



# Published research on the human health implications of climate change between 2012 and 2021: cross sectional study

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## ABSTRACT

**OBJECTIVE** To better understand the state of research on the effects of climate change on human health, including exposures, health conditions, populations, areas of the world studied, funding sources, and publication characteristics, with a focus on topics that are relevant for populations at risk.

**DESIGN** Cross sectional study.

**DATA SOURCES** The National Institute of Environmental Health Sciences climate change and human health literature portal, a curated bibliographical database of global peer reviewed research and grey literature was searched. The database combines searches of multiple search engines including PubMed, Web of Science, and Google Scholar, and includes added-value expert tagging of climate change exposures and health impacts.

**ELIGIBILITY CRITERIA** Inclusion criteria were peer reviewed, original research articles that investigated the health effects of climate change and were published in English from 2012 to 2021. After

identification, a 10% random sample was selected to manually perform a detailed characterisation of research topics and publication information.

**RESULTS** 10 325 original research articles were published between 2012 and 2021, and the number of articles increased by 23% annually. In a random sample of 1014 articles, several gaps were found in research topics that are particularly relevant to populations at risk, such as those in the global south (134 countries established through the United Nations Office for South-South Cooperation) (n=444; 43.8%), adults aged 65 years or older (n=195; 19.2%), and on topics related to human conflict and migration (n=25; 2.5%) and food and water quality and security (n=148; 14.6%). Additionally, fewer first authors were from the global south (n=349; 34.4%), which may partly explain why research focusing on these countries is disproportionately less.

**CONCLUSIONS** Although the body of research on the health effects of climate change has grown substantially over the past decade, including those with a focus on the global south, a disproportionate focus continues to be on countries in the global north and less at risk populations. Governments are the largest source of funding for such research, and governments, particularly in the global north, need to re-orient their climate and health research funding to support researchers in the global south and to be more inclusive of issues that are relevant to the global south.

## WHAT IS ALREADY KNOWN ON THIS TOPIC

- ⇒ Climate change is one of the most pressing public health threats of the 21st century, contributing to more than 250 000 deaths each year
- ⇒ The environmental effects of climate change have increasingly important and varied implications for human health, disproportionately affecting vulnerable and oppressed populations, including people living in poverty
- ⇒ Research articles on the effects on human health of climate change increased eightfold between 2007 and 2019

## WHAT THIS STUDY ADDS

- ⇒ The number of original research articles on human health and climate change published between 2012 and 2021 increased by 23% annually
- ⇒ Fewer research articles were relevant to at risk populations, eg, people in the global south and older adults, and were on topics related to human conflict, migration, and food and water quality and security
- ⇒ Articles studying the global south grew 41% annually, largely about China, but fewer articles compared the global south and global north, and a smaller number were published in high impact journals

## HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE, OR POLICY

- ⇒ By 2100, 77% of the world's population is predicted to live in the global south
- ⇒ Funding for research on the effects of climate change on human health should therefore be directed towards investigators from the global south and topics relevant to populations more at risk
- ⇒ As populations living in the global south, particularly older adults and children, are less likely to have the resources to adapt to the effects of climate change more research is needed for these groups

## INTRODUCTION

Climate change is one of the most pressing public health threats of the 21st century, contributing to more than 250 000 deaths each year.<sup>1 2</sup> Global temperatures were 1.09°C warmer over 2011 to 2020 compared with 1850 to 1900, changing oceanic and atmospheric systems and contributing to rising sea levels, wild fires, flooding, droughts, and other extreme weather events.<sup>3</sup> The environmental effects of climate change have increasingly important and varied implications for human health through multiple pathways. Climate change has direct and indirect effects on morbidity and mortality, food and water insecurity, and social and economic challenges, such as financial stability and human displacement.<sup>3 4</sup> The type and severity of climate change effects vary by region, and countries in the global south that historically have contributed the least to anthropogenic climate change are often

disproportionately affected.<sup>1 4-7</sup> Climate related stressors exacerbate existing inequalities within regions and disproportionately affect susceptible and oppressed populations, including people living in poverty.<sup>8,9</sup> Understanding the local economic, social, and environmental factors that affect how at risk a population is to climate change is critical to effectively and equitably address this threat worldwide.<sup>10</sup>

