public health and climate  
26 471 communication literature.<sup>2,114–116</sup> However, the health framing of climate change information is  
27 472 still underused in climate communications, and researchers suggest we should be doing more  
28 473 to make the link between human health and climate change more explicit to increase  
29 474 engagement with the climate crisis.<sup>2,116–118</sup> The health framing of climate communication also  
30 475 has implications for healthcare professionals<sup>119</sup> and policymakers, as these actors could play a  
31 476 key part in climate communication, adaptation, and mitigation.<sup>116,117,120</sup> These key stakeholders'  
32 477 perspectives on the climate-health link, as well as their perceived role in climate adaptation and  
33 478 mitigation could be explored,<sup>121</sup> since research suggests that health professionals are important  
34 479 voices in climate communications<sup>119</sup> and especially since, ultimately, these adverse health  
35 480 outcomes will engender pressure on and cost to our health systems and health workers.  
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## 37 481 Strengths and Limitations

38 482 To the best of our knowledge, the current study provides the first broad overview of previous  
39 483 systematic reviews exploring the health impacts of climate change. Our review has three main  
40 484 strengths. First, by targeting systematic reviews, we achieve a higher-order summary of findings  
41 485 than what would have been possible by consulting individual original studies. Second, by  
42 486 synthesizing findings across all included studies and according to the combination of climate  
43 487 impact and health outcome, we offer a clear, detailed, and unique summary of the current state  
44 488 of evidence and knowledge gaps about how climate change may influence human health. This  
45 489 summary may be of use to researchers, policymakers, and communities. Third, we included  
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3 490 studies published in all languages about any climate impact and any health outcome. In doing  
4 491 so, we provide a comprehensive and robust overview.

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7 493 Our work has four main limitations. First, we were unable to access some full texts and  
8 494 therefore some studies were excluded, even though we deemed them potentially relevant after  
9 495 title and abstract inspection. Other potentially relevant systematic reviews may be missing due  
10 496 to unseen flaws in our systematic search. Second, due to the heterogeneity of the included  
11 497 systematic reviews and the relatively small proportion of studies reporting meta-analytic  
12 498 findings, we could not conduct meta-meta-analyses of findings across reviews. Future research  
13 499 is needed to quantify the climate and health links described in this review, as well as to  
14 500 investigate the causal relationship and other interacting factors. Third, due to limited resources,  
15 501 we did not assess overlap between the included reviews concerning the studies they included.  
16 502 Frequencies and findings should be interpreted with potential overlap in mind. Fourth, we  
17 503 conducted the systematic search of the literature in June 2019, and it is therefore likely that  
18 504 some recent systematic reviews are not included in this study.

## 21 22 23 505 **Conclusions**

24  
25 506 Overall, most systematic reviews of the health impacts of climate change suggest an  
26 507 association between climate change and the deterioration of health in multiple ways, generally  
27 508 in the direction that climate change is associated with adverse human health outcomes. This is  
28 509 worrisome since these outcomes are predicted to rise in the near future, due to the rise in  
29 510 temperature and increase in climate-change-related events such as extreme weather events  
30 511 and worsened air quality. Most studies included in this review focused on meteorological  
31 512 impacts of climate change on adverse physical health outcomes. Future studies could fill  
32 513 knowledge gaps by exploring other climate-related impacts and broader psychosocial health  
33 514 outcomes. Moreover, studies on health impacts of climate change have mostly been conducted  
34 515 by first authors affiliated with institutions in high-income countries. This inequity needs to be  
35 516 addressed, considering that the impacts of climate change are and will continue to  
36 517 predominantly impact lower-income countries. Finally, although most reviews also recommend  
37 518 more research to better understand and quantify these associations, to adapt to and mitigate  
38 519 climate change's impacts on health, it will also be important to unpack the 'what, how, and  
39 520 where' of these effects. Health effects of climate change are unlikely to be distributed equally or  
40 521 randomly through populations. It will be important to mitigate the changing climate's potential to  
41 522 exacerbate health inequities.

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## 536 Authors' Contributions

537 RN, CF, ACT, HOW contributed to the design of the study. CB, RN, LPB, RAPR and HOW  
538 contributed to the systematic search of the literature and selection of studies. RR, HOW, LC  
539 conducted data analysis and interpretation. RR and HOW drafted the first version of the article  
540 with early revision by CB, LC and RN. All authors critically revised the article and approved the  
541 final version for submission for publication. RR and HOW had full access to all the data in the  
542 study and had final responsibility for the decision to submit for publication.

## 543 Conflict of Interest Statement

544 The authors have no conflict of interest to declare.

## 545 Data Sharing Statement

546 No additional data available.

## 547 Ethics Statement

548 Since this is a systematic review of previous systematic reviews, no ethics approval was  
549 required, as we did not collect original data.

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## 876 Figure Legends

877

878 **Figure 1. The flow chart for included articles in this review.**

879

880 **Figure 2. Number of included systematic reviews by year of publication.**

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882 **Figure 3. Number of publications according to geographic affiliation of the first author.**

883

884 **Figure 4. Summary of the combination of climate impact and health outcome**

885 **(frequencies).** *Note:* The total frequency for one category of health outcome could exceed the  
886 number of publications included in this health outcome, since one publication could explore the  
887 health impact according to more than one climate factor (e.g., one publication could explore  
888 both the impact of extreme weather events and temperature on mental health.



### PRISMA 2009 Flow Diagram

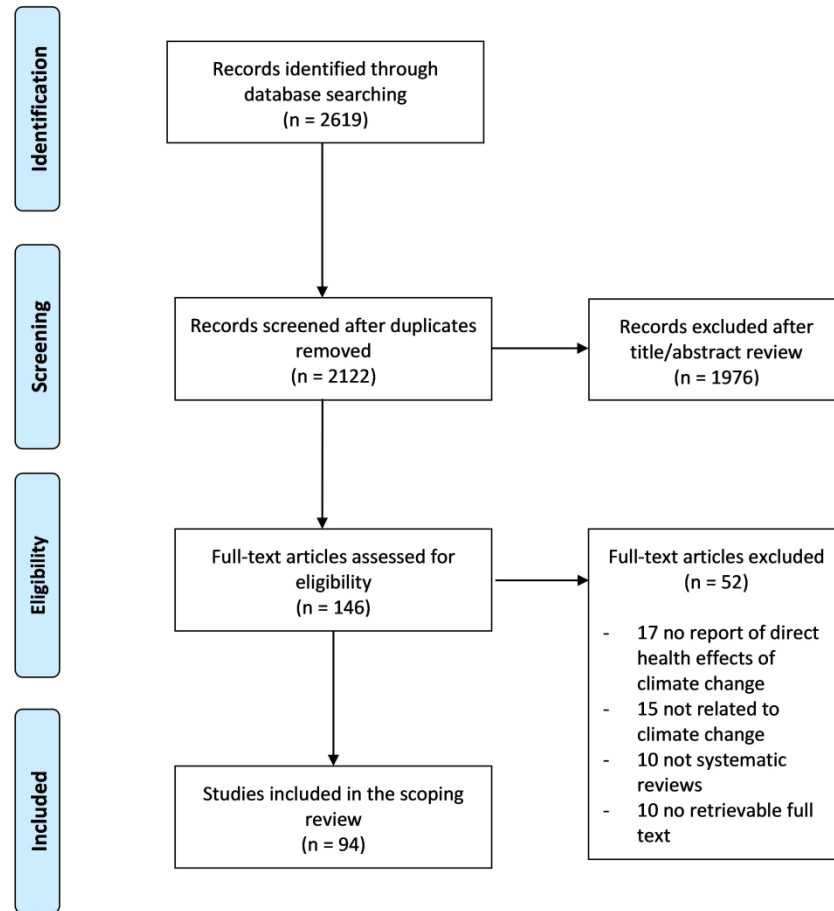


Figure 1. The flow chart for included articles in this review.

