

# 2021 Climate and Health Review – Uncharted Territory: Extreme Weather Events and Morbidity

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## Abstract

Extreme weather events (EWEs) affected health in every world region during 2021, placing the planet in “uncharted territory.” Portraying the human impacts of EWEs is part of a health frame that suggests public knowledge of these risks will spur support for needed policy change. The health frame has gained traction since the Paris COP21 (United Nations Climate Change Conference) and arguably helped to achieve modest progress at the Glasgow COP26. However, reporting rarely covers the full picture of health impacts from EWEs, instead focusing on cost of damages, mortality, and displacement. This review summarizes data for 30 major EWEs of 2021 and, based on the epidemiological literature, discusses morbidity-related exposures for four hazards that marked the year: wildfire smoke; extreme cold and power outages; extreme, precipitation-related flooding; and drought. A very large likely burden of morbidity was found, with particularly widespread exposure to risk of respiratory outcomes (including interactions with COVID-19) and mental illnesses. There is need for a well-disseminated global annual report on EWE morbidity, including affected population estimates and evolving science. In this way, the public health frame may be harnessed to bolster evidence for the broader and promising frame of “urgency and agency” for climate change action.

## Keywords

climate change, health, extreme weather events, morbidity

## Extreme Weather and Health In 2021

Characterizing another year of catastrophic extreme weather events (EWEs)—from Arctic cold in Texas to desert heat in Siberia—the Secretary-General of the World Meteorological Organization (WMO) summarized: The planet is in “uncharted territory”<sup>1</sup>. EWEs had devastating impacts on populations in all regions during the year. Portraying the human health impacts of major climate hazards such as EWEs has been seen as a compelling way to foster climate action<sup>2</sup>. EWEs shock and resonate with people<sup>3</sup>, and a health frame may help to convince the public and decision-makers of their self-interest in proactive climate policy<sup>2,4</sup>. Among elements of this health framing, the World Health Organization (WHO) has called the 2015 Paris Agreement “potentially the most important public health agreement of the century”<sup>5</sup>, while the Lancet *Countdown on Health and Climate Change* annually monitors and disseminates health and climate indicators, including those associated with EWEs such as heatwaves and wildfires<sup>2</sup>.

The health frame was highlighted at the major climate change event of 2021, the Glasgow United Nations

Framework Convention on Climate Change (UNFCCC) 26th Conference of the Parties (COP26) meeting, via such efforts as WHO’s 10-point *Health Argument for Climate Action* report<sup>6</sup> and a letter, endorsed by millions of health professionals, calling the climate crisis the “single biggest health threat facing humanity”<sup>7</sup>. While the COP26 outcome disappointed many—particularly in lower ambition of country commitments than needed and in failing to assure robust funding for low- and middle-income countries (LMICs)—nations succeeded in formally endorsing the 1.5 degree C goal, referred for the first time to “fossil fuels,” and set in motion reductions in coal and methane<sup>8</sup>. Arguably, the public health frame helped to achieve this

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modest progress<sup>7,9</sup>. Yet, observers have wondered if the health frame is sufficient to motivate people and policymakers to greater ambition<sup>4</sup>.

A second major climate event of 2021 was publication of the first installment of the Intergovernmental Panel on Climate Change Sixth Assessment Report (AR6)<sup>10</sup>. AR6 carries a message of urgency: Climate changes are “widespread, rapid, and intensifying”; touch every region; and affect human well-being inequitably. The report includes a chapter on EWEs that calls it “an established fact” that human-driven climate change has contributed to increased frequency and/or intensity of some EWEs<sup>11</sup>. AR6 also concludes that the effect of greenhouse gas reductions on global surface temperature could be “discernible...within around twenty years” and on air quality within several years<sup>10</sup>. Knowing this should increase public and policymaker support for climate reforms. With this in mind, climate scientist Michael Mann proposed in his 2021 book, *The New Climate War*, an “urgency and agency” framing<sup>12</sup>: The situation is code-red serious; but governments, firms, and societies have tools and strategies and can choose to act in time. Health can help to underpin this broader frame by providing “cogency”—that is, helping to develop and share relevant evidence in support of both urgency and agency. But to do so will require that more of the health evidence people care about reaches the public.