Governments and researchers have been paying increasing attention to understanding the human health implications of climate change.<sup>11</sup> In 2013, the Intergovernmental Panel on Climate Change published a landmark report concluding that global warming is unequivocally the result of human actions.<sup>12</sup> In 2015, the same year that the Paris Agreement was adopted by 196 countries pledging to limit global warming to well below 2°C, preferably to 1.5°C, compared with pre-industrial levels, *The Lancet* created a commission on health and climate change that publishes a yearly report on the topic called the *Lancet* Countdown.<sup>11,13,14</sup> Beyond the *Lancet* Countdown, articles on the human health effects of climate change increased eightfold between 2007 and 2019.<sup>1</sup> According to a study that used machine learning to systematically map the existing literature on climate change and human health, the most commonly studied topics were heat related effects on health.<sup>15</sup> Major gaps in research were reported for non-physical health topics such as mental health, and the research was disproportionately produced by high income countries, consistent with prior studies.<sup>1 3 6 16</sup> The term global south includes the collection of postcolonial and low and middle income countries that united into the Group of 77 in 1964, and now includes 134 countries. Recognising the need to promote, coordinate, and support the interests of these countries, the United Nations established the UN Office for South-South Cooperation, which maintains the membership of this group and helps to coordinate cooperative goals and initiatives. In 2022, the UN Office for South-South Cooperation published a paper focusing on the impact of climate change on developing countries and discussed how the South-South Cooperation can help countries build climate resilience.<sup>17</sup> The global north is defined as all other countries.

While prior studies have characterised the topics studied in the literature on the health effects of climate change, publication characteristics and funding sources have not been comprehensively characterised. Understanding the sources of funding for literature that focuses on topics relevant to countries in the global south was also an unmet need. We conducted a cross-sectional study of a representative sample of original research on the human health effects of climate change published between 2012 and 2021 in order to better understand the state of research that has examined the effects of climate change on health.

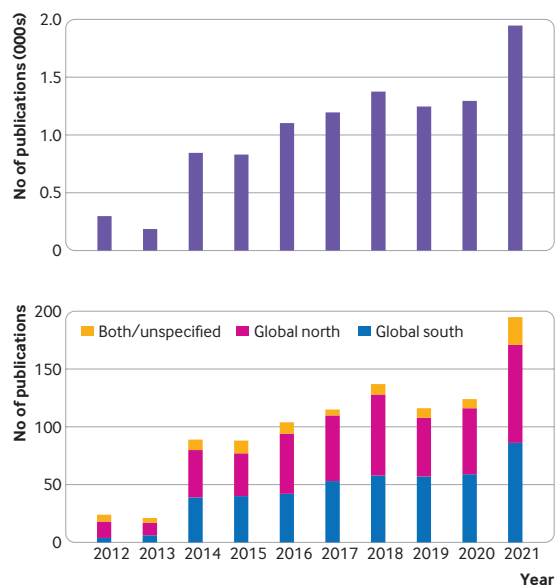
We characterised the climate change-related topics studied, including exposures, health conditions, populations, geographies studied, funding sources, and publishing characteristics, with a focus on differentiating what has been studied in the global south and global north. Details of the literature on climate change and human health and the topical emphases of prior studies can help to direct future research and policy efforts to topics and geographies with the greatest need.

## Methods

### Search strategy

We searched the National Institute of Environmental Health Sciences (NIEHS) climate change and human health literature portal, the largest curated bibliographical database of global peer-reviewed research and grey literature on the science of climate impact on human health, to identify peer-reviewed original research investigating the health effects of climate change published from 2012 to 2021.<sup>18,19</sup> At the time of our study, the portal's curation of 2022 articles was not complete, so we did not include articles published after 2021. The database combines searches of multiple search engines including PubMed, Web of Science, and Google Scholar and includes added-value expert tagging of climate change exposures and health impacts. This approach of identifying studies via screening records from an evidence hub, rather than relying on keyword searches in traditional bibliographical databases, provides a comprehensive and consistent source of climate change literature, as compared with independent keyword searches.

We filtered our search by publication year, limited to original research articles (defined as an article in a peer-reviewed journal containing original data) published in English. Search results for articles published between 2012 and 2019 were downloaded on 20 June 2021, and those for articles published in 2020 and 2021 were downloaded on 7 September 2023. After identifying all original research articles, we selected a 10% random sample to manually perform a detailed characterisation of research topics and publication information. Three investigators (VLB, HD, and MM) read the title and abstract to verify that the articles examined associations between climate change and health. Three investigators (VLB, HD, and MM) read the abstracts, and full text, if necessary, of each article in the sample to characterise the study characteristics. Each investigator validated a 5% random sample of the articles characterised by the other two investigators, with inter-rater reliability of 96.3%. Any uncertainties were clarified with a fourth investigator (JSR).



