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Climate Change and Cardiovascular Health
A Systematic Review

Dhruv S. Kazi, MD, MSc, MS; Ethan Katznelson, MD; Chia-Liang Liu, MS; Nora M. Al-Roub, MBBS; Richard S. Chaudhary, MD; Diane E. Young, MLS; Megan McNichol, MLS, AHIP; Loretta J. Mickley, PhD; Daniel B. Kramer, MD, MPH; Wayne E. Cascio, MD; Aaron S. Bernstein, MD, MPH; Mary B. Rice, MD, MPH

IMPORTANCE Climate change may increase the risk of adverse cardiovascular outcomes by causing direct physiologic changes, psychological distress, and disruption of health-related infrastructure. Yet, the association between numerous climate change–related environmental stressors and the incidence of adverse cardiovascular events has not been systematically reviewed.

OBJECTIVE To review the current evidence on the association between climate change–related environmental stressors and adverse cardiovascular outcomes.

EVIDENCE REVIEW PubMed, Embase, Web of Science, and Cochrane Library were searched to identify peer-reviewed publications from January 1, 1970, through November 15, 2023, that evaluated associations between environmental exposures and cardiovascular mortality, acute cardiovascular events, and related health care utilization. Studies that examined only nonwildfire-sourced particulate air pollution were excluded. Two investigators independently screened 20 798 articles and selected 2564 for full-text review. Study quality was assessed using the Navigation Guide framework. Findings were qualitatively synthesized as substantial differences in study design precluded quantitative meta-analysis.

FINDINGS Of 492 observational studies that met inclusion criteria, 182 examined extreme temperature, 210 ground-level ozone, 45 wildfire smoke, and 63 extreme weather events, such as hurricanes, dust storms, and droughts. These studies presented findings from 30 high-income countries, 17 middle-income countries, and 1 low-income country. The strength of evidence was rated as sufficient for extreme temperature; ground-level ozone; tropical storms, hurricanes, and cyclones; and dust storms. Evidence was limited for wildfire smoke and inadequate for drought and mudslides. Exposure to extreme temperature was associated with increased cardiovascular mortality and morbidity, but the magnitude varied with temperature and duration of exposure. Ground-level ozone amplified the risk associated with higher temperatures and vice versa. Extreme weather events, such as hurricanes, were associated with increased cardiovascular risk that persisted for many months after the initial event. Some studies noted a small increase in cardiovascular mortality, out-of-hospital cardiac arrests, and hospitalizations for ischemic heart disease after exposure to wildfire smoke, while others found no association. Older adults, racial and ethnic minoritized populations, and lower-wealth communities were disproportionately affected.

CONCLUSIONS AND RELEVANCE Several environmental stressors that are predicted to increase in frequency and intensity with climate change are associated with increased cardiovascular risk, but data on outcomes in low-income countries are lacking. Urgent action is needed to mitigate climate change–associated cardiovascular risk, particularly in vulnerable populations.

Supplemental content

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Author Affiliations: Author affiliations are listed at the end of this article.

Corresponding Author: Dhruv S. Kazi, MD, MSc, MS, Beth Israel Deaconess Medical Center, 375 Longwood Ave, MS448, Boston, MA 02215 (dkazi@bidmc.harvard.edu).

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Cardiovascular disease (CVD) is the leading cause of morbidity and mortality globally.[1] Substantial improvements in CVD prevention and treatment have produced a 33% decline in age-adjusted CVD mortality in the past 2 decades,[1] but climate change may undermine this progress. Combustion of fossil fuels and other human activities over the past 150 years have greatly increased the atmospheric concentrations of heat-trapping greenhouse gases, such as carbon dioxide and methane, and caused climate change, which includes long-term shifts in average weather patterns, disturbance of ecosystems, and rising sea levels (**Table**).[2,3] A core feature of climate change is global warming. Earth is now 1.4 °C (2.5 °F) warmer than in the late 19th century, and the 10 warmest years on record have all occurred in the past decade[4-6] (**Figure 1**).

Climate change may affect cardiovascular health through several pathways (**Figure 2**). First, exposure to environmental stressors produces physiologic changes, such as increased heart rate and plasma viscosity with extreme heat exposure or local and systemic inflammation after inhalation of airborne particulate matter.[7-11] Second, coping with extreme weather events increases stress, anxiety, and depression, and these adverse mental health effects may contribute to cardiovascular risk.[12] Third, extreme events like hurricanes or floods disrupt health care infrastructure and delivery (eg, through power outages or disrupted supply chains).[13] Fourth, long-term socioeconomic effects of climate change may adversely affect cardiovascular health. For instance, changing rainfall patterns, increasing temperatures, and saltwater intrusion into aquifers are projected to produce declines in agricultural productivity in many parts of the world; the resulting food insecurity may compromise nutritional quality and cardiovascular health.[14] Climate-related migration will change where we seek and supply cardiovascular care. Rising sea levels may damage existing health care and transportation infrastructure, compromising health care access and delivery. Collectively, these pathways have the potential to undermine the cardiovascular health of the population, but the magnitude and the populations that will be particularly susceptible are uncertain.