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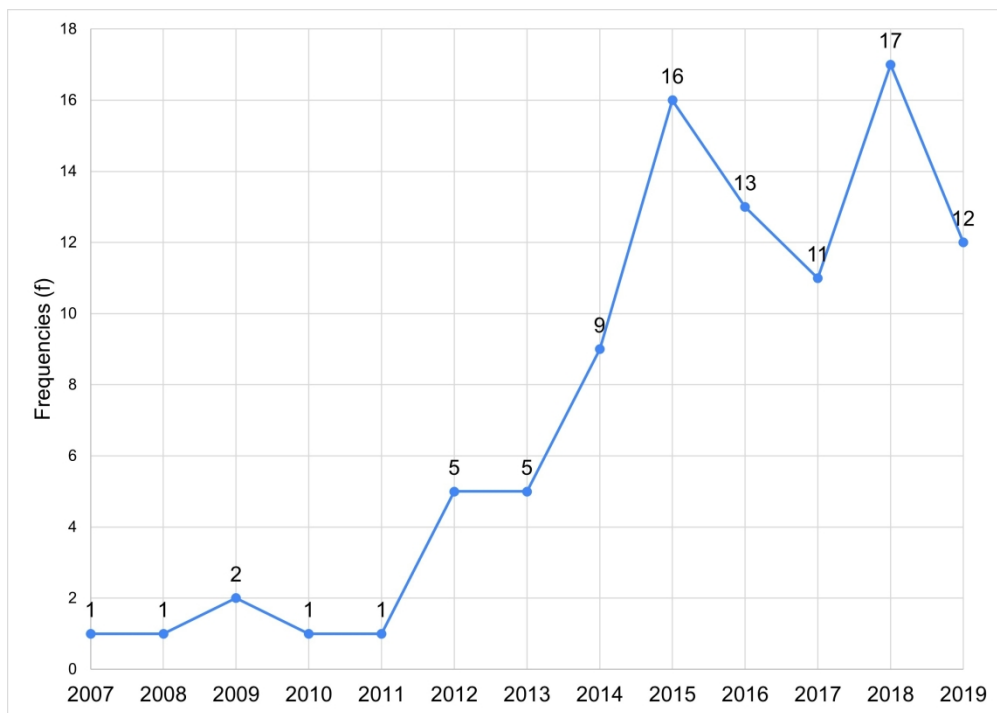


Figure 2. Number of included systematic reviews by year of publication.

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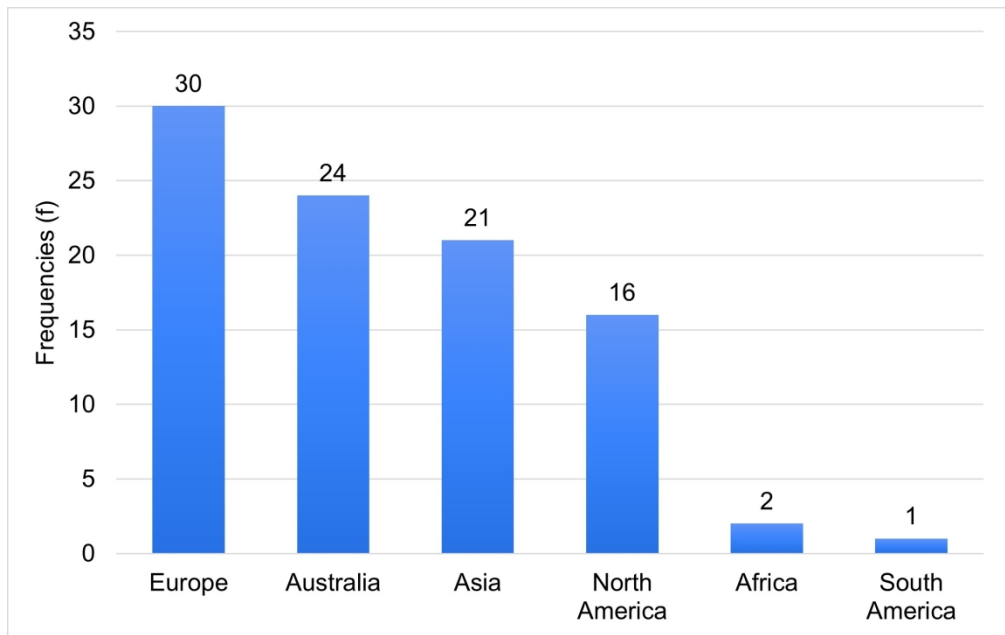
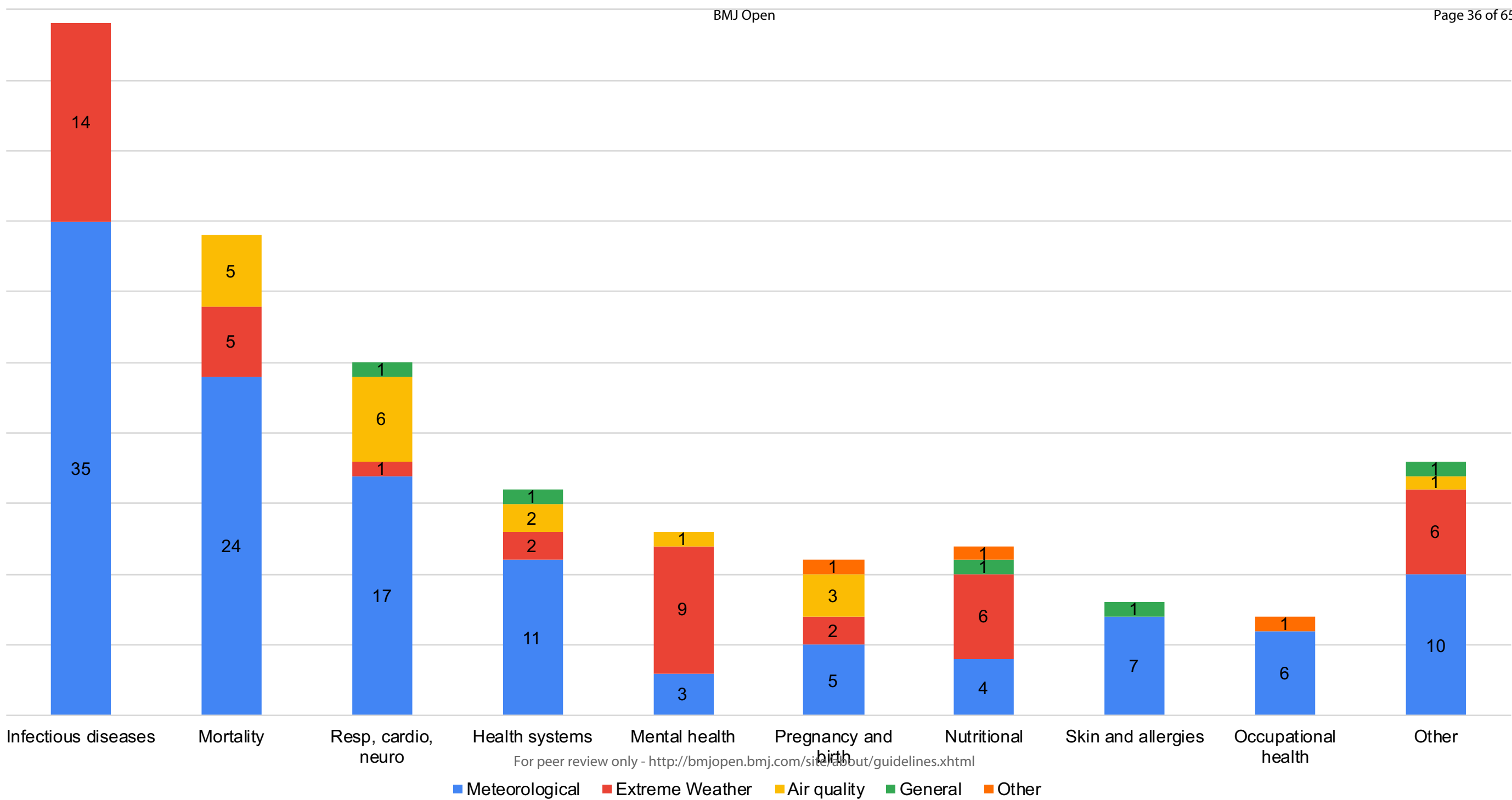


Figure 3. Number of publications according to geographic affiliation of the first author.