**Figure 1 | Original research articles studying the association between climate change and health, 2012-21, in total (n=10 325) and in random 10% sample (n=1014)**

### Study characteristics

For each article, we abstracted the climate change exposures, health effects, geographical locations, and populations studied. We also determined the publication year, journal impact factor, number of authors, location of the first author's affiliation, and funding sources. Climate change exposures were categorised into eight groups: general exposure; air pollution; extreme weather; food and water quality and security; human conflict and displacement; indoor environment; seasonality, temperature, and meteorological factors; and other. Health effects were categorised into 19 groups. These groups were based on the categories in the NIEHS portal. Articles were categorised as studying general health effects if they did not name a specific health effect but health was mentioned generally and the climate change exposure studied was one that clearly affects health (eg, water quality, food security, and heat waves). Geographical location was categorised as North America, South America, Europe, Asia, Africa, Australasia, Antarctica, global, or unspecified. Articles categorised as global were those in which specific geographies were not stated or global data were analysed in aggregate. We also characterised whether the article studied one or more countries in the global south, according to the United Nations' definition of the global south.<sup>20</sup> Articles that studied only countries in the global north were characterised as global north, and articles that studied only countries in the global south were also characterised as global south. If an article had a global focus, or if

it studied countries in the global south and global north, we counted it in a third category of both global north and global south.

Population focuses were categorised as children, adults, older adults (aged 65 years or older), or not specified. Funding sources were categorised as government, non-profit, for-profit, academic, and not specified. The journal's 2020 impact factor was obtained from Web of Science Journal Citation Reports, and categorised as 0-4.99, 5.00-9.99, or 10.00 and greater.

### Statistical analyses

We used descriptive statistics to characterise the 10% sample. For categorical variables, we reported the percentage of articles within each category. For continuous variables, we reported the median and interquartile range. We also used the same methodology to characterise the subset of articles studying the global south. Within the random sample, we calculated the average annual percentage change in the number of articles for each variable if the total was greater than 20 articles. Data were analysed in Excel, version 16.54 (Microsoft).

### Patient and public involvement

Patients and the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research. On publication, results will be widely disseminated through social media and will be sent directly to the National Institute of Environmental Health Sciences (NIEHS).

## Results

### Number of articles and years published

Based on search results from the NIEHS portal on 20 July 2021 and 7 September 2023, we identified 10 325 original research articles published between 2012 and 2021: 297 (4.2%) articles were published in 2012, 187 (2.6%) in 2013, 845 (11.9%) in 2014, 831 (11.7%) in 2015, 1103 (15.6%) in 2016, 1196 (16.9%) in 2017, 1376 (19.4%) in 2018, 1247 (17.6%) in 2019, 1296 (13%) in 2020, and 1947 (19%) in 2021, representing a 23% compound annual growth (figure 1). The largest year-to-year growth in the number of articles studied was from 2013 to 2014 (187 to 845 articles) and from 2020 to 2021 (1296 to 1947 articles).

In the random 10% sample of 1034 articles, 13 (1.3%) were excluded because they were not directly related to health or climate change. Seven (0.7%) were excluded because we were not able to access the full article. Of the remaining 1014 articles, 24 (2.4%) were published in 2012, 21 (2.1%) in 2013, 89 (8.8%) in 2014, 88 (8.7%) in 2015, 104 (10.3%) in 2016, 104 (10.3%) in 2017, 137 (13.5%) in 2018,

117 (11.5%) in 2019, 124 (12.2%) in 2020, and 195 (19.2%) in 2021. This represented a 26% compound annual growth in total number of articles published.

#### Climate change exposures studied

Among the 1014 articles, 697 (68.7%) studied seasonality, temperature, and meteorological factors, 318 (45.6%) of which studied the global south; 306 (30.2%) studied extreme weather, 119 (38.9%) of which studied the global south; and 148 (14.6%) studied food and water quality and security, 82 (55.4%) of which studied the global south (table 1). The number of articles studying seasonality, temperature, and meteorological factors grew by 30% annually, in addition to the increase in number of articles studying extreme weather (28%) and air pollution (24%) (figure 2).

#### Health effects studied

Infectious disease was investigated by 288 (28.4%) of 1014 studies, of which 166 (57.6%) studied the global south; 244 (24.1%) articles studied general health, of which 107 (43.9%) studied the global south; 171 (16.9%) studied morbidity and mortality, of which 55 (32.2%) studied the global south; 82 (8.1%) studied economic effects, of which 41 (50.0%) studied the global south; and 53 (5.2%) studied mental health effects, of which 15 (28.3%) studied the global south (table 1). The three most rapidly growing health effects studied were medical visits (34% yearly increase), temperature related (33% yearly increase), and mental health and wellbeing (22% yearly increase) (figure 2).