Therefore, we undertook a systematic review to summarize the associations between climate change–related events and cardiovascular health, clarify implications for clinicians and health systems, and identify knowledge gaps to direct future investigation.

Key Points

Question Is there an association between climate change–related environmental stressors and cardiovascular health outcomes?

Findings In this systematic review of 492 observational studies, exposure to climate change–related environmental stressors like extreme temperature and hurricanes was associated with increased morbidity and mortality from cardiovascular disease, while increased risk after exposure to wildfire smoke was less certain. Older adults, individuals from racial and ethnic minoritized groups, and lower-wealth communities were disproportionately affected, while data on outcomes in low-income countries were lacking.

Meaning Urgent action is needed to reduce greenhouse gas emissions and lower climate change–associated cardiovascular risk in vulnerable populations.

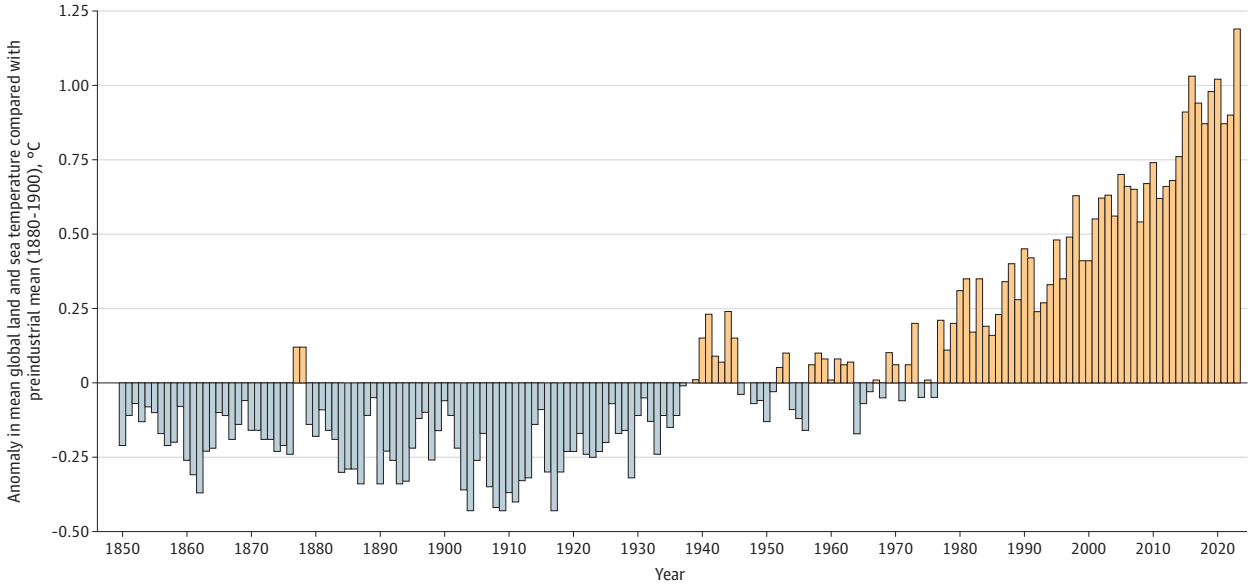
Table. Key Terminology in Climate Change

Term	Description
Climate change	Long-term shifts in global temperatures and weather patterns. These shifts may be natural, such as through variations in the solar cycle. However, since the 1800s, human activities have been the undisputable primary driver of climate change, primarily due to burning fossil fuels, such as coal, oil, and gas. Global warming is one component of climate change, which is causing disruption of ecosystems and rising sea levels
Global warming	Long-term heating of Earth's surface observed since the preindustrial period (between 1850 and 1900) due to human activities, primarily fossil fuel burning, which increases heat-trapping greenhouse gas levels in Earth's atmosphere. Rising land and water temperatures set up positive feedback cycles: because water reflects less heat than ice, melting of polar ice caps contributes to further warming. Similarly, melting of the tundra ice exposes trapped carbonaceous material that releases additional carbon dioxide as it decays, setting up a vicious cycle
Heat wave	A period of abnormally hot weather. The temperature threshold and duration of heat that is used to define a heat wave varies substantially by location, season, and study design. Adverse health outcomes vary by location and the population in consideration, but they often increase in frequency starting on the first day of high temperatures
Cold spell	A period of abnormally cold weather. The temperature threshold and duration of cold that are used to define a cold spell vary substantially by location, season, and study design. Adverse health outcomes vary by location and the population in consideration, and they may begin to increase in incidence on the first day of cold temperatures or be delayed by a few days
Ground-level ozone	Ground-level ozone, also known as *tropospheric ozone*, is an air pollutant generated by chemical reactions between oxides of nitrogen and volatile organic compounds. This occurs when pollutants emitted by cars, power plants, industrial boilers, refineries, chemical plants, and other sources chemically react in the presence of sunlight. Higher temperatures accelerate the production of ground-level ozone
Climate penalty	Amplification of air pollution by climate change. For instance, higher temperatures increase production of ground-level ozone, both of which are associated with worse health outcomes. This is of particular concern in Asia, which is home to a quarter of the world's population and where many countries are already grappling with enormous epidemics of premature cardiovascular disease
Carbon sinks	Natural resources, such as forests and oceans, that absorb more carbon dioxide than they release into the atmosphere