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■ Meteorological ■ Extreme Weather ■ Air quality ■ General ■ Other

## Appendix 1. Search Strategy

Database: **MEDLINE (OVID)**

No database limit

Concepts	#	Search strategy
Global Warming	1	exp Climate Change/
	2	"Global warming".ti,ab,kw
	3	"Climate Change?".ti,ab,kw
Global Warming combined	4	or/1-3
Systematic review and meta-analysis	5	exp Meta-Analysis as Topic/
	6	"Meta-Analysis"/
	7	Meta-Analysis.ti,ab,kw
	8	"meta analy*".ti,ab,kw
	9	metaanaly*.ti,ab,kw
	10	"Systematic Review"/
	11	"Systematic Reviews as Topic"/
	12	(systematic adj2 review).ti,ab,kw
	13	(review adj1 ("selection criteria" OR "data extraction")).ti,ab
Systematic review and meta-analysis combined	14	or/5-13
Combination of concepts	15	4 AND 14

Database: **Embase.com**

No database limit

Concepts	#	Search strategy
Global Warming	1	'climate change'/de
	2	'greenhouse effect'/de
	3	"Global warming":ti,ab,kw
	4	"Climate Change*":ti,ab,kw
Global Warming combined	5	#1 OR #2 OR #3 OR #4
Systematic review and meta-analysis	6	'meta analysis'/exp
	7	'meta analysis (topic)'/de
	8	Meta-Analysis:ti,ab,kw
	9	"meta analy*":ti,ab,kw
	10	metaanaly*:ti,ab,kw
	11	'systematic review'/de
	12	(systematic NEAR/2 review):ti,ab,kw
	13	(review NEAR/2 ("selection criteria" OR "data extraction")):ti,ab
Systematic review and meta-analysis combined	14	#7 OR #8 OR #9 OR #10 OR #11 OR #12 OR #13 OR #14

Combination of concepts	15	#14 AND #5
Embase database only	16	AND [embase]/lim NOT ([embase]/lim AND [medline]/lim)

Database: **Web of Science**

Limit to: Science Citation Index Expanded (SCI-EXPANDED) and Emerging Sources Citation Index (ESCI) index only

Concepts	#	Search strategy
Global Warming	1	TS=("Global warming" OR "Climate Change\$")
Systematic review and meta-analysis	2	TS=(Meta-Analysis)
	3	TS=("meta analy*")
	4	TS=(metaanaly*)
	5	TS=(systematic NEAR/2 review)
	6	TS=(review NEAR/1 ("selection criteria" OR "data extraction"))
Systematic review and meta-analysis combined	7	#6 OR #5 OR #4 OR #3 OR #2
Combination of concepts	8	#7 AND #1

Database: **CINAHL**

No database limit

Concepts	#	Search strategy
Global Warming	1	MH "Climate Change"

	2	MH "Greenhouse Effect"
	3	TI "Global warming"
	4	TI "Climate Change?"
	5	AB "Global warming"
	6	AB "Climate Change?"
Global Warming combined	7	S1 OR S2 OR S3 OR S4 OR S5 OR S6
Systematic review and meta-analysis	8	MH "Meta Analysis"
	9	TI "Meta-Analysis"
	10	AB "Meta-Analysis"
	11	TI "meta analy**"
	12	AB "meta analy**"
	13	TI metaanaly*
	14	AB metaanaly*
	15	MH "Systematic Review"
	16	TI (systematic N2 review)
	17	AB (systematic N2 review)
	18	TI (review N1 ("selection criteria" OR "data extraction"))
	19	AB (review N1 ("selection criteria" OR "data extraction"))

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Systematic review and meta-analysis combined	20	S8 OR S9 OR S10 OR S11 OR S12 OR S13 OR S14 OR S15 OR S16 OR S17 OR S18 OR S19
Combination of concepts	21	S7 AND S20

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**Appendix 2.** Summary of AMSTAR-2 items and modified AMSTAR-2 items.

Topic #	AMSTAR-2 Original Items	AMSTAR-2 Modifications
1	<p>Did the research questions and inclusion criteria for the review include components of PICO?</p> <ul style="list-style-type: none"> <li>- Population</li> <li>- Intervention</li> <li>- Comparator group</li> <li>- Outcome</li> <li>- Timeframe for follow-up (optional)</li> </ul>	<p>“Population” became “Population and/or location”.</p> <p>“Intervention” became “Exposure”.</p> <p>The “Comparator group” category was taken out.</p> <p>A new section (#1.b)) was created, it includes “Definition of the exposure”, “Definition of the outcome” and “Timeframe for follow up”.</p>
2	<p>Did the report of the review contain an explicit statement that the review methods were established prior to the conduct of the review and did the report justify any significant deviations from the protocol?</p>	<p>To score “yes”, a protocol must have been established before the review. There are no sub-criteria, you can only score yes or no.</p>
3	<p>Did the review authors explain their selection of the study designs for inclusion in the review?</p>	<p>If the study designs are specified, you score “partial yes”. They must be explained to score “yes”. No specific study design is required.</p>
4	<p>Did the review authors use a comprehensive literature search strategy?</p>	<p>The “searched trial/study registries” category was taken out.</p> <p>Justified publication restrictions (e.g. language) moved from (partial yes) to (yes)</p>
5	<p>Did the review authors perform study selection in duplicate?</p>	<p>No modifications.</p>
6	<p>Did the review authors perform data extraction in duplicate?</p>	<p>No modifications.</p>
7	<p>Did the review authors provide a list of excluded studies and justify the exclusion?</p>	<p>The explanation of the inclusion and exclusion criteria is evaluated.</p> <p>If there is only one out of the two, you score “partial yes”. The two must be explained to score “yes”.</p>
8	<p>Did the review authors describe the included studies in adequate detail?</p>	<p>“Populations” became “Populations and/or locations”.</p> <p>“Interventions” became “Exposures”.</p> <p>“Comparator groups” became “Comparator groups (if applicable)”.</p> <p>“Populations and/or locations”, “Exposures” and “Outcomes” must be described in details to score “yes”</p>
9	<p>Did the review authors use a satisfactory technique for assessing the risk of bias (RoB) in individual studies that were included in the review?</p>	<p>“RoB” became “limitations”. Instead of assessing the RoB, the review authors must have used a satisfactory technique for assessing the limitations in individual studies that were included in the review.</p>



10	Did the review authors report on the sources of funding for the studies included in the review?	No modifications.
11	If meta-analysis was performed did the review authors use appropriate methods for statistical combination of results?	No modifications.
12	If meta-analysis was performed, did the review authors assess the potential impact of RoBin individual studies on the results of the meta-analysis or other evidence synthesis	No modifications.
13	Did the review authors account for RoB in individual studies when interpreting/discussing the results of the review?	“RoB” became “limitations”. Instead of accounting for RoB in individual studies, the review authors must have accounted for limitations when interpreting/ discussing the results of the review.
14	Did the review authors provide a satisfactory explanation for, and discussion of, any heterogeneity observed in the results of the review?	No modifications.
15	If they performed quantitative synthesis did the review authors carry out an adequate investigation of publication bias (small study bias) and discuss its likely impact on the results of the review?	No modifications.
16	Did the review authors report any potential sources of conflict of interest, including any funding they received for conducting the review?	No modifications.

**Appendix 3.** Overview of included studies (N=94) according to study characteristics and summary of climate impacts on health outcomes. Studies are presented in alphabetical order according to the first author's last name.

	First Author	Year	Country	Years of included publications	Years of the studies included in the reviews	# of articles	Meta-analysis	Specific Area of focus	Specific Population of interest	Climate Impact	Health Outcome	Summary of findings
1	Alderman	2012	Australia	2004-2011	1931-2007	35	No			Extreme weather	Infectious diseases Mortality Health systems Mental health Pregnancy and birth Other	Floods are associated with infectious diseases (water- and vector-borne diseases), mortality (e.g., drowning), exacerbation of chronic illnesses, mental health issues (e.g., PTSD), hospital admissions, pregnancy outcomes and injuries.
2	Amegah	2016	Ghana	1995-2014	1960-2010	23	No	Sub-saharan Africa		Meteorological	Infectious diseases Mortality Respiratory, cardiovascular, and neurological outcomes Health systems Nutritional Skin diseases and allergies	Temperature and temperature variability are suggested to be associated with infectious diseases, such as Ebola, cardiovascular diseases, mortality, cholera outbreaks, meningitis, undernutrition in children, respiratory outcomes, such as asthma, and skin diseases.
3	An	2018	United States	2002-2017	2002-2016	50	No			General	Nutritional	Climate change is associated with obesity. This association can be explained in 4 ways, such that climate change may impact obesity, obesity may impact climate change, both factors may be associated with common causes, or both factors may influence each other.