#### Population geographical location studied

Of the 1014 sampled, Asia was the most commonly studied continent (n=358; 35.3%), followed by Europe (n=203; 20.0%), North America (n=192; 18.9%), Africa (n=101; 10.0%), Oceania (n=66; 6.5%), then South America (n=42; 4.1%). Fifty seven (5.6%) articles had a global focus, and 29 (2.9%) studies did not specify a geography (table 1). The number of articles that studied Asia grew by 62% annually, those studying Africa grew by 30% annually, and those studying North America and South America both grew by 28% annually (figure 2). In 2012, only four (16.7%) of the 24 articles studied the global south, whereas in 2021, 86 (44.1%) of 195 did, representing a 41% year-over-year growth (figure 1). Almost half of the articles did not study any country in the global south (n=475; 46.8%). China was the most commonly studied country (n=138; 13.6%), followed by the United States (n=125; 12.3%), and Australia (n=51; 5.0%). Articles about China grew by 45% annually and made up 31.1% (138 of 444) of all articles that exclusively studied the global south.

#### Population demographics studied

Most articles did not specify an age related population or report the age distributions (eg, mean or median) (n=617; 60.8%), while 303 (29.9%) studied adult, 175 (17.3%) paediatric, and 195 (19.2%) older people populations (table 1). Among articles with age related information, the populations in the global south that were studied were 128 (42.2%) adult, 94 (53.7%) paediatric, and 78 (40.0%) older people.

#### Author characteristics

The median number of authors per article was 5 (interquartile range 3-7). Of the 1014 articles, the most common first author's primary affiliation location was Asia (n=319; 31.5%), followed by Europe (n=276; 27.2%), North America (n=229; 22.6%), Oceania (n=80; 7.9%), Africa (n=42; 4.1%), and South America (n=21; 2.4%). The number of articles with the first author's primary affiliation in Asia grew by 60% annually, in Africa by 24% annually, and in Europe by 21% annually (table 2). First authors with a primary affiliation in a global south country made up 34.4% (n=349) of articles, and those in a global north country 64.4% (n=653) of articles; author affiliations were missing for the remainder (n=12). The number of articles with a first author primary affiliation in a global south country grew by 43% annually. Of the 444 articles that exclusively studied the global south, 322 (72.5%) had a first author with their primary affiliation in the global south. Of the 653 articles with a first author's primary affiliation in the global north, 465 (71.2%) studied only countries in the global north, while 114 (17.5%) studied only countries in the global south. Most authors who had a primary affiliation in the global south studied countries in the global south (n=322; 92.3%), with the number of such articles growing by 40% annually.

Most of the 1014 articles were funded by government sources (n=618; 60.9%), while 225 (22.2%) were funded by academic sources, 83 (8.2%) by non-profit sources, and 10 (1.0%) by for-profit sources. Eighty seven (8.6%) articles stated they did not receive funding, while 193 (19.0%) did not specify whether or not they received funding for the work presented (table 2).

#### Journal characteristics

In journals with an impact factor of less than five, 831 (82.0%) articles were published, of which 369 (44.4%) studied a country in the global south. Among the 161 (15.9%) articles that were published in journals with an impact factor of five to 9.99, 67 (41.6%) studied a country in the global south. Of the 23 (2.3%) articles published in journals with an impact factor of 10 and above, eight (34.8%) studied a country in the global south (table 2). Articles in journals with an impact factor of five to 9.99 grew

**Table 1 | Research topics of original research articles studying the association between climate change and health, 2012-21**