Methods

We searched PubMed, Embase, Web of Science, and Cochrane Library for peer-reviewed English-language publications from January 1, 1970, through November 15, 2023, that evaluated associations of (1) extreme ambient temperatures; (2) wildfires and resulting particulate air pollution; (3) ground-level ozone; (4) extreme weather events, such as hurricanes, dust storms, or drought; (5) sea level rise; (6) saltwater intrusion; and (7) climate-related migration with acute cardiovascular events (ie, ischemic heart disease, heart failure, cardiac arrest, arrhythmias, and stroke), cardiovascular mortality, and CVD health care utilization. We excluded studies that examined only the well-established causal relationship between nonwildfire-sourced particulate air pollution and CVD[12,15] or that exclusively focused on occupational exposures. Additional studies were identified through a review of the bibliographies of relevant publications (see eTable 1 in the Supplement for the full search strategy and included health outcomes). The protocol was registered in the International Prospective Register of Systematic Reviews and follows the Preferred Reporting Items for Systematic Reviews and Meta-

Figure 1. Global Temperature Trends, 1850 to 2023



Negative and positive deviations from the average 20th-century land temperature from 1850 to 2023 are shown. Despite year-on-year variability, a clear trend of warming temperatures is noted. All 10 of the warmest years on record have occurred in the past decade, and 2023 was the warmest year on record since recordkeeping began in 1850. Data are from the National Centers for Environmental Information, National Oceanic and Atmospheric Administration.[6]

Analyses (PRISMA) reporting guidelines.[16,17] Since the review exclusively used publicly available data, the institutional review board at Beth Israel Deaconess Medical Center deemed that it did not constitute human subjects research and did not require informed consent.

Two investigators independently screened all included articles. For studies that met inclusion criteria, we extracted study design, exposure assessment, association of exposure with study outcomes, and, if reported, lag structure and observed heterogeneity.

The quality of studies was evaluated using the Navigation Guide framework for reviews of observational studies in environmental health.[18-20] Briefly, we assessed each study for risk of bias (overall and separately for exposure, outcome, and confounders), evaluated the quality of evidence across studies, and examined the strength of evidence across studies (eAppendix and eTable 2 in the Supplement). Country-level income category was assigned using the World Bank 2021 classification.[21] Race and ethnicity, where available, were reported as defined by individual studies. Study-level estimates were qualitatively synthesized as substantial study design differences precluded quantitative meta-analysis. The review was performed using Covidence systematic review software (Veritas Health Innovation).