4	Augustin	2008	Germany	1996-2006	NS	320	No	Germany		Meteorological	Skin diseases and allergies	Although skin and allergic diseases are climate sensitive, there is not sufficient evidence to suggest a prediction concerning skin and allergic diseases linked to climate change in Germany.
5	Babaie	2018	Iran	2007-2017	1970-2015	14	No	Iran		Meteorological	Infectious diseases	Temperature, precipitation and humidity are associated with the risk of transmission of Malaria.
6	Bai	2013	China	1995-2011	1951-2010	57	No	China		Meteorological	Infectious diseases	Variability in temperature, precipitation and wind are associated with the risk of transmission of mosquito-borne diseases.
7	Benevolenza	2019	United States	2006-2017	2005-2015	13	No		Vulnerable populations	Extreme weather	Mental health Pregnancy and birth Other	Extreme weather events are associated with an exacerbation of pre-existing chronic health conditions, mental health issues (e.g., PTSD, isolation) and adverse birth outcomes.
8	Berhane	2016	Ethiopia	NS	NS	23	No	Ethiopia		Meteorological Extreme weather	Infectious diseases Nutritional	Meteorological factors and extreme weather events are associated with under- and mal- nutrition and the increased risk of climate sensitive infectious diseases (e.g., malaria, diarrhea, zoonotic infections, etc.).
9	Bernhardt	2019	Germany	1997-2017	NS	464	No			Meteorological	Infectious diseases	Rising temperatures are predicted to be associated with myiasis in the future.
10	Binazzi	2019	Italy	NS	1994-2013	8	Yes		Workers	Meteorological	Occupational health and injuries	High temperatures are positively associated with occupational injuries.
11	Bonafede	2016	Italy	2000-2014	1985-2010	8	No		Workers	Meteorological	Occupational health and injuries	Extreme temperature (particularly heat) is associated with occupational injuries.

12	Brown	2013	United Kingdom	2004-2012	1975-2012	38	No	Europe		Extreme weather	Infectious diseases	Floods are associated with infectious diseases, including water-, rodent- and vector-borne diseases (from weeks to months after flooding).
13	Bunker	2016	Germany	1995-2015	1974-2013	61	Yes		Elderly	Meteorological	Mortality Respiratory, cardiovascular, and neurological outcomes Other	Higher and lower temperatures are associated with cardiovascular and respiratory morbidity and mortality. Heat is also associated with diabetes and genitourinary infections.
14	Campbell	2018	Australia	1964-2017	NS	188	No			Meteorological	Mortality Health systems	Most studies exploring the heat impacts on health focus on mortality outcomes, followed by hospital admissions and ambulance call outs.
15	Cann	2013	United Kingdom	1973-2010	NS	83	No			Extreme weather	Infectious diseases	Extreme water-related events are associated with outbreaks of water-related infectious diseases.
16	Carolan-Olah	2014	Australia	1997-2012	1988-2009	7	No			Meteorological	Pregnancy and birth	High temperatures are associated with preterm birth.
17	Cheng	2014	China	1990-2013	1941-2012	25	No		Adults, Elderly, Children	Meteorological	Infectious diseases Mortality Respiratory, cardiovascular, and neurological outcomes Health systems Other	Diurnal temperature range is associated with mortality and cardiovascular and respiratory outcomes, hospital admissions, and Hand Foot Mouth disease in children and genitourinary outcomes among the elderly.
18	Coates	2019	Denmark	2003-2018	NS	72	No			Meteorological	Infectious diseases	Some meteorological factors (temperature, humidity) are positively associated with Hand Foot Mouth disease (HFMD). Precipitation, wind speed and sunshine are not associated with HFMD.

19	Cong	2017	China	1994-2015	1982-2013	26	Yes			Meteorological	Respiratory, cardiovascular, and neurological outcomes	Temperature drop is associated with asthma.
20	Cunrui	2011	Australia	1997-2010	1961-2100	14	No			Meteorological	Mortality	Higher temperature is associated with heat-related mortality.
21	deSousa	2018	Brazil	1976-2016	NS	106	No			Meteorological	Infectious diseases Respiratory, cardiovascular, and neurological outcomes	Meteorological factors (e.g., temperature, precipitation) are associated with infectious diseases (e.g., dengue, malaria) and cardiovascular and respiratory outcomes.
22	Dhimal	2015	Nepal	1956-2014	1948-2098	50	No	Nepal		Meteorological	Infectious diseases	Higher temperatures are associated with the distribution of vector-borne diseases.
23	Doocy	2013	United States	1975-2011	1974-2008	60	No			Extreme weather	Mortality Other	Cyclones are associated with mortality (e.g., drowning) and injuries.
24	Duan	2019	China	2010-2018	2000-2016	51	Yes	Southeast and East Asia		Meteorological	Infectious diseases	Some meteorological factors (mean maximum temperature, rainfall, humidity and sunshine) are positively associated with Hand Foot Mouth disease (HFMD), whereas air pressure is negatively associated with this disease and wind speed is not associated with HFMD.
25	Fan	2015	China	2004-2013	1985-2012	33	Yes			Meteorological	Infectious diseases	Temperature is positively associated with transmission and incidence of Dengue.
26	Fernandez	2015	Australia	1995-2014	NS	83	No			Extreme weather	Mental health	Floods are associated with negative mental health outcomes (e.g., PTSD, increased anxiety, depression, use of psychotropic medication). Conflicting evidence concerning suicide,

												tobacco, alcohol and substance abuse.
27	Flouris	2018	Greece	1954-2018	NS	111	Yes		Workers	Meteorological	Occupational health and injuries	High temperatures are positively associated with occupational heat strains, dehydration, kidney diseases and injuries.
28	Gao	2019	China	1994-2018	1969-2015	16	Yes			Meteorological	Mental health	Temperature increase is associated with suicide. No association between sunlight duration and suicide.
29	Gao	2014	China	1996-2012	1971-2010	37	No		Children	Meteorological	Infectious diseases Respiratory, cardiovascular, and neurological outcomes Skin diseases and allergies	Ambient humidity is associated with gastrointestinal, respiratory and allergic diseases in children.
30	Ghanizadeh	2017	Iran	2009-2016	1990-2015	13	No			Meteorological	Mortality Respiratory, cardiovascular, and neurological outcomes	Meteorological factors, such as temperature and humidity, are associated with cardiopulmonary health. Cold temperatures are also associated with mortality from heart diseases.
31	Ghazani	2018	Australia	2006-2017	1991-2011	11	No			Meteorological	Infectious diseases	Higher temperature is associated with bacterial gastrointestinal infections. Humidity and rainfall may influence this association.
32	Gracia	2015	Sweden	2003-2011	1959-2008	9	No	Europe		Meteorological	Infectious diseases	Temperature is positively associated with Human Puumala Hantavirus in some regions of Europe. Results concerning precipitation and humidity are contradictory or null.
33	Hajat	2010	United Kingdom	1994-2008	1973-2003	11	No			Meteorological	Mortality	Ambient heat is associated with mortality.

34	Hedlund	2014	Sweden	1970-2012	1750-2009	29	No	Arctic, sub-Arctic	Vulnerable populations	Meteorological Extreme weather	Infectious diseases	Higher temperatures and flooding are associated with food- and water-borne diseases. This association is weaker for vector- and rodent-borne diseases. Air temperature and humidity seem to be associated with air-borne diseases.
35	Hii	2016	Sweden	2007-2015	2003-2012	9	No	Malaysia		Meteorological	Infectious diseases	Some meteorological factors (temperature, rainfall and humidity) are associated with Dengue, although these associations are inconsistent at times.
36	Huang	2016	Taiwan	1990-2014	1978-2011	19	Yes			General	Skin diseases and allergies	Climate change, in general, may be associated with skin and soft-tissue infections.
37	Kampe	2016	United Kingdom	1998-2015	1971-2010	13	No	High-income countries		Meteorological	Other	Higher temperature is associated with unintentional injuries.
38	Khader	2015	Jordan	2003-2014	1991-2012	78	No	Eastern Mediterranean	Vulnerable countries	Meteorological Extreme weather Air quality	Infectious diseases Mortality Respiratory, cardiovascular, and neurological outcomes Health systems Mental health Pregnancy and birth Nutritional	High temperature is associated with mortality. Temperature, humidity and precipitation are associated with vector-, food- and water-borne diseases. Air pollution is associated with respiratory outcomes, although some findings are inconsistent. Higher temperature is associated with mental health outcomes and hospital admissions. Higher temperature may also be associated with adverse birth outcomes. Meteorological and extreme weather events are associated with food insecurity.
39	Klinger	2014	United Kingdom	2011-2013	NS	20	No			Extreme weather	Health systems	Extreme weather events may lead to power outages which may pose challenges to healthcare quality.