A look at reports on EWEs in 2021 reveals one reason health is challenged in making its case: The full picture of human impacts from such events is rarely conveyed. When governments, aid agencies, and meteorological organizations tabulate EWE tolls—in turn captured in media reporting—the economic cost of damage to assets is frequently the main measure; reports of mortality and, when available, estimates of evacuations or displacement are indicators most often used to capture human impact<sup>13–15</sup>. Yet the larger numbers of those affected—whether by exposure to hazards, risk of potential harms and losses, or actual reports of injuries and illness—are seldom provided. An exception illustrates the point: Typhoon Rai hit the Philippines in mid-December 2021 as a massive Category 5 storm and, according to the national disaster agency, caused \$460 million (all amounts in U.S. Dollars) in damages, took the lives of more than 400 people, injured 1,147, damaged 530,000 houses, forced evacuation of 500,000 people, and affected in some way an estimated 4.5 million—or nearly 10-fold the number displaced<sup>17</sup>. Such comprehensive reporting of human impact is rare. An estimate of all those affected by an event is one measure of broad human impact; for example, a partial review of 2021 EWEs in Europe found that floods and storms account for the largest share of those affected by EWEs<sup>18</sup>. Another measure is estimated population exposure to a specific EWE; for example, the *Lancet Countdown* tracks exposure to heatwaves (more than 3 million more person-days for older adults in 2020) and to wildfires (more than 70% of

countries reporting more days in 2020)<sup>19</sup>. Going one step further is actual post-event morbidity—for example, hospital admissions for injuries, infectious and respiratory disease, mental illness, and other outcomes associated with EWEs. Another approach, if data are available, is estimating morbidity based on exposed populations and association with outcomes reported in epidemiological reviews or other studies.

## A Fuller Picture of Human Impacts

The aim of this 2021 review is to illustrate the potential value of enhanced reporting of both EWE-exposed populations and actual and/or estimated morbidity, toward the broader goal of providing a fuller picture of human impact. To this end, available data on economic cost, mortality, and displacement for 30 of the major EWEs of 2021 were first aggregated from three sources: (a) the WMO’s report of “high-impact events” (annual reporting of EWEs based on inputs from member countries)<sup>13</sup>; (b) the U.S. National Oceanic and Atmospheric Administration (NOAA) billion-dollar disaster report (EWE damage cost estimates in the United States based on a predefined methodology)<sup>14</sup>; and (c) the nongovernmental relief agency Christian Aid’s 2021 EWE cost and human impact report (based on a variety of scientific, relief agency, and news media sources)<sup>16</sup>. Second, key hazard pathways of exposure to morbidity risk from EWEs in 2021 were inferred, together with population exposed, based on EWE type, location, and context. Associations of EWEs and morbidity were then synthesized based on epidemiological reviews and reports published during the year. The result is an indicative narrative perspective on population exposures and potential types of morbidity risks for the 30 EWEs.

As caveats, it should be clarified that the cost, mortality, and displacement data for these 30 events were incomplete. Where available, these were updated with more recent estimates, but the picture remains partial. Moreover, myriad other less catastrophic 2021 EWEs are not included. In addition, estimates of exposed populations rely on crude proxies, such as city or region population. It is also recognized that the epidemiological relationships between EWE exposures and morbidity, less well-studied than mortality in many cases, are often insufficient to robustly estimate population health burden<sup>20</sup>; and that many climate-related illnesses are not tracked at local or national levels in formal surveillance, making aggregated reporting more challenging<sup>21</sup>. This review focused on four EWE hazards that particularly marked 2021: wildfire smoke; extreme cold and power outages; extreme precipitation-related flooding; and drought.

## Cost, Mortality, and Displacement

The 30 major EWEs of 2021 affected people in every world region and occurred throughout the year (Table 1). They

include eight major cyclones (including Category 4 Hurricane Ida in the United States, an unusual “medicane” in the Black Sea, and Category 5 Typhoon Rai in the Philippines), two tornado outbreaks, seven extreme floods (including massive flooding in Henan, China, and in Germany), an unprecedented heatwave in the Pacific Northwest, three extensive wildfires (in Siberia, the North American West, and the Mediterranean), three extreme cold spells (including Texas Winter Storm Uri), five major droughts (including in the Colorado and Paraná River basins, as well as several in Africa), and a massive sandstorm in China. Of the total, about half occurred in high-income countries and half in LMICs. The hazards involved were extreme heat, wildfires, wildfire smoke, extreme cold, major cyclones and storms (including tornadoes) and related flooding and landslides, precipitation-related flooding, and drought.