Research topics	No. of articles (% of sample)*	Compound annual growth (%)†	Articles with global south focus (%)‡
Total	1014 (100.0)	26	444 (43.8)
Climate change exposures§:			
General exposure	135 (13.3)	12	52 (38.5)
Air pollution	154 (15.2)	24	67 (43.5)
Extreme weather	306 (30.2)	28	119 (38.9)
Food and water quality and security	148 (14.6)	20	82 (55.4)
Human conflict and displacement	25 (2.5)	8	13 (52.0)
Indoor environment	32 (3.2)	18	9 (28.1)
Seasonality, temperature, and meteorological factors	697 (68.7)	30	318 (45.6)
Other	61 (6.0)	—	23 (37.7)
Health effects:			
Cancer	7 (0.7)	—	5 (71.4)
Cardiovascular	70 (6.9)	25	34 (48.6)
Dermatological	11 (1.1)	—	4 (36.4)
Developmental	12 (1.2)	—	6 (50.0)
Diabetes, obesity/overweight	6 (0.6)	—	1 (16.7)
Economic	82 (8.1)	28	41 (50.0)
General health	244 (24.1)	19	107 (43.9)
Infectious disease	288 (28.4)	23	166 (57.6)
Injury	16 (1.6)	—	4 (25.0)
Malnutrition	20 (2.0)	—	17 (85.0)
Medical visit	54 (5.3)	34	21 (38.9)
Mental health and wellbeing	53 (5.2)	22	15 (28.3)
Morbidity and mortality	171 (16.9)	21	55 (32.2)
Neurological	20 (2.0)	—	8 (40.0)
Reproductive	20 (2.0)	—	7 (35.0)
Respiratory	86 (8.5)	31	40 (46.5)
Temperature related health	169 (16.7)	33	42 (24.9)
Urologic	17 (1.7)	—	2 (11.8)
Other health	47 (4.6)	7	15 (31.9)
Geographical area:			
Unspecified	29 (2.9)	17	—
Global	57 (5.6)	16	2 (3.5)
North America	192 (18.9)	28	7 (3.6)
South America	42 (4.1)	28	39 (92.9)
Europe	203 (20)	20	2 (1.0)
Asia	358 (35.3)	62	302 (84.4)
Africa	101 (10.0)	30	95 (94.1)
Oceania	66 (6.5)	5	5 (7.6)
Region:			
Global south¶	444 (43.8)	41	NA
Global north	475 (46.8)	22	NA
Both global north and global south	65 (6.4)	17	NA
Population focus:			
Older people	195 (19.2)	25	78 (40.0)
Adults	175 (17.3)	32	94 (53.7)
Children	303 (29.9)	25	128 (42.2)
Not specified	617 (60.8)	24	273 (44.2)

Continued

Table 1 Continued

Research topics	No. of articles (% of sample)*	Compound annual growth (%)†	Articles with global south focus (%)‡
NA=not available. Research topics were not mutually exclusive because articles could be assigned to multiple subgroups.			
*Sample is 10% of total number of articles.			
†Annual increase not calculated if total less than or equal to 20.			
‡Denominator was number of articles in the sample.			
§Climate change exposures: extreme weather related event or disaster (ie, extreme precipitation events, tropical cyclones, floods, droughts, wildfires, heat waves, and cold waves); food and water quality and security; human conflict and displacement; indoor environment; air pollution; seasonality, temperature, and meteorological factors; general exposures; other (including ecosystem change, solar radiation, sea level rise, and sea surface oscillation).			
¶According to the United Nations' Finance Center for South-South Cooperation.			

by 23% annually, and those with an impact factor of less than five grew by 28% annually.

## Discussion

### Main findings

In this cross-sectional analysis of a random sample of original research articles that studied the effects on human health of climate change and published between 2012 and 2021, we found that the number of articles published increased by 23% annually. We found particularly steep increases from 2013 to 2014, and from 2020 to 2021. Despite this growth, we found several gaps in research topics that are relevant to more at risk populations, such as those in the global south and older people. Fewer first authors were from the global south, which may partly explain the disproportionately less research focusing on these countries, and may be linked to research funding sources and allocation.

The number of articles studying the global south grew by 41% annually, with a large portion of this driven by articles about China, which increased by 45% annually and made up almost a third of articles studying the global south. Despite this rapid growth, articles about the global south still constitute a smaller proportion of original research articles studying climate change and human health and a smaller percentage of them are published in high impact journals as compared with those studying the global north. However, by 2100, 77% of the world's population is predicted to live in the global south, where countries bear a disproportionate share of the effects of global warming.<sup>21 22</sup> In addition, the distribution of climate change exposures studied reflects a bias towards those that affect higher income countries. The two most studied topics—extreme weather and seasonality, and temperature and meteorology—had disproportionately fewer articles studying the global south. By contrast, articles studying human conflict and migration, all of which studied the global south, made up a small proportion of all articles. The impact of climate change on human conflict and migration is especially relevant for countries in the global south. Given that the number of climate refugees from Latin America, sub-Saharan Africa, and Southeast Asia alone is predicted to increase by 143 million people before 2050, research into this consequential climate change exposure and its potentially global effects is

essential.<sup>23</sup> Similarly, food and water quality and security was also one of the least studied exposures, but most articles studied the global south, reflecting the disproportionate burden that these countries bear from this climate change exposure.