40	Kuehn	2017	United States	2002-2017	NS	28	No		Pregnant people	Meteorological	Pregnancy and birth	Extreme heat exposure is associated with adverse birth outcomes (e.g. stillbirth, birth weight).
41	Lake	2017	United Kingdom	NS	NS	66	No	Europe		General	Respiratory, cardiovascular, and neurological outcomes	Climate change may be associated with ragweed pollen allergy.
42	Lal	2019	Australia	1982-2011	NS	36	Yes		Children	Meteorological	Infectious diseases	Rainfall is associated with childhood diarrhea, although this association differed according to season and latitude.
43	Lal	2015	Australia	NS	NS	16	No	New Zealand		Meteorological	Infectious diseases	Temperature variability, higher temperature and rainfall are associated with enteric diseases.
44	Lawton	2019	Australia	2000-2015	NS	71	No			Meteorological	Mortality Respiratory, cardiovascular, and neurological outcomes	Heat exposure is associated with heat stroke, long-term neurological outcomes (e.g., cerebellar injury) and heat-related mortality.
45	Levi	2018	Italy	2003-2017	1977-2014	184	No		Workers	Meteorological	Occupational health and injuries	Heat exposure is associated with occupational injuries.
46	Levy	2016	United States	1972-2013	1948-2010	208	No			Meteorological Extreme weather	Infectious diseases	Temperature is associated with bacterial diarrhea and drought is associated with all-cause diarrhea, although few studies explored the association between drought and diarrhea.
47	Leyva	2017	Asia	2009-2017	NS	30	No		Elderly	Meteorological Extreme weather Air quality	Infectious diseases Mortality Respiratory, cardiovascular, and	Meteorological factors, extreme weather events (e.g. typhoon, floods) and air pollution are associated with mortality and morbidity, especially cardiovascular- and respiratory-specific. Higher temperature is associated with



											neurological outcomes Health systems Mental health	vector-borne diseases. Heat and cold temperatures are associated with hospital admissions. Flooding is associated with mental health outcomes (e.g. PTSD, depression).
48	Li	2018	China	1988-2017	NS	81	No	China		Meteorological Extreme weather	Infectious diseases	Meteorological factors (temperature, precipitation, humidity, air pressure) and extreme weather events (floods, typhoons) are associated with Dengue fever in China.
49	Lian	2015	China	2003-2014	NS	20	Yes			Meteorological	Mortality Respiratory, cardiovascular, and neurological outcomes	Higher and lower temperatures are associated with stroke-related mortality and low temperatures are also associated with stroke-related morbidities.
50	Liu	2015	United States	1990-2014	NS	61	No			Air quality	Mortality Respiratory, cardiovascular, and neurological outcomes Health systems Pregnancy and birth Other	Wildfire smoke exposure is associated with mortality, respiratory outcomes and hospital admissions. Wildfire smoke exposure could also be associated with cardiovascular, ophthalmic and pregnancy outcomes, although more research is needed.
51	Madaniyazi	2015	Australia	2004-2013	1961-2100	15	No			Air quality	Mortality	Air pollution is associated with future mortality.
52	Matysiak	2017	Puerto Rico	2001-2005	NS	26	No	Puerto Rico (United States)		Meteorological Extreme weather	Infectious diseases	Meteorological factors (higher temperature and increased rainfall) are associated with vector-borne diseases, such as Dengue and Zika. Extreme weather events are less researched, but the few studies investigating this association suggest no association between hurricanes

												and floods and vector-borne diseases.
53	Moghaddamnia	2017	Iran	2011-2016	1979-2013	26	Yes			Meteorological	Mortality	Higher and lower temperature are associated with cardiovascular mortality.
54	Naish	2014	Australia	NS	1931-2010	16	No			Meteorological	Infectious diseases	Meteorological factors (especially temperature, rainfall and humidity) are associated with Dengue.
55	Nichols	2009	United Kingdom	1999-2008	NS	36	No			Meteorological Extreme weather Air quality	Infectious diseases Mortality Respiratory, cardiovascular, and neurological outcomes Mental health Nutritional Skin diseases and allergies Other	Meteorological factors (e.g., higher temperature) are associated with mortality and various infectious diseases. Increased UV exposure is associated with skin cancer and cataracts. Extreme weather events are associated with mortality, injury, mental health outcomes, malnutrition, and food- and water-borne diseases. Air pollution is associated with cardio-respiratory outcomes.
56	Odame	2018	United States	2006-2017	1893-2013	14	Yes		Rural populations	Meteorological	Mortality	Higher temperature is associated with all-cause mortality and cardiovascular specific mortality.
57	Park	2017	Korea	1920-2015	1961-2013	10	Yes			Meteorological	Other	Higher temperature is associated with acute gouty arthritis.
58	Phalkey	2015	Germany	1989-2012	1982-2008	15	No	Low to middle-income countries	Children	Meteorological Extreme weather	Nutritional	Meteorological factors (rainfall, temperature) and extreme weather events are associated with childhood undernutrition.
59	Philipsborn	2016	Georgia	NS	1973-2010	28	Yes			Meteorological	Infectious diseases	Higher temperature is associated with Diarrheagenic Escherichia coli. No significant relationship between rainfall and E. coli.
60	Phung	2015	Australia	2004-2013	NS	13	No	Southeast Asia		Meteorological	Infectious diseases	Meteorological factors (temperature, humidity) and extreme weather

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										Extreme weather		events (flooding) are associated with vector- and water-borne infectious diseases.
61	Porpora	2019	Italy	1964-2019	NS	78	No			Other	Pregnancy and birth	Environmental pollutants may be associated with preterm birth, however this association remains unclear due to conflicting evidence.
62	Poursafa	2015	Iran	2001-2013	NS	15	No			Meteorological	Pregnancy and birth	Meteorological factors (higher temperature, lower temperature, humidity, sunlight intensity) are associated with adverse birth outcomes (low birth weight, preterm birth, hypertension, eclampsia).
63	Racloz	2012	Australia	NS	NS	63	No			Meteorological	Infectious diseases	Higher temperature, increased precipitation and humidity are associated with Dengue.
64	Rataj	2016	Germany	1981-2012	1978-2008	17	No	Low to middle income countries		Extreme weather	Mental health Other	Extreme weather events are associated with mental health outcomes (e.g., PTSD, anxiety, depression) and injuries.
65	Reid	2016	United States	1990-2015	NS	53	No		Susceptible populations	Air quality	Mortality Respiratory, cardiovascular, and neurological outcomes Mental health Pregnancy and birth	Wildfire smoke exposure is associated with respiratory outcomes (e.g., asthma) and mortality. Wildfire smoke exposure may be associated with cardiovascular, birth, and mental health outcomes, but more research is needed.
66	Rifkin	2018	United States	1995-2017	1992-2016	16	No			Meteorological Extreme weather	Other	Temperature and extreme weather events (hurricanes) are associated with sleep quality.
67	Salve	2018	India	NS	NS	11	No	India		Meteorological	Mortality Health systems Nutritional	Increase in temperature is associated with all-cause mortality, cause-specific mortality (e.g., myocardial

												infarctions, stroke, heart diseases), hospitalizations (e.g., heat-related admissions, neonatal intensive unit admissions), and food insecurity and malnutrition, via agricultural issues.
68	Sanderson	2017	United Kingdom	1988-2017	1900-2101	63	No			Meteorological	Mortality	Higher temperatures and heat waves are associated with mortality and heat-related mortality is likely to increase with increased temperatures.
69	Sawatzky	2018	Canada	2005-2016	NS	85	No	Arctic and Subarctic		General	Health systems	Climate change, in general, is associated with a strain in public health resources, via population health issues and surveillance systems may guide future adaptation to climate change.
70	Semenza	2012	Sweden	1998-2009	1995-2007	722	No			Meteorological	Infectious diseases	Meteorological factors (temperature, rainfall) are associated with some food- and water-borne diseases.
71	Stanke	2013	United Kingdom	1967-2011	1876-1879 and 1961-2010	87	No			Extreme weather	Infectious diseases Mortality Respiratory, cardiovascular, and neurological outcomes Mental health Nutritional Other	Droughts are associated with malnutrition, mortality, infectious diseases, cardiovascular and respiratory outcomes, mental health (e.g., increased worry, anxiety), injuries, and cancer.
72	Stensgaard	2019	Denmark	1995-2017	NS	20	No			Meteorological	Infectious diseases	Meteorological factors (temperature, precipitation, humidity) are associated with schistosomiasis and increasing temperatures are likely to affect the geographic range of this parasite.
73	Sun	2018	China	1999-2017	1974-2014	30(review)	Yes			Meteorological	Mortality	Heat and cold exposure are associated with myocardial