### ***Economic Damage Largely Reflects Flood and Storm Impacts in High-Income Urban Areas***

Total damages of \$215 billion were reported for the 30 events, with floods and storms representing 70% (see Table 1). Three North American events (Storm Uri, Hurricane Ida, and the Pacific Northwest heatwave) accounted for half of the total, while major floods in Henan, China, and Germany accounted for a further 28%. The fact that many EWEs affected one or more populous, middle- or high-income city—among them Houston, Madrid, New Orleans, New York City, Shanghai, Sydney, Vancouver, and Zhengzhou—increased their potential for economic impact. Insurance coverage for all EWEs was 43% of total, indicating large gaps; 55% of damages from Hurricane Ida were insured<sup>22</sup>, 33% of flooding damages in Germany<sup>23</sup>, and only 17% of total EWE damages in Asia<sup>22</sup>. The cost of damages in low-income countries is not well-captured; of the 12 EWEs without cost estimates, 10 were in LMICs, and none of the droughts had cost estimates. Data from the United States suggest droughts are the second costliest disaster, after hurricanes<sup>24</sup>. Re-insurer estimates of total damages from all natural disasters in 2021 (including earthquakes) was \$280 billion<sup>22</sup>; at 77%, the 30 EWEs represent a large fraction of this estimate.

### ***Mortality Has Declined and Is Now Led by Extreme Heat, But Reports Do Not Likely Reflect True Impact***

A total of 3,490 casualties were reported for the 30 major events of 2021. Nearly one-third (1,037 deaths) were attributed to a single event, the June–July heatwave in the Pacific Northwest (see Table 1), when a wobble in the jet stream facilitated a persistent “heat dome” over the region—deemed by a rapid attribution study to be “virtually

impossible” without climate change<sup>25</sup>. Storms and flooding accounted for more than half of reported deaths, often from drowning; while the extreme cold of the Texas winter storm led to a reported 246 deaths, mostly from hypothermia. Death toll reports often change over time, due to additional information, missed counts or classifications, or other reasons. For example, one re-analysis found that as many as 750 may have died in the cold spell in Texas<sup>26</sup>. Droughts and floods caused the lion’s share of EWE-linked deaths in the past; however, early-warning systems and preparedness have led to a decline over several decades<sup>27</sup>. Heatwaves are now the deadliest extreme event, estimated by the Lancet *Countdown* to take the lives of an estimated 345,000 older adults globally in 2019<sup>19</sup>. This review has captured only a small portion of likely actual deaths associated with the full range of EWEs in 2021.

### ***Displacement, Driven Mainly by Floods and Storms, Affects Those Least Equipped to Adapt***

Floods, cyclones, and droughts affect large numbers of people through temporary evacuation and/or longer-term internal displacement; this is of particular concern because displacement affects disproportionately “those least equipped to recover and adapt,” as noted by the WMO<sup>27</sup>. Displacement of more than 4.5 million people was reported for the 30 EWEs in 2021 (see Table 1). Flooding in China and in South Sudan accounted for most displacements reported. Inconsistencies and gaps in the data are apparent, however, with estimates available for only 17 of the 30 events (particularly lacking for droughts). The United Nations High Commissioner for Refugees suggests that storms, droughts, and sea-level rise lead more than 20 million people to move within their countries annually<sup>28</sup>. The Internal Displacement Monitoring Center reported that 30 million people left their homes due to weather-related disasters in 2020; floods (14 million) and storms (14.6 million) were by far the largest causes of displacement<sup>29</sup>. The data reviewed here capture only a small share of the likely 2021 total.

### ***Adding Morbidity to Understand Impacts***

Examining morbidity from wildfire smoke; extreme cold and associated power outages; torrential, precipitation-driven flooding (including storm-related); and drought provides a fuller understanding of impacts due to these acute as well as slower onset events.