The distribution of illnesses studied also suggests disproportionate gaps in research that is most relevant to countries in the global south. The impact of climate change on infectious diseases and general health were the most commonly studied, while mental health and economic effects were studied by fewer articles. Evidence suggests that low income countries in the global south are the most affected by heat related reductions in labour capacity, with 2015 average estimated losses equivalent to 3.9–5.9% of gross domestic product in countries such as Indonesia, India, and Cambodia.<sup>1</sup> Moreover, financial stress is the strongest predictor of mental health issues after natural disasters, and people living in the global south are at increased risk of exposure to extreme weather events and poverty, and are less likely to have access to insurance to protect against damage from extreme weather events.<sup>24</sup>

Few articles studied older people or children, both of whom are especially at risk populations. Fewer than half of the articles of older people were in the context of the global south, and about half of articles of paediatric populations studied the global south. Both children and older adults are especially susceptible to the effects of climate change, including extreme weather events, air quality, and infectious disease.<sup>25</sup> Moreover, low income older adults and children are less likely to have the resources to adapt to the effects of climate change. More research is needed to understand the unique needs of these at risk populations and to find geographically appropriate solutions.

Most articles' first authors were from countries in the global north, and less than a fifth of them studied global south countries. Additionally, articles studying global south countries were disproportionately published in journals with lower impact factors. Most articles received government funding, which may be less likely to fund studies that do not focus on their own geographical region. These findings may partially explain the disproportionate gap in quality and quantity of articles studying the global south observed. Moreover, health-related research bodies

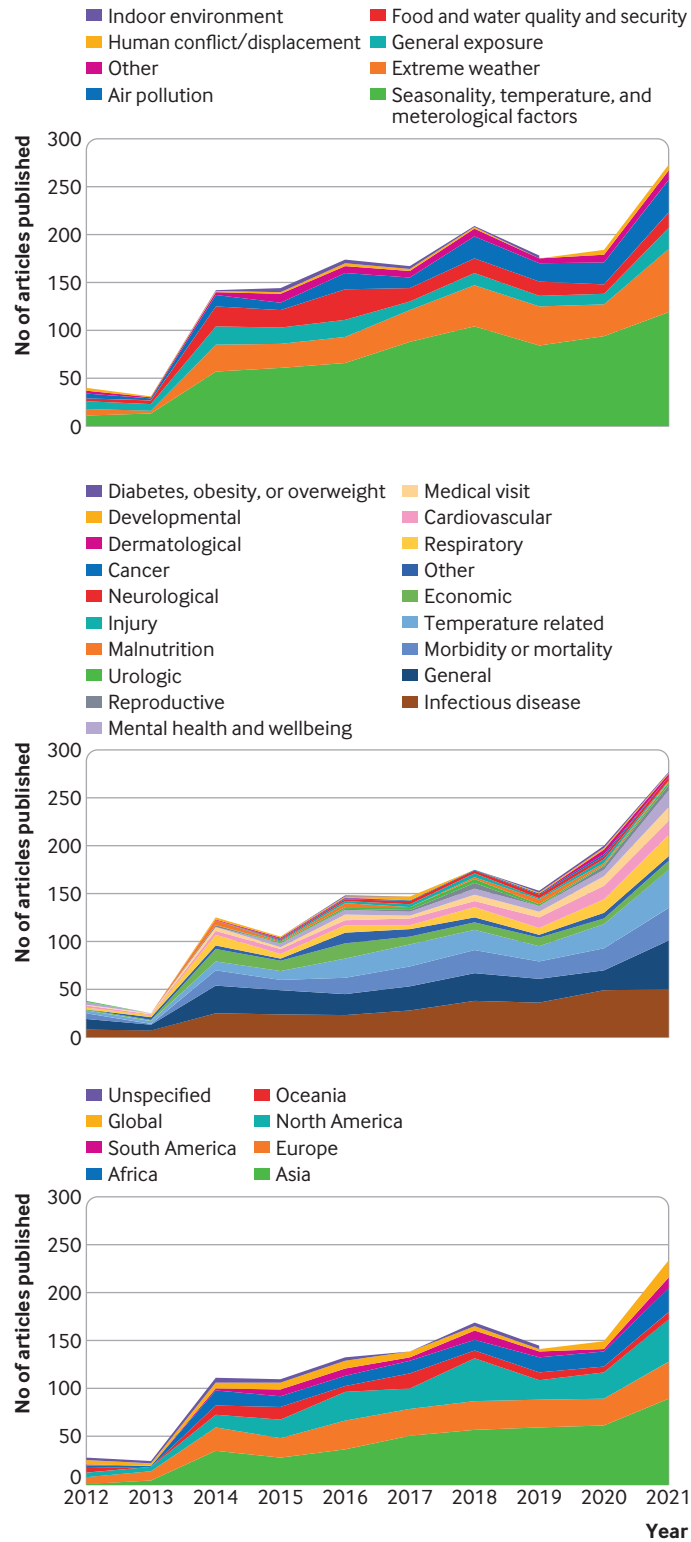


Figure 2 | (Top) Climate change exposures; (middle) health effects; and (bottom) geographies studied in original research articles studying the association between climate change and health, 2012-21

globally underfund and underemphasise research on climate change and health.<sup>10</sup> Greater funding of climate change and health research is needed, and particularly of researchers from countries in the global south and of studies that are relevant to the people that live in these locations, especially as the

proportion of the world's population that live in the global south continues to grow.<sup>26</sup> This funding will require government, academic, non-profit, and for-profit sources in the global north to invest in and support investigators from the global south and their research.