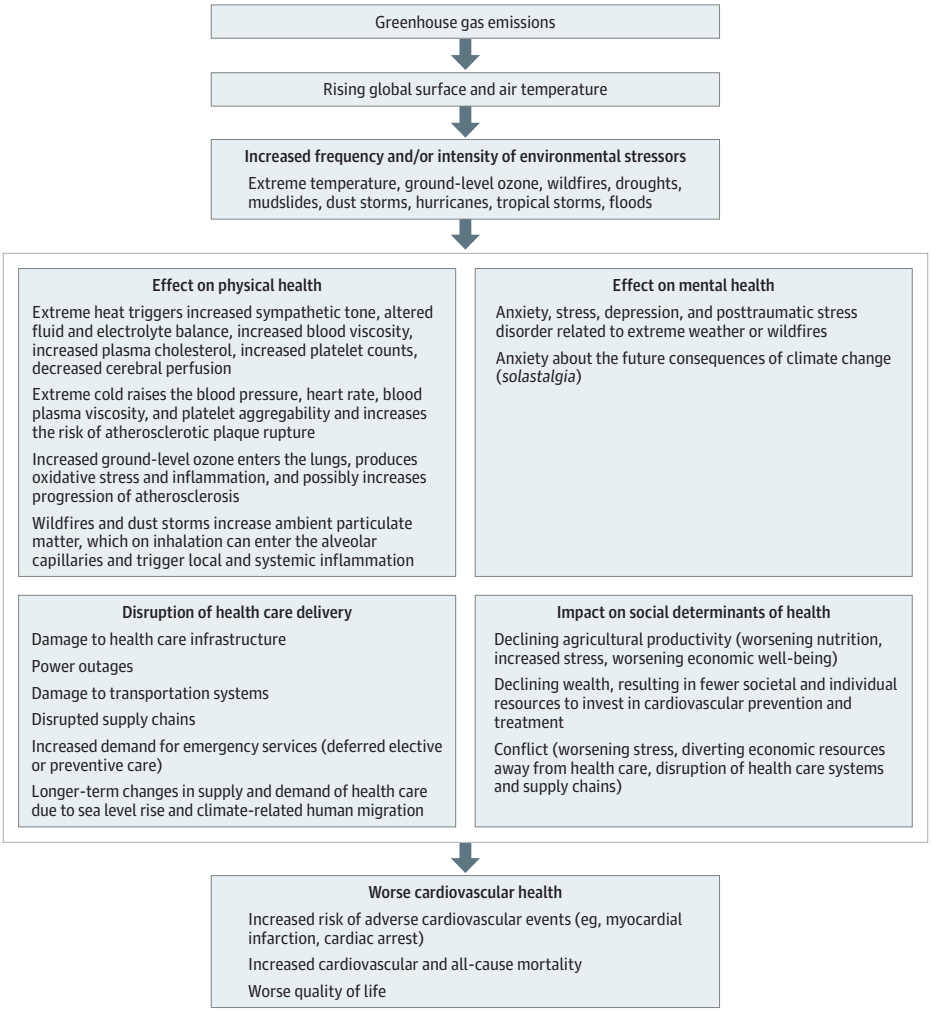
Results

Two investigators independently screened 20 798 articles, of which 2564 were selected for full-text review based on relevancy of titles and abstracts (**Figure 3**). A total of 492 studies met inclusion criteria (eTable 3 in the Supplement), including 182 extreme temperature (167 extreme heat, 97 extreme cold, 82 examining both), 210 ground-level ozone, 45 wildfire, and 63 extreme weather event studies (Figure 3). We identified no studies evaluating the association between sea level rise, saltwater intrusion, or climate-related migration and cardiovascular outcomes. The studies reported data from 30 high-income countries, 13 upper-middle–income countries, 4 lower-middle–income countries, and 1 low-income country (**Figure 4**). All studies were observational in design. A total of 446 studies (91%) were rated with low risk or probably low risk of bias (eFigure in the Supplement). Across all studies, the quality of evidence was rated as high for extreme temperature, hurricanes, and dust storms; moderate for ozone and wildfire smoke; and low for other exposures. The overall strength of evidence was rated as sufficient for extreme temperature, ozone, hurricanes, and dust storms (ie, the conclusion is unlikely to be strongly affected by the results of future studies); limited for wildfire smoke (ie, the observed outcomes could change as more information becomes available); and inadequate for floods, drought, and mudslides (ie, more information may allow an assessment of associations).

Extreme Heat and Heat Waves

The majority of studies examining extreme heat exposure reported an association with increased cardiovascular mortality (87 of 101 studies [86%]) (eTable 4 in the Supplement). For instance, in a study of all counties in the contiguous US, each additional day of heat exposure (defined as heat index ≥90 °F [32.2 °C] and in the 99th percentile of the maximum heat index for that day) was associated with a 0.12% (95% CI, 0.04%-0.21%; $P = .004$) increase in monthly cardiovascular mortality among adults 20 years or older.[22] The authors estimated that between 2008 and 2017, an estimated 5958 (95% CI, 1847-10 069) excess CVD-related deaths were asso-

Figure 2. Climate Change and Cardiovascular Health



Climate change may adversely affect cardiovascular health through several pathways, including direct effects on physical and mental health and indirect effects from disruption of health care delivery or worsening social determinants of health. The relative importance of each of these mechanisms may vary by community and over time, but collectively they have the potential to undermine the substantial gains in cardiovascular health achieved globally in recent decades.

ciated with heat exposure.[22] Alahmad et al[23] found similar results in a multicountry cohort from 567 cities in 27 countries: extreme heat (99th percentile) was associated with higher risk of dying of any CVD, ischemic heart disease, stroke, and heart failure. Since the risk typically increased starting on the day of exposure, short lags fully captured the association of extreme heat and heat waves with CVD.

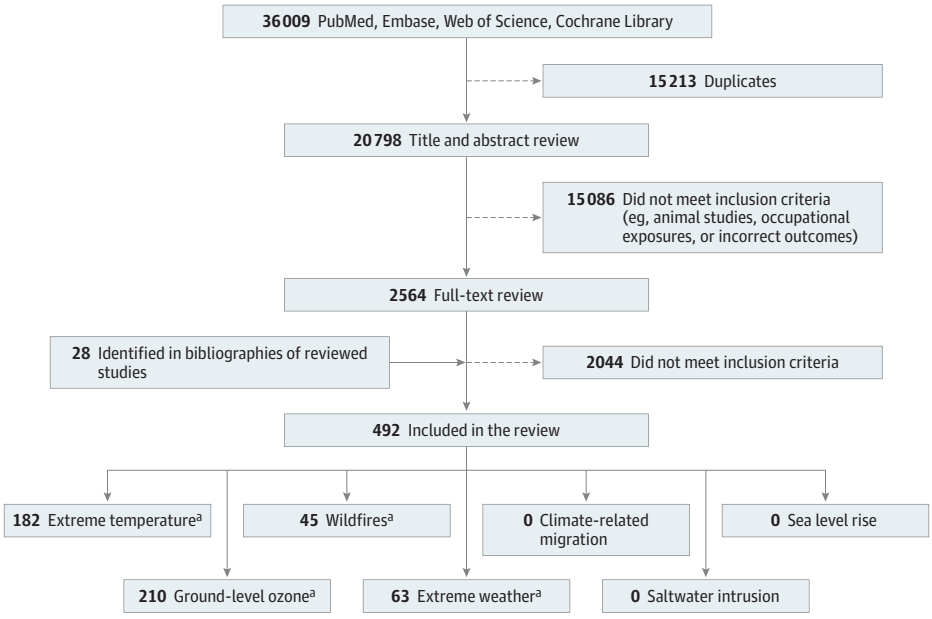
Among a subset of studies that examined heat waves, ie, sustained periods of high temperature typically defined as lasting 2 or more days, 24 of 28 (86%) reported an association with increased cardiovascular mortality. Cardiovascular risk increased with higher temperatures and longer heat waves.[24] Studies examining the association of extreme heat or heat waves with cardiovascular morbidity or health care utilization found less consistent results than studies examining cardiovascular mortality (35 of 69 morbidity studies [51%] reported a positive association) (eTable 4 in the Supplement).