#### ***Wildfire Smoke: “Airpocalypse”***

With extreme heat and dry conditions, wildfires in 2021 were intense, fast-moving, and difficult to extinguish, and they

**Table 1.** Thirty large-scale extreme weather events, 2021.

Month	Event and data source	Location	Cost (\$B)	Deaths	Displaced	Population affected	Morbidity category
Jan	Winter Storm Filomena <sup>a</sup>	Spain, Portugal	1.7	5	NA	Madrid pop 3.2 M	I R
Feb	Winter Storm Uri <sup>a b c</sup>	Southeast U.S. (Texas), N Mexico	24.0	246	NA	10 M homes without power	I R D C B
Mar	Sandstorm <sup>a</sup>	China (Beijing)	NA	9	341	Beijing pop 21.7 M	R M
Mar	Floods <sup>a c</sup>	N S Wales, Australia	2.1	4	18,000	Sydney pop 5.3 M	I R D M
Mar	Tornado outbreak <sup>b</sup>	E U.S.	3.2	14	hundreds	40,000 homes without power	I M
Apr	Cyclone Seroja <sup>a</sup>	Indonesia, East Timor, Australia	0.7	272	21,000	74,325 homes affected	I R D M
Apr	Cold Wave <sup>a c</sup>	France	5.6	NA	NA	30% drop in wine production	M
May	Flash flooding <sup>a</sup>	Afghanistan (Herat, Badghis)	NA	84	9457	2600 homes destroyed	I R D M
May	Cyclone Tauktae <sup>c</sup>	India, Sri Lanka, Maldives	1.5	198	200,000	Coinciding w/peak COVID-19	I R D M
May	Cyclone Yaas <sup>c</sup>	India, Bangladesh	3.0	19	11,000	1.3 M affected	I R D M
Jun-Dec	Wildfires <sup>a b c</sup>	W U.S.	10.6	8	NA	31,000; smokewave in large U.S. cities	H R M
Jun-Jul	Heatwave <sup>a b c</sup>	Pacific NW (U.S. and Canada)	8.9	1037	NA	9 M heat alert, 3500 HRI hospital	H M
Jul-Aug	Wildfires <sup>a</sup>	Mediterranean Basin	NA	108	thousands	Hundreds of non-fatal injuries	H R M
Jul-Oct	Wildfires <sup>a</sup>	Russia (Siberia)	NA	NA	NA	Yakustk pop 0.3 M	H R M
Jul	Floods <sup>a c</sup>	N Europe (Germany, Belgium)	43.0	240	thousands	Thousands of homes without power	I R D M
Jul	Floods <sup>a c</sup>	China (Henan Province)	17.6	398	1.4 million	Henan pop 100 M, Zhengzhou 10.4 M	I R D M
Jul	Typhoon In-fa <sup>a c</sup>	China, Philippines, Japan	2.0	5	>300,000	Shanghai pop 26 M	I R D M
Jul	Flash flooding <sup>a</sup>	Afghanistan (Nuristan)	NA	113	NA	22,000 affected	I R D M
Jul-Nov	Floods <sup>a c</sup>	S Sudan	NA	20	1.7 million	>100,000 close to famine	I R D M N
Aug	Medicane Falchion <sup>a</sup>	Turkey (Black Sea Coast)	NA	77	NA	Landslides, flooding	I R D M
Aug-Sep	Hurricane Ida <sup>a b c</sup>	E U.S.	75.0	96	30,000	New Orleans pop 0.4 M, NYC 19.8 M	I R D M
Sep-Oct	Cyclone Gulab <sup>a</sup>	India, Pakistan, Oman, Iran	2.0	39	200,000	Flooding across India	I R D M
Nov	Floods <sup>a c</sup>	British Columbia, Canada	7.5	4	15,000	Significant agricultural losses	I R D M
Dec	Tornado outbreaks <sup>b</sup>	MW and SE U.S.	5.7	94	hundreds	Significant damage, loss of property	I M
Dec	Typhoon Rai <sup>d</sup>	Philippines	0.5	400	500,000	4.5 M; 1157 injured; 530,000 losses	I R D M
	Drought <sup>a</sup>	Paraná Basin (Brazil, Paraguay)	NA	NA	NA	Parana Basin pop 40 M	D M N
	Drought <sup>a b</sup>	Colorado Basin (Western U.S.)	NA	NA	NA	Colorado Basin pop 40 M	M
	Drought <sup>a</sup>	Madagascar	NA	NA	NA	1.14 M need food aid 400,000 famine	D M N V
	Drought <sup>c</sup>	Lake Chad (Cameroon)	NA	NA	NA	5.5 million	D M N V
	Drought <sup>c</sup>	E Africa (Kenya, Ethiopia, Somalia)	NA	NA	NA	10 M	D M N V