**Table 2 | Study characteristics of original research articles studying the association between climate change and health, 2012-21**

	Number of articles (% of sample*)	Annual increase† (%)	Articles with global south focus (%‡)
Total	1014 (100.0)	26	444 (43.8)
Journal impact factor:			
0.00-4.99	23 (2.3)	-7	8 (34.8)
5.00-9.99	161 (15.9)	23	67 (41.6)
≥10.00	831 (81.8)	28	369 (44.4)
Median number of authors (interquartile range)	5 (3-7)	—	—
First author location (continent):			
North America	229 (22.6)	20	40 (17.5)
South America	24 (2.4)	20	23 (95.8)
Europe	276 (27.2)	21	41 (14.9)
Asia	319 (31.5)	60	257 (80.6)
Africa	42 (4.1)	24	39 (92.9)
Oceania	80 (7.9)	6	20 (25.0)
First author location (region):			
Global south§	349 (34.4)	43	322 (92.3)
Global north	653 (64.4)	21	114 (17.5)
Funding source:			
Government	618 (60.9)	30	262 (42.4)
Non-profit	83 (8.2)	40	31 (37.3)
For-profit	10 (1)	—	4 (40)
Academic	225 (22.2)	35	111 (49.3)
Not specified	193 (19)	9	86 (44.6)
None	87 (8.6)	42	33 (37.9)
Conflict of interest:			
Oil and gas funding	1 (0.1)	—	0 (0)
Pharmaceutical funding	9 (0.9)	—	1 (11.1)
No funding	623 (61.4)	38	275 (44.1)
Not specified	367 (36.2)	8	161 (43.9)

\*Sample is 5% of total number of articles.

†Annual increase calculated if total greater than 20.

‡Denominator was number of articles in the sample.

§According to the United Nations' Finance Centre for South-South Cooperation.

### Policy implications

Increasing the number and variety of research studies on the health effects of climate change may contribute to increased popular support for government engagement with climate change. Currently, only a small percentage of research on climate change focuses on its health effects.<sup>1</sup> In the annual United Nations General Assembly, engagement with the health effects of climate change is high in governments of island nations who face greater risks, particularly in the western Pacific region, while engagement is low among countries with the highest carbon dioxide emissions, including the United States and those in the European Union.<sup>1</sup> Increasing research on the effects of climate change, especially on topics relevant to the global south, may draw attention to and allow for increased investment in mitigating the health effects of climate change globally.

### Limitations

There are several limitations to this study. Firstly, we manually characterised a random subset of all research articles. Although we did not consider all articles, the random 10% sample is a standard method and should be representative of the total population of research on climate change and human health. Secondly, when characterising the geographical location of the authors, we only considered the first author, so this may not reflect the full scope of affiliations of all co-authors. Thirdly, we did not include articles published before 2012, or those that were not published in English. This may have disproportionately affected our ability to capture articles written by investigators from the global south. However, the NIEHS portal offers a comprehensive resource that is most likely to identify the articles of greatest impact by researchers and those used by policy makers.



## Conclusion

In this characterisation of original research on the health effects of climate change, we found that although the body of research has grown substantially over the past decade, including those with a focus on the global south, a disproportionate focus continues to be on countries in the global north and less at risk populations. By increasing funding for research on neglected topics, such as human conflict and displacement, economic effects, older populations, and countries in the global south, populations worldwide might be better equipped to address some of the most devastating potential effects of climate change. Governments are the largest source of funding for such research, and governments, particularly in the global north, need to re-orient their climate and health research funding to support researchers in the global south and to be more inclusive of issues that are relevant to the global south.