The association between heat and CVD varied by characteristics of the exposed population and by location. Being older than 65 years, being male, being from racial or ethnic minoritized populations, having preexisting cardiovascular or pulmonary conditions, and being employed in outdoor work were associated with increased CVD risk following heat exposure.[22,24] Residence in urban heat islands—areas warmer than surrounding areas due to the relative lack of vegetation, increased presence of heat-absorbing artificial surfaces (ie, concrete), and inefficient ventilation of warm air—was associated with increased risk of CVD,[25] whereas access to air-conditioning was protective. There was marked regional variation, with cardiovascular hospitalizations increasing at lower temperatures in cooler climates than in warmer climates.

Extreme Cold and Cold Spells

Although climate change is primarily projected to increase episodes of extreme heat globally, some regions may paradoxically experience increases in extremely cold weather due to arctic ice melt and changes in atmospheric circulation patterns and ocean currents.[26] Forty-nine of 60 studies (82%) found associations between cold exposure and cardiovascular mortality, but the magnitude of the association ranged widely (from 3%-172% increase, varying by region and temperature thresholds used) (eTable 5 in the Supplement).[27,28] This association appeared to persist after accounting for seasonality and the concurrent burden of influenza cases (which may confound the association of

Figure 3. Preferred Reporting Items for Systematic Reviews and Meta-Analyses Flow Diagram



PubMed, Embase, Web of Science, and Cochrane Library databases were searched for relevant publications from January 1, 1970, through November 15, 2023. Two investigators independently screened the titles and abstracts of 20 798 articles, of which 2564 were considered for full-text review. A total of 492 studies were included in the final analysis.

[a]Six studies assessed both extreme temperature and ground-level ozone, 1 study assessed both extreme temperature and wildfires, and 1 study assessed both wildfires and extreme weather (dust storms).

extreme cold with cardiovascular outcomes). Longer lag periods were required to capture the full association of cold with cardiovascular mortality because the increased risk peaked days to weeks after cold exposure.[25] Among a subset of 11 studies evaluating cold spells, defined as extreme low temperatures lasting 2 or more days, 10 studies (91%) reported an association with increased CVD mortality.

The majority of studies (33 of 43 [77%]) demonstrated an association between cold exposure and increased cardiovascular morbidity or health care utilization. For instance, cold spells were associated with increases in CVD-related emergency department visits in Canada[29] and stroke hospitalizations in Australia.[30]

Women and older individuals were more susceptible to the increased cardiovascular risk associated with extreme cold exposure.[31,32] Differences in outcomes by socioeconomic level appeared to be less pronounced than with heat exposure.[25]

Ground-Level Ozone

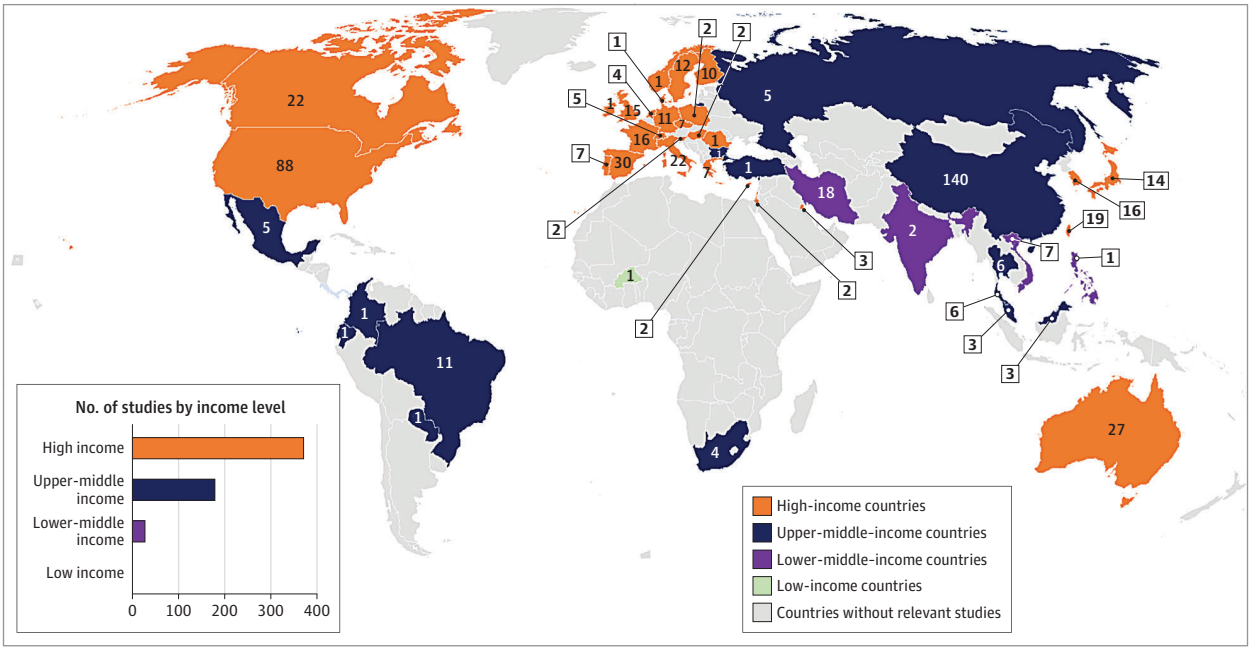
High temperatures increase ground-level ozone production by accelerating photochemical reactions involving oxides of nitrogen and volatile organic compounds. Of studies that evaluated increased ground-level ozone concentrations, 44 of 71 (62%) identified an association with increased CVD mortality (eTable 6 in the Supplement). The association with cardiovascular morbidity was less consistent: 82 of 143 studies (57%) reported increased CVD morbidity, 51 (36%) reported no change, and 10 (7%) reported a negative correlation. In studies based out of the United States and France, ozone exposure after a myocardial infarction was associated with increased risk of recurrent ischemic events (cerebral or cardiac; odds ratio [OR], 1.07 [95% CI, 1.02-1.14] per 10 μg/m^3 in straight 8-hour mean ambient ozone concentration), worse anginal symptoms, and higher cardiovascular mortality.[33,34] In contrast, a study from Boston, Massachusetts, of more than 15 000 patients found no significant correlation between elevated ground-level ozone and admission for myocardial infarction (proportional increase, 0.90% [95% CI, −8.36% to 6.55%]).[35]