(continued)

Table 1. (continued)

Month	Event and data source	Location	Cost (\$B)	Deaths	Displaced	Population affected	Morbidity category
<b>Totals</b>			<b>214.6</b>	<b>3490</b>	<b>&gt; 4.5 M</b>		

<sup>a/</sup>WMO; <sup>b/</sup>NOAA; <sup>c/</sup>Christian Aid; <sup>d/</sup>Reuters (Note: Typhoon Rai occurred after publication of WMO, NOAA, and Christian Aid reports). Morbidity categories: I = injuries (including toxicological events such as CO poisoning); R = respiratory illnesses; D = infectious diseases; M = mental illness; N = malnutrition (including stunting, wasting), H = heat-related illness, C = cognitive decline, B = adverse birth outcomes, V = vector-borne disease.

generated toxic, traveling smoke plumes. The largest fires by area burned (18 million hectares) occurred in Siberia<sup>30</sup> and generated one of the most toxic air pollution episodes on record—an “airpocalypse” of smoke containing ammonia, benzene, and hydrogen cyanide—forcing the 320,000 residents of the city of Yakutsk indoors as PM<sub>2.5</sub> exceeded 1,000 micrograms/m<sup>3</sup> (10-fold the levels of some of the world’s most polluted cities); the smoke plume reached Ulaanbaatar, Mongolia, 2,000 miles away<sup>31</sup>. The North American wildfires occurring in the same season burned at least 3 million hectares in the Western United States and Canada<sup>32</sup>. One of largest, the Dixie fire in California, was so intense that it generated its own weather system of storm clouds and lightning, carrying a smoke-wave to major urban centers on the East Coast, nearly 3,000 miles away<sup>33</sup>. Heatwaves in 2021 also led to wildfires across the Mediterranean Basin. In Turkey, an inadequate public emergency response left residents fighting the blazes on their own<sup>34</sup>, while fires brought Greece its “greatest ecological disaster in decades,” and more than two dozen firefighters were among the victims in Algeria’s wildfires<sup>35</sup>. Wildfire PM<sub>2.5</sub> was elevated throughout much of this populous region for weeks<sup>36</sup>.

Wildfire smoke PM<sub>2.5</sub> is known to worsen respiratory conditions, including asthma and chronic obstructive pulmonary disease (COPD)<sup>37</sup>, and to increase risk of lower respiratory infections such as bronchitis and pneumonia<sup>38</sup>. Research in 2021 contributed to strengthening the evidence that PM<sub>2.5</sub> from wildfire smoke—which may contain residue from burned buildings and other materials—is also more toxic than ambient PM<sub>2.5</sub>. A review highlighted that wildfire smoke contains many of the carcinogenic components of cigarette smoke<sup>39</sup>, and an experimental study found it to induce both oxidative stress and DNA damage<sup>40</sup>. An observational study in Southern California found 10-fold more respiratory hospitalizations in those exposed to wildfire PM<sub>2.5</sub> compared to those exposed to the same amount of ambient PM<sub>2.5</sub><sup>41</sup>. Another study examining crowdsourced-data in California found PM<sub>2.5</sub> was three times higher indoors during wildfires, indicating the challenge of sheltering<sup>42</sup>. A review of wildfire smoke exposure found increased risk of COVID-19 infection<sup>43</sup>; firefighters were observed to have greater risk of COVID-19 severity<sup>38</sup>; while tens of thousands of COVID-19 cases in the U.S.

West in 2020 were likely attributable to exposure to wildfire PM<sub>2.5</sub>.<sup>44</sup> With the Siberia, Pacific Northwest, and Mediterranean wildfires, tens of millions were likely exposed to wildfire PM<sub>2.5</sub>, often in tandem with COVID-19 pandemic waves, suggesting a large global disease burden of new or worsened respiratory illness.