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## REFERENCES

- Watts N, Amann M, Arnell N, *et al*. The 2020 report of the Lancet Countdown on health and climate change: responding to converging crises. *The Lancet* 2021;397:129–70. 10.1016/S0140-6736(20)32290-X
- World Health Organization. Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s. Geneva: World Health Organization, 2014.
- Intergovernmental Panel on Climate Change. Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, 2021.
- Romanello M, McGushin A, Di Napoli C, *et al*. The 2021 report of the Lancet Countdown on health and climate change: code red for a healthy future. *The Lancet* 2021;398:1619–62. 10.1016/S0140-6736(21)01787-6
- Orru H, Ebi KL, Forsberg B. The interplay of climate change and air pollution on health. *Curr Environ Health Rep* 2017;4:504–13. 10.1007/s40572-017-0168-6
- Rocque RJ, Beaudoin C, Ndjaboue R, *et al*. Health effects of climate change: an overview of systematic reviews. *BMJ Open* 2021;11:e046333. 10.1136/bmjopen-2020-046333
- Khatana SAM, Werner RM, Groeneveld PW. Association of extreme heat with all-cause mortality in the contiguous US, 2008–2017. *JAMA Netw Open* 2022;5:e2212957. 10.1001/jamanetworkopen.2022.12957
- Field C, Barros V, Dokken D, *et al*. Intergovernmental Panel on Climate Change fifth assessment report on climate change 2014: impacts, adaptation, and vulnerability. 2014. 10.1017/CBO9781107415386
- Sharpe JD, Wolkin AF. The epidemiology and geographic patterns of national disaster and extreme weather mortality by race and Ethnicity, United States, 1999–2018. *Public Health Rep* 2022;137:1118–25. 10.1177/00333549211047235
- Ebi KL, Semenza JC, Rocklöv J. Current medical research funding and frameworks are insufficient to address the health risks of global environmental change. *Environ Health* 2016;15:108. 10.1186/s12940-016-0183-3
- Cook J, Nuccitelli D, Green SA, *et al*. Quantifying the consensus on anthropogenic global warming in the scientific literature. *Environ Res Lett* 2013;8:024024. 10.1088/1748-9326/8/2/024024
- Intergovernmental Panel on Climate Change. Climate change 2013 – the physical science basis. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY USA: Cambridge University Press, 24 March 2014. 10.1017/CBO9781107415324
- United Nations Framework Convention on Climate Change. The Paris agreement. 2021. Available: <https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement> [Accessed 16 Jan 2024].
- Watts N, Adger WN, Agnolucci P, *et al*. Health and climate change: policy responses to protect public health. *The Lancet* 2015;386:1861–914. 10.1016/S0140-6736(15)60854-6
- Berrang-Ford L, Sietsma AJ, Callaghan M, *et al*. Systematic mapping of global research on climate and health: a machine learning review. *Lancet Planet Health* 2021;5:e514–25. 10.1016/S2542-5196(21)00179-0
- Verner G, Schütte S, Knop J, *et al*. Health in climate change research from 1990 to 2014: positive trend, but still underperforming. *Glob Health Action* 2016;9. 10.3402/gha.v9.30723

- 17 Banga R, Fortunato P, Wang D. South–South cooperation for climate adaptation and sustainable development. *United Nations Conference on Trade and Development* 2022.
- 18 Climate change and human health literature portal. National Institute of environmental health science. Available: <https://tools.niehs.nih.gov/cchhl> [Accessed Jan 2024].
- 19 Thigpen Tart K, Holmgren S, Castranio T, *et al*. The NIEHS climate change and human health literature portal: the way to the science you want. *Environmental Epidemiology* 2019;3:393–4. 10.1097/01.EE9.0000610392.99412.15
- 20 Finance Center for South-South Cooperation. Global South countries (group of 77 and China). 2015. Available: [http://www.fc-ssc.org/en/partnership\\_program/south\\_south\\_countries](http://www.fc-ssc.org/en/partnership_program/south_south_countries) [Accessed 16 Jan 2024].
- 21 Butler CD, Hanigan IC. Anthropogenic climate change and health in the global South. *Int J Tuberc Lung Dis* 2019;23:1243–52. 10.5588/ijtld.19.0267
- 22 Solarz MW, Wojtaszczyk M. Population pressures and the North–South divide between the first century and 2100. *Third World Quarterly* 2015;36:802–16. 10.1080/01436597.2015.1024452
- 23 Rigaud KK, de Sherbinin A, Jones B, *et al*. Groundswell. In: *Groundswell: Preparing for Internal Climate Migration*. World Bank Group, 19 March 2018. 10.1596/29461
- 24 Pollack AA, Weiss B, Trung LT. Mental health, life functioning and risk factors among people exposed to frequent natural disasters and chronic poverty in Vietnam. *BJPsych Open* 2016;2:221–32. 10.1192/bjpo.bp.115.002170
- 25 Rhoades JL, Gruber JS, Horton B. Developing an in-depth understanding of elderly adult’s vulnerability to climate change. *Gerontologist* 2018;58:567–77. 10.1093/geront/gnw167
- 26 World population prospects. 2022. Available: <https://population.un.org/wpp> [Accessed 16 Jan 2024].