A positive interaction between ozone level and temperature on adverse cardiovascular events was observed in 11 of 16 studies (69%), with higher levels of ozone amplifying the association of high temperature or high temperature amplifying the association of ground-level ozone exposure.[36] For instance, an increase in the 24-hour mean ambient ozone concentration was associated with increased cardiovascular mortality when the temperature was above the 75th percentile but not when temperatures were less than the 25th percentile.[37]

Wildfires

The 45 studies evaluating the association between wildfire smoke and CVD used varying definitions of fire exposure (eg, satellite imagery of smoke vs ground-level monitoring of particulate pollution) and outcomes (eTable 7 in the Supplement). As a result, the findings were less consistent: 4 of 10 studies (40%) examining the association with cardiovascular mortality found a positive association, whereas 6 of 10 (60%) did not. A large study using a global chemical transport model to estimate wildfire-related concentrations of particles 2.5 μm or less in diameter (PM2.5) and daily death counts from 749 cities in 43 countries and regions found a 1.7% (95% CI, 1.2%-2.1%) increase in the pooled relative risk (RR) of cardiovascular mortality associated with a 10-μg/m^3 increase in the 3-day moving average of wildfire-related PM2.5 concentrations.[38] However, no significant association was seen with Australian bushfire smoke using particulate matter data from fixed monitoring sites.[39] Because wildfire smoke can be carried by the wind over very long distances, the association with CVD outcomes was detectable hundreds of miles from the source of the fire.

Figure 4. Countries With Studies Examining the Association Between Climate Change and Cardiovascular Health



The 492 studies that met inclusion criteria for this systematic review reported data from 30 high-income countries, 13 upper-middle–income countries, 4 lower-middle–income countries, and 1 low-income country. Numbers indicate the number of included studies from each country. Several studies included data from more than 1 country. The dearth of studies from low- and middle-income countries is problematic both because of the large number of people at risk and because of the greater expected impact of climate change in these countries.

Studies also reported variable associations with cardiovascular morbidity or health care utilization, with 16 of 37 studies (43%) reporting a positive association. Of these, the strongest associations were observed for increased emergency department visits or hospitalization for ischemic heart disease[40-42] and cardiac arrest.[40,43-45] Wildfire smoke exposure was associated with more emergency department visits for heart failure, arrhythmias, and hypertension.[40,42,46,47] Among studies that reported an association with CVD, the association peaked on lag days 1 to 3 but extended up to a week after smoke exposure.[40,48,49]

Populations with lower baseline air pollution exposure, older adults, and residents of lower-wealth communities had larger increases in adverse CVD outcomes associated with wildfire smoke exposure.[40,46,50] For instance, in Australia, Indigenous people exposed to wildfire smoke were more likely to be hospitalized for ischemic heart disease than non-Indigenous people (OR, 1.71 [95% CI, 1.14-2.55]) despite similar exposure levels.[47]