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						w)2 3m eta- anal ysis					Respiratory, cardiovascular, and neurological outcomes Health systems	infarctions (MI) and hospitalization for MI. Heat exposure is associated with MI-specific mortality.
74	Swynghe dauw	2009	France	NS	NS	NS	No			Meteorolo gical Extreme weather	Infectious diseases Mortality Skin diseases and allergies Other	Heat and cold exposure are associated with mortality and more specifically, respiratory- and cardiovascular-specific mortality. Exposure to UV is associated with skin cancer and cataracts. Higher temperatures are associated with infectious diseases (mosquito- and food-borne diseases) and extreme weather events are associated with undernutrition and food-borne diseases.
75	Tall	2014	Australi a	1946- 2009	1886- 2006	22	No	Australi a		Extreme weather	Infectious diseases	There is no strong evidence for the association between flooding and the Ross River Virus.
76	Varghese	2018	Australi a	1983- 2017	1922- 2017	26	No		Workers	Meteorolo gical	Occupational health and injuries	Heat is associated with occupational injuries in many contexts of work (e.g., agriculture, transport, construction, fishing).
77	Veenema	2017	United States	2006- 2016	NS	47	No			Extreme weather	Infectious diseases Mortality Mental health	Extreme water-related weather events are associated with mortality, water- and vector-borne infectious diseases, mental health issues (e.g., PTSD, depression, anxiety).
78	Vilcins	2018	Australi a	NS	NS	72	No		Children	Other	Nutritional	Certain environmental risk factors (e.g., sanitation, cooking fuels), which could be aggravated by climate change, may be associated with childhood stunting.
79	Vins	2015	United States	1995- 2005	NS	82	No			Extreme weather	Mental health	Drought is likely associated with adverse mental health outcomes.

80	Waits	2018	Finland	1970-2017	NS	43	No	Arctic		Meteorological	Infectious diseases	Meteorological factors (especially higher temperature and precipitation) are associated with infectious diseases (e.g. tick borne diseases, tularemia) in the Arctic.
81	Wald	2019	United States	2009-2018	NS	17	No	United States		Meteorological	Health systems	Higher temperature is associated with emergency department (heat-related visits) visits and costs for healthcare systems.
82	Welch	2019	United States	NS	NS	91	No			Meteorological	Infectious diseases	Meteorological factors (temperature, precipitation) are associated with Salmonella.
83	Wimalawansa	2016	United States	NS	NS	NS	No	Tropical Countries	Workers	Meteorological Other	Occupational health and injuries	Increasing temperatures and environmental pollution (e.g., heavy metals, fertilizers) are associated with occupational health outcomes, such as chronic kidney disease of multifactorial origin.
84	Witt	2015	Germany	NS	NS	33	Yes		Chronic lung disease patients	Meteorological	Mortality Respiratory, cardiovascular, and neurological outcomes	Heat is associated with lung disease outcomes and mortality in patients with chronic lung diseases.
85	Xu	2018	Australia	2004-2016	1978-2013	19	No		Children	Meteorological	Respiratory, cardiovascular, and neurological outcomes	Heat and cold temperatures are associated with childhood asthma.
86	Xu	2012	Australia	2000-2012	1983-2010	33	No		Children	Meteorological	Infectious diseases Mortality Respiratory, cardiovascular, and neurological outcomes Health systems	Heat and cold are associated with hospital admissions and mortality in children. Temperature is also associated with various infectious diseases (e.g., HFMD, malaria), respiratory diseases (e.g., asthma) and skin outcomes (e.g. eczema). For example, high temperature is associated with Hand Foot Mouth

											Skin diseases and allergies Other	Disease and renal diseases and low temperature is associated with eczema.
87	Xu	2016	Australia	2001-2015	NS	60	Yes			Meteorological	Mortality	Heat waves are associated with mortality and it seems that the intensity of heatwaves is particularly important compared to length of heatwave.
88	Xu	2014	Australia	1998-2012	1983-2009	12	No		Children	Meteorological	Mortality Respiratory, cardiovascular, and neurological outcomes Health systems Other	Heat waves are associated with hospital admissions, respiratory diseases, renal diseases, fever and electrolyte imbalances. Evidence concerning the association between heatwaves and children mortality is inconsistent.
89	Youssouf	2014	France	1990-2011	1987-2008	94	No			Air quality	Mortality Respiratory, cardiovascular, and neurological outcomes Health systems Pregnancy and birth	Wildfire smoke exposure is associated with mortality, respiratory and cardiovascular outcomes, hospital admissions. Wildfire smoke exposure may also be associated with adverse birth outcomes (low birth weight).
90	Yu	2015	Australia	1998-2012	1961-1990 et 2020-2100	20	No			Meteorological	Infectious diseases	Meteorological factors (temperature, rainfall, humidity) may be associated with future malaria transmission, although findings are inconsistent, partly according to geographical focus.
91	Yu	2012	Australia	1997-2008	1973-2006	15	Yes		Elderly	Meteorological	Mortality	Heat and cold temperatures are associated with mortality for the elderly, although heat-related associations seem stronger than cold-related associations.

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92	Zhang	2007	Australia	NS	NS	NS	No		People with disabilities	General	Other	Climate change, in general, may be associated with disability-adjusted life years (DALY), and the cost of DALY could be particularly important in low to middle income countries.
93	Zhang	2017	China	1997-2016	1981-2012	36	No		Pregnant people	Meteorological	Pregnancy and birth	High temperature is associated with adverse birth outcomes, such as preterm birth, low birth weight and stillbirth. Low temperature is also associated with some adverse birth outcomes, including preterm birth and low birth, although the evidence is stronger for high temperature than for low temperatures.
94	Zuo	2015	Australia	NS	NS	173	No			Meteorological	Mortality Respiratory, cardiovascular, and neurological outcomes Health systems Mental health Skin diseases and allergies Other	Heat waves are associated with mortality, hospital admissions, sunburn, heat exhaustion, cardiovascular outcomes (e.g., heart attacks) and mental health outcomes.

\*NS = non-specified



**Appendix 4.** Summary of quality assessment according to revised AMSTAR-2 items. (Y = yes, PY = partial yes, N = no, NA = non-applicable).