Extreme Weather Events

Hurricanes or Cyclones, Floods, and Mudslides

Of studies examining the association of hurricanes or cyclones (n = 17), floods (n = 3), and mudslides (n = 1), the majority reported increased CVD mortality (8 of 9 studies [89%]) and worse cardiovascular morbidity (17 of 20 studies [85%]) during these events (eTables 8-10 in the Supplement). Notably, the increased CVD risk outlasted the extreme weather event in several studies. For instance, among US adults 65 years or older exposed to Hurricane Sandy, cardiovascular morbidity was greater during the storm than during similar periods before and after the storm (rate ratio, 2.65 [95% CI, 2.64-2.66]),[51] and risk remained elevated up to 12 months after the storm (rate ratio, 2.64 [95% CI, 2.64-2.65]).[51] Disrupted health care access due to Hurricane Sandy was also associated with worse blood pressure control among US veterans after 2 years.[52] Women and older adults may be at greater risk of adverse cardiovascular events from hurricanes.[53,54] Hurricanes also affected mental health, an important determinant of CVD risk. Hurricane Katrina survivors who developed posttraumatic stress disorder or depression were more likely to require hospital admission or die of CVD.[55,56] Given the small number of studies that examined floods and mudslides, their association with cardiovascular outcomes was uncertain (eTables 9 and 10 in the Supplement).

Dust Storms

Of studies examining the association between dust storms and adverse CVD outcomes (n = 30), a majority reported an association with increased CVD mortality (12 of 19 studies [63%]) or CVD morbidity (9 of 12 studies [75%]) (eTable 11 in the Supplement). Dust storms were associated with an increase in the odds of hospitalization for myocardial infarction with nonobstructive coronary artery disease (OR, 1.65 [95% CI, 1.18-2.29]) in Japan[57] and with a relative increase in mortality from ischemic heart disease (RR, 1.18 [95% CI, 1.02-1.35]) in China.[58]

Drought

Four studies examined the association of drought with CVD, all of which adjusted for temperature (eTable 12 in the Supplement). Of 3 studies that examined cardiovascular mortality, 2 reported a small

but statistically significant increase in cardiovascular mortality during drought compared with nondrought reference periods. Drought was associated with worse cardiovascular outcomes in Portugal (RR for cardiovascular mortality, 1.01 [95% CI, 1.00-1.02])[59] but not in the United States.[60]

Discussion

This systematic review of 492 studies yields several key insights regarding the association between climate change–related environmental stressors and cardiovascular health. First, most included studies found that extreme ambient temperatures, ground-level ozone, and severe weather events, such as hurricanes and dust storms, were associated with adverse cardiovascular outcomes. On the other hand, the association with adverse cardiovascular outcomes was less certain for exposure to wildfire smoke and extreme weather events, such as floods, mudslides, and drought. Second, the temporal association between the exposure and cardiovascular events was variable: the increased risk was observed on the day of the exposure in the case of some exposures, such as extreme heat, or delayed days to weeks in other cases, as in the case of extreme cold. For some environmental exposures, the increased risk persisted well beyond the inciting event. For instance, increased cardiovascular risk was observed to persist 12 months after a severe storm. Third, we found evidence of an interaction among some stressors: heat-fueled production of ground-level ozone amplified the increased cardiovascular risk associated with high temperatures. This is of particular concern in Asia, which is home to a quarter of the world's population and where many countries are already grappling with extreme temperatures, high concentrations of ozone and other pollution, and epidemics of premature CVD. Fourth, people living hundreds of miles from the source were observed to experience increased CVD risk, as with wildfire smoke and dust storms. Fifth, while all segments of the population were affected in some way, older adults, individuals from racial and ethnic minoritized groups, and lower-wealth communities had disproportionately higher climate change–associated CVD risk. This may have been due to differences in baseline health and nutrition status, access to health care, and available resources to respond to extreme weather.[25] Thus, climate change may compound health inequities that arise from socioeconomic disadvantage and structural racism.[61]

This review identified major knowledge gaps and priority areas for future investigation. Only 1 study was conducted in a low-income country and only 5 were based in Africa. This gap is particularly alarming given expected greater harms of climate change in low- and middle-income countries.[62] Studying the health effects of climate change in low-income countries will require investments in both environmental measurements and surveillance systems for accurate collection of health data. The traditional observational study designs used in the included studies precluded causal attribution; future studies applying newer causal inference frameworks should address this limitation. Future studies should examine whether the association varies by exposure subtypes (eg, whether wildfires are burning natural vegetation or building materials), characterize the sequelae of recurrent exposures (eg, consecutive summers of active wildfires), and clarify the biological and socioeconomic mechanisms underlying the observed association between environmental exposures and CVD outcomes. For instance, although the association of environmental exposures with long-term CVD outcomes may be partially explained by disruption in health care delivery, changes in health care–seeking behavior, and declines in mental health, further defining causal mechanisms (eg, epigenetic changes resulting from chronic stress) may help identify solutions. Because of substantial individual variability in risk, a climate change CVD risk score that helps clinicians identify patients at greatest risk of adverse cardiovascular outcomes with environmental stressors is urgently needed.[63,64] Future studies should help identify interventions to mitigate climate change–associated cardiovascular risk, such as the use of high-efficiency particulate air purifiers during periods of high levels of wildfire smoke.

Despite these knowledge gaps, our findings have important clinical implications. Clinicians should consider evaluating each patient's CVD risk from climate change exposures based on individual, community, and health system attributes.[65] For instance, does the patient have higher-than-average exposure to environmental stressors (eg, employment that requires outdoor work), higher susceptibility (eg, presence of cardiorespiratory comorbidities), or limited resources to avoid the exposure (eg, housing without air-conditioning)? Clinicians should be aware that heat-associated cardiovascular risk varies by community, paradoxically increasing at lower temperatures in cooler areas (such as the northwestern US, where homes do not typically have air-conditioning) compared with areas accustomed to high temperatures (such as the southwestern US, where air-conditioning is widely available).[29] Conversely, cold-associated cardiovascular risk is greater in the southern US than in the northern US.[25] Thus, local data are necessary to guide policy and clinical practice. In regions with frequent wildfire smoke days, susceptible patients should learn how to interpret local air quality indices and stay indoors during periods of high wildfire-smoke levels. In areas prone to extreme weather events, such as hurricanes or flooding, clinicians should assist patients in developing contingency plans to ensure uninterrupted access to medications and health care as needed. Clinicians, who are trusted members of their communities, can also effectively advocate for climate change adaptation and mitigation and improved air quality, which can have immediate benefits to cardiovascular health.

This review also highlights the need for health systems to anticipate and address climate change–related threats to their infrastructure. This will require regular vulnerability assessments and implementation of resilience plans for operations and facilities, such as installing backup flood-resistant power generators. Careful attention should be paid to supply chains, as disruptions may have widespread consequences (eg, when Hurricane Maria's landfall in Puerto Rico led to protracted national intravenous fluid shortages).[13] Since high-quality cardiovascular care requires long-term capital investments and a specialized workforce, long-term planning of cardiovascular services should incorporate climate-related human migration and threats to existing infrastructure. Finally, health systems in high-income countries are major greenhouse gas emitters, especially from supply chains and pharmaceuticals.[66] Reducing these emissions will require a transition off of fossil fuels, judicious use of pharmaceuticals and procedures with carbon-intensive supply chains, and divestment of financial investments from carbon-

intensive industries.[67] Health systems of the future must be both climate resilient and climate responsible.

Limitations

Our study has a few limitations. Study heterogeneity, particularly with regard to how exposures are ascertained and quantified, limits interstudy comparability. For instance, there is no universal definition of what constitutes extreme heat, how many days of extreme heat constitute a heat wave, or how one measures wildfire smoke exposure. Universal definitions would enhance comparability among studies and allow clinicians and policymakers to apply the findings to their own contexts. Our evaluation of temperature focused on studies examining the association of extreme temperature and cardiovascular health and therefore excluded studies examining more moderate but nonoptimal temperatures. Our analysis was restricted to studies that examined fatal and nonfatal cardiovascular outcomes and therefore cannot address questions about underlying mechanisms or potential mitigation strategies, which are the focus of future work.

Conclusions

Exposure to climate change–related environmental stressors is associated with an increased risk of CVD mortality and morbidity, but persistent knowledge gaps include the lack of studies in low-income countries, the long-term cardiovascular sequelae of recurrent environmental events, and the interplay between climate change and social determinants of health. Continued gains in cardiovascular health require urgent action to identify and implement cost-effective interventions to reduce climate change–associated CVD risk, particularly in vulnerable populations.

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Author Affiliations: Richard A. and Susan F. Smith Center for Outcomes Research, Beth Israel Deaconess Medical Center, Boston, Massachusetts (Kazi, Liu, Al-Roub, Chaudhary, Kramer); Department of Medicine, Harvard Medical School, Boston, Massachusetts (Kazi, Kramer, Rice); Division of Cardiology, Beth Israel Deaconess Medical Center, Boston, Massachusetts (Kazi, Bernstein); Department of Cardiology, Weill Cornell Medical Center, New York, New York (Katznelson); Knowledge Services, Beth Israel Deaconess Medical Center, Boston, Massachusetts (Young, McNichol); John A. Paulson School of Engineering and Applied Sciences, Harvard University, Cambridge, Massachusetts (Mickley); US Environmental Protection Agency, Durham, North Carolina (Cascio); Center for Climate, Health, and Global Environment, Harvard T.H. Chan School of Public Health, Boston, Massachusetts (Bernstein); Division of General Pediatrics, Boston Children's Hospital, Boston, Massachusetts (Bernstein); Department of Pediatrics, Harvard Medical School, Boston, Massachusetts (Bernstein); Pulmonary, Critical Care & Sleep Medicine, Beth Israel Deaconess Medical Center, Boston, Massachusetts (Rice).

Author Contributions: Drs Kazi and Katznelson had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Drs Bernstein and Rice contributed equally.
Concept and design: Kazi, Katznelson, Liu, Chaudhary, McNichol, Mickley, Cascio, Bernstein, Rice.
Acquisition, analysis, or interpretation of data: Kazi, Katznelson, Liu, Al-Roub, Chaudhary, Young, Kramer, Cascio, Bernstein, Rice.
Drafting of the manuscript: Kazi, Katznelson, Liu, Al-Roub, Chaudhary, Young, Cascio.
Critical review of the manuscript for important intellectual content: Kazi, Katznelson, Chaudhary, McNichol, Mickley, Kramer, Cascio, Bernstein, Rice.
Statistical analysis: Kazi, Katznelson, Al-Roub, Chaudhary.
Obtained funding: Kazi.
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Supervision: Kazi, Rice.

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