First author	Year	AMSTAR-2 Items																
		1	1b	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Alderman	2012	Y	N	N	PY	PY	N	N	PY	PY	N	N	NA	NA	Y	N	NA	N
Amegah	2016	Y	N	N	Y	PY	N	N	PY	Y	Y	N	NA	NA	Y	Y	NA	Y
An	2018	N	Y	N	N	PY	Y	N	Y	N	Y	N	NA	NA	Y	N	NA	Y
Augustin	2008	Y	Y	N	N	PY	N	N	PY	N	PY	N	NA	NA	Y	N	NA	Y
Babaie	2018	Y	Y	N	N	PY	Y	N	Y	PY	N	N	NA	NA	N	N	NA	N
Bai	2013	Y	Y	N	PY	PY	N	N	PY	PY	Y	N	NA	NA	Y	N	NA	Y
Benevolenza	2019	Y	Y	N	PY	N	N	N	Y	PY	PY	N	NA	NA	Y	N	NA	N
Berhane	2016	Y	N	Y	N	N	N	N	N	PY	PY	N	NA	NA	Y	N	NA	N
Bernhardt	2019	Y	N	N	N	N	N	N	PY	PY	PY	N	NA	NA	PY	N	NA	Y
Binazzi	2019	Y	Y	N	Y	PY	Y	N	Y	Y	Y	N	Y	Y	Y	Y	Y	Y
Bonafede	2016	Y	N	N	PY	PY	Y	N	Y	Y	Y	N	NA	NA	Y	Y	NA	Y
Brown	2013	Y	Y	N	PY	PY	N	N	Y	Y	PY	N	NA	NA	Y	Y	NA	Y
Bunker	2016	Y	Y	N	Y	N	Y	PY	Y	Y	PY	N	Y	Y	Y	Y	Y	Y
Campbell	2018	Y	N	N	N	PY	N	N	Y	PY	N	N	NA	NA	Y	PY	NA	Y
Cann	2013	Y	Y	Y	PY	PY	N	N	Y	PY	PY	N	NA	NA	Y	Y	NA	Y
Carolan-Olah	2014	Y	Y	N	N	PY	N	N	Y	PY	Y	N	NA	NA	PY	PY	NA	N
Cheng	2014	Y	N	N	PY	PY	N	N	Y	Y	Y	N	NA	NA	Y	PY	NA	N
Coates	2019	N	N	N	N	N	N	N	PY	PY	Y	N	NA	NA	Y	PY	NA	N
Cong	2017	N	Y	N	N	PY	N	Y	Y	Y	Y	N	Y	N	Y	Y	Y	Y
Cunrui	2011	Y	N	N	PY	PY	N	N	Y	PY	N	N	NA	NA	Y	N	NA	Y
deSousa	2018	Y	N	N	PY	PY	N	N	Y	N	N	N	NA	NA	Y	N	NA	Y
Dhimal	2015	Y	Y	N	PY	PY	N	N	Y	Y	N	N	NA	NA	N	N	NA	N
Doocy	2013	Y	N	N	N	PY	Y	N	Y	Y	N	N	NA	NA	Y	PY	NA	Y
Duan	2019	Y	N	N	N	PY	N	N	Y	PY	Y	N	Y	Y	Y	Y	Y	Y
Fan	2015	N	Y	N	N	PY	Y	Y	PY	PY	Y	N	Y	Y	Y	Y	Y	Y
Fernandez	2015	Y	Y	N	PY	PY	Y	N	Y	PY	PY	N	NA	NA	Y	N	NA	N
Flouris	2018	Y	N	Y	PY	PY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Gao	2019	N	Y	N	PY	PY	Y	N	Y	Y	Y	N	Y	Y	Y	Y	Y	Y
Gao	2014	Y	N	N	PY	PY	N	PY	Y	Y	Y	N	NA	NA	Y	Y	NA	Y
Ghanizadeh	2017	N	Y	N	PY	N	Y	PY	Y	PY	Y	N	NA	NA	N	N	NA	Y
Ghazani	2018	N	N	N	N	PY	Y	N	Y	Y	PY	N	NA	NA	Y	PY	NA	Y
Gracia	2015	Y	Y	N	PY	PY	Y	N	Y	PY	Y	N	NA	NA	Y	N	NA	Y
Hajat	2010	Y	N	N	Y	PY	N	N	Y	PY	N	N	NA	NA	N	PY	NA	Y
Hedlund	2014	Y	N	N	PY	N	Y	Y	Y	PY	Y	N	NA	NA	Y	N	NA	Y
Hii	2016	Y	N	N	PY	PY	N	N	PY	PY	N	N	NA	NA	N	N	NA	Y
Huang	2016	N	N	N	N	PY	Y	N	PY	Y	Y	N	Y	Y	Y	PY	N	Y
Kampe	2016	Y	N	N	PY	PY	Y	N	Y	Y	PY	N	NA	NA	Y	N	NA	Y
Khader	2015	Y	N	N	PY	PY	Y	N	Y	Y	N	N	NA	NA	Y	PY	NA	Y
Klinger	2014	N	N	N	N	PY	Y	N	Y	N	Y	N	NA	NA	Y	N	NA	Y
Kuehn	2017	Y	N	N	N	PY	N	N	Y	Y	PY	N	NA	NA	Y	N	NA	Y
Lake	2017	Y	Y	N	N	PY	Y	Y	PY	PY	N	N	NA	NA	N	N	NA	Y
Lal	2019	Y	N	Y	N	PY	N	Y	Y	PY	Y	N	Y	Y	Y	Y	N	Y
Lal	2015	Y	Y	N	N	PY	N	N	Y	PY	PY	N	NA	NA	Y	PY	NA	Y
Lawton	2019	Y	N	N	PY	PY	N	N	Y	Y	N	N	NA	NA	Y	N	NA	Y
Levi	2018	Y	Y	N	PY	PY	Y	N	Y	Y	N	N	NA	NA	Y	PY	NA	Y
Levy	2016	N	N	N	PY	PY	Y	PY	Y	Y	Y	N	NA	NA	Y	Y	NA	Y
Leyva	2017	Y	Y	N	PY	PY	N	N	Y	N	Y	N	NA	NA	Y	N	NA	N
Li	2018	Y	N	N	N	PY	N	N	N	PY	N	N	NA	NA	N	N	NA	Y
Lian	2015	Y	N	N	PY	PY	Y	Y	Y	N	Y	N	Y	Y	Y	Y	Y	Y
Liu	2015	Y	Y	N	Y	PY	N	N	Y	Y	PY	N	NA	NA	Y	PY	NA	Y
Madaniyazi	2015	N	N	N	PY	PY	N	N	Y	PY	N	N	NA	NA	Y	N	NA	Y
Matysiak	2017	Y	Y	N	PY	PY	N	N	Y	PY	Y	N	NA	NA	Y	N	NA	Y
Moghadamnia	2017	Y	N	N	PY	PY	Y	N	Y	Y	Y	N	Y	N	Y	Y	N	Y
Naish	2014	Y	Y	N	PY	PY	N	N	PY	PY	PY	N	NA	NA	Y	N	NA	Y
Nichols	2009	Y	N	N	PY	PY	Y	Y	Y	Y	N	N	NA	NA	N	N	NA	Y
Odame	2018	Y	N	N	PY	PY	N	N	PY	PY	N	N	Y	N	Y	Y	Y	Y
Park	2017	Y	N	N	N	PY	Y	Y	N	PY	Y	N	Y	PY	Y	Y	N	Y
Phalkey	2015	Y	Y	N	PY	PY	Y	Y	Y	PY	PY	N	NA	NA	Y	N	NA	Y

Philipsborn	2016	Y	Y	N	PY	N	N	N	Y	PY	N	N	Y	Y	N	Y	N	Y
Phung	2015	Y	Y	N	N	PY	N	N	Y	Y	PY	Y	NA	NA	N	N	NA	Y
Porpora	2019	Y	Y	Y	PY	PY	N	N	Y	PY	N	N	NA	NA	N	Y	NA	Y
Poursafa	2015	Y	N	N	PY	PY	Y	Y	PY	Y	PY	N	NA	NA	Y	Y	NA	Y
Racloz	2012	Y	N	N	N	PY	N	N	N	PY	N	N	NA	NA	Y	Y	NA	Y
Rataj	2016	Y	Y	Y	PY	PY	Y	Y	PY	PY	Y	N	NA	NA	Y	Y	NA	Y
Reid	2016	Y	N	N	PY	PY	N	N	N	PY	PY	N	NA	NA	Y	PY	NA	Y
Rifkin	2018	Y	Y	Y	PY	PY	Y	Y	Y	PY	N	N	NA	NA	Y	N	NA	Y
Salve	2018	Y	Y	N	N	PY	Y	Y	PY	PY	N	N	NA	NA	Y	N	NA	Y
Sanderson	2017	Y	Y	N	N	PY	Y	N	Y	PY	PY	N	NA	NA	Y	N	NA	Y
Sawatzky	2018	Y	Y	N	N	PY	Y	N	Y	N	N	N	NA	NA	N	N	NA	Y
Semenza	2012	N	N	N	N	N	N	N	N	N	Y	N	NA	NA	N	N	NA	N
Stanke	2013	Y	N	N	PY	PY	N	N	Y	PY	N	N	NA	NA	Y	N	NA	Y
Stensgaard	2019	Y	Y	N	N	PY	N	Y	N	PY	N	N	NA	NA	N	N	NA	Y
Sun	2018	Y	Y	N	PY	PY	N	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y
Swynghedauw	2009	Y	Y	N	N	N	N	N	N	N	N	N	NA	NA	N	N	NA	Y
Tall	2014	Y	N	N	N	PY	N	N	Y	Y	PY	N	NA	NA	Y	N	NA	Y
Varghese	2018	Y	N	N	N	PY	N	N	Y	Y	N	N	NA	NA	Y	N	NA	Y
Veenema	2017	Y	N	Y	N	PY	N	N	Y	N	PY	N	NA	NA	N	N	NA	N
Vilcins	2018	Y	N	Y	N	PY	N	N	Y	N	Y	N	NA	NA	Y	N	NA	Y
Vins	2015	Y	Y	N	N	PY	N	N	Y	N	N	N	NA	NA	Y	PY	NA	Y
Waits	2018	Y	Y	N	N	PY	N	N	Y	N	N	N	NA	NA	N	N	NA	Y
Wald	2019	Y	N	N	N	PY	N	N	Y	Y	N	N	NA	NA	Y	N	NA	N
Welch	2019	Y	Y	N	N	N	N	N	PY	PY	N	N	NA	NA	N	N	NA	N
Wimalawansa	2016	Y	N	N	N	N	N	N	N	N	N	N	NA	NA	N	N	NA	Y
Witt	2015	Y	N	N	N	PY	N	N	Y	N	N	N	N	Y	Y	N	N	Y
Xu	2018	Y	N	N	PY	PY	N	N	PY	PY	N	N	NA	NA	Y	N	NA	Y
Xu	2012	Y	N	N	PY	PY	N	N	PY	Y	PY	N	NA	NA	N	N	NA	Y
Xu	2016	Y	N	N	PY	PY	N	N	Y	Y	N	N	Y	N	Y	Y	N	Y
Xu	2014	Y	Y	N	N	PY	N	N	Y	Y	N	N	NA	NA	N	Y	NA	N
Youssef	2014	Y	Y	N	PY	PY	N	N	Y	Y	N	N	NA	NA	Y	N	NA	Y

Yu	2015	N	N	N	PY	PY	N	N	Y	Y	N	N	NA	NA	Y	PY	NA	Y
Yu	2012	Y	Y	N	PY	N	N	Y	Y	Y	N	N	Y	N	Y	Y	Y	Y
Zhang	2007	Y	N	N	N	N	N	N	N	N	N	N	NA	NA	Y	N	NA	N
Zhang	2017	Y	Y	N	PY	PY	N	N	PY	Y	Y	N	NA	NA	Y	Y	NA	Y
Zuo	2015	Y	Y	N	N	PY	N	N	N	N	N	N	NA	NA	N	N	NA	Y
TOTAL	Yes	81	44	9	5	0	32	17	64	36	31	2	17	12	70	28	11	78
	Partial Yes	0	0	0	47	80	0	4	19	41	22	0	0	1	2	15	0	0
	No	13	50	85	42	14	62	73	11	17	41	92	1	5	22	51	7	16
	Not- Applic able	0	0	0	0	0	0	0	0	0	0	0	0	76	76	0	0	76

**Appendix 5.** Summary table of publications according to climate impact and health outcome according to frequencies and references. References with a \* explore only this specific combination of climate impact and health outcome and therefore appear only once in this table. Number of studies and references (according to alphabetical order) for each combination of categories are presented in the cells. Empty cells in this Table indicate an absence of studies at this combination of categories.

Health Outcome	Climate Impact				
	Meteorological (71)	Extreme weather (24)	Air quality (7)	General (5)	Other (3)
Infectious diseases (41)	<p><b>35</b></p> <p>Amegah, Babaie*, Bai*, Berhane, Bernhardt*, Cheng, Coates*, de Sousa, Dhimal*, Duan*, Fan*, Gao 2014, Ghazani*, Gracia*, Hedlund, Hii*, Khader, Lal 2015*, Lal 2019*, Levy, Leyva, Li, Matysiak, Naish*, Nichols, Philipsborn*, Phung, Racloz*, Semenza*, Stensgaard, Swynghedau, Waits*, Welch*, Xu 2012, Yu 2015*</p>	<p><b>14</b></p> <p>Alderman, Berhane, Brown*, Cann*, Hedlund, Levy, Li, Matysiak, Nichols, Phung, Stanke, Swynghedau, Tall*, Veenema</p>			
Mortality (32)	<p><b>24</b></p> <p>Amegah, Bunker, Campbell, Cheng, Cunrui*, Ghanizadeh, Hajat*, Khader, Lawton, Leyva, Lian, Moghdamnia*, Nichols, Odame*, Salve, Sanderson*, Sun, Swynghedau, Witt, Xu 2012, Xu 2014, Xu 2016*, Yu 2012*, Zuo</p>	<p><b>5</b></p> <p>Alderman, Doocy, Leyva, Stanke, Veenema</p>	<p><b>5</b></p> <p>Leyva, Liu, Madniyazi*, Reid, Youssouf</p>		
Respiratory, cardiovascular, and neurological (23)	<p><b>17</b></p> <p>Amegah, Bunker, Cheng, Cong*, de Sousa, Gao 2014, Ghanizadeh, Lawton, Leyva, Lian, Nichols, Sun, Witt, Xu 2012, Xu 2014, Xu 2018*, Zuo</p>	<p><b>1</b></p> <p>Stanke</p>	<p><b>6</b></p> <p>Khader, Leyva, Liu, Nichols, Reid, Youssouf</p>	<p><b>1</b></p> <p>Lake*</p>	

1 2 3 4 5 6 7	Health systems (16)	<b>11</b> Amegah, Campbell, Cheng, Khader, Leyva, Salve, Sun, Wald*, Xu 2012, Xu 2014, Zuo	<b>2</b> Alderman, Klinger*	<b>2</b> Liu, Youssouf	<b>1</b> Sawatzky*	
8 9 10 11 12 13	Mental Health (13)	<b>3</b> Gao 2019*, Khader, Zuo	<b>9</b> Alderman, Benevolenza, Fernandez*, Leyva, Nichols, Rataj, Stanke, Veenema, Vins*	<b>1</b> Reid		
14 15 16 17 18 19	Pregnancy and birth outcomes (11)	<b>5</b> Carolan-Olah*, Kuehn*, Poursafa*, Khader, Zhang 2017*	<b>2</b> Alderman, Benevolenza	<b>3</b> Liu, Reid, Youssouf		<b>1</b> Porpora*
20 21 22 23 24	Nutritional (9)	<b>4</b> Amegah, Khader, Phalkey, Salve	<b>6</b> Berhane, Khader, Nichols, Phalkey, Stanke, Swynghedauw		<b>1</b> An*	<b>1</b> Vilcins*
25 26 27 28 29	Skin diseases and allergies (8)	<b>7</b> Amegah, Augustin*, Nichols, Gao 2014, Swynghedauw, Xu 2012, Zuo			<b>1</b> Huang*	
30 31 32 33 34 35	Occupational health and injuries (6)	<b>6</b> Binazzi*, Bonafede*, Flouris*, Levi*, Varghese*, Wimalawans				<b>1</b> Wimalawans
36 37 38 39 40 41 42 43 44 45 46 47	Other (17)	<b>10</b> Bunker, Cheng, Kampe*, Nichols, Park*, Rifkin, Swynghedauw, Xu 2012, Xu 2014, Zuo	<b>6</b> Alderman, Benevolenza, Doocy, Rataj, Rifkin, Stanke	<b>1</b> Liu	<b>1</b> Zhang 2007*	



# PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
<b>TITLE</b>			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
<b>ABSTRACT</b>			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	1
<b>INTRODUCTION</b>			
Rationale	3	Describe the rationale for the review in the context of what is already known.	2
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	2
<b>METHODS</b>			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	3
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	3
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	3
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	31
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	3,4
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	4
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	4
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	5
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	4
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., $I^2$ ) for each meta-analysis.	4,5



# PRISMA 2009 Checklist

Page 1 of 2

Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	5, 53-56
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	NA
<b>RESULTS</b>			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	6
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	6-8
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	8
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	38-52
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	11-17
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	8,53-56
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	NA
<b>DISCUSSION</b>			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	17-18
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	19
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	19
<b>FUNDING</b>			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	21

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(6): e1000097. doi:10.1371/journal.pmed1000097

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