### *Extreme Cold: “Everything Gets Worse If You Don’t Have Electricity”*

In February, the Northern Hemisphere jet stream veered dramatically south, bringing Arctic freeze to parts of Southern Canada, the United States, and Northern Mexico and giving Texas its coldest spell in four decades<sup>45</sup>. The “deep freeze” led to the worst power outage in the state’s history, largely due to inadequately winterized natural gas infrastructure, which left more than 10 million homes without power and heat and many without water<sup>46</sup>. “Catastrophes...compounded one another in a true humanitarian crisis” as water pipes burst, shelters filled, and under-resourced communities felt the brunt of the impact<sup>47</sup>. More than 500 people were treated for carbon monoxide (CO) poisoning in Houston hospitals alone as people turned to generators and cars for warmth<sup>48</sup>. At the same time, millions of Mexicans experienced extreme cold and power outages, as a result of the country’s reliance on frozen Texas natural gas pipelines. “Catastrophic weather wasn’t contemplated in Texas or Mexico,” according to one observer<sup>49</sup>. Spain experienced similar extreme cold and snow in January, leading to power outages in Madrid, and hospitals filled with injuries<sup>50</sup>. In Cañada Real, Europe’s largest informal settlement on the outskirts of Madrid, these conditions brought respiratory infections and CO poisoning to those least able to protect themselves, with one person observing that “everything gets worse if you don’t have electricity”<sup>51</sup>.

As experience with polar vortex shifts grows, awareness of the harms from such devastating cold spells is increasing. Evidence suggests extreme cold increases risk of illness, particularly among the elderly and those with pre-existing cardiovascular disease (CVD) and respiratory illness<sup>52</sup>. In China, where cold is an ongoing health concern in some regions, studies found respiratory emergency department visits were more frequent<sup>53</sup>, as were asthma and upper respiratory infections in children<sup>54</sup>, during cold spells. A systematic review found cold

exposure associated with poorer cognitive function and memory in the elderly<sup>55</sup>. Winter storms in New York State were associated with increased morbidity from CVD, respiratory illness, and food- and water-borne diseases (stronger effects jointly with power outages)<sup>56</sup> and with higher COPD hospitalizations (power outages mediating a large share of the effect)<sup>57</sup>. A review found loss of power in ice storms to be the weather disaster most associated with negative birth outcomes<sup>58</sup>. With the cold disasters in Texas, Mexico, and Spain, many millions were likely exposed to days of extreme cold weather—including many days without power, heat, or water—suggesting risk of injuries and respiratory illness, as well as infectious disease, cognitive impairment in the elderly, and adverse birth outcomes.

### **Extreme, Precipitation-Related Flooding: “Stunned Scientists”**

Intense rainfall in July in Henan Province, China—home to 100 million people—buried this vast region under water; homes, infrastructure, and industry, including Apple and Nissan factories, were badly damaged<sup>59</sup>. An unprecedented 20 centimeters of rain fell in 24 hours in the capital Zhengzhou, exacerbating drainage vulnerabilities, flooding the subway, displacing more than 1 million<sup>60</sup>, and challenging the city’s nature-based “sponge-city” drainage infrastructure<sup>61</sup>. In the same month, intense rain fell across parts of Germany and Belgium, with up to 15 centimeters in 24 hours causing flash flooding and leaving residents and climate scientists alike “stunned” at the quantity of rain. Despite ample warning, “we weren’t expecting this amount of water,” as one resident observed<sup>62</sup>. People found themselves “knee-deep in sewage”<sup>63</sup>; in some towns, 80% of houses were uninhabitable, with mold-covered walls, and residents had to choose whether to rebuild or move<sup>64</sup>. The next month, Hurricane Ida rapidly intensified over a 24-hour period from a Category 1 to a Category 4 storm as it struck New Orleans, creating power outages affecting 1 million homes, putting tens of thousands under evacuation orders, and leading to a curfew to protect people from theft<sup>65</sup>. The hurricane then tracked northward, flooding populous urban areas in the Northeast United States, including New York City, where tens of thousands were displaced or had no running water, and half a million were under boil-water orders<sup>66</sup>.

In 2021, research added to knowledge of morbidity impacts from intense rainfall and rapid flooding in part through examination of experience with similar previous events. For example, studies of Hurricane Harvey in Houston found flooding was associated with increased emergency department visits for CO poisoning, insect bites, dehydration, hypothermia, intestinal infections, and pregnancy complications<sup>67</sup>; greater risk of upper respiratory and asthma symptoms, both a month and a year after the event<sup>68</sup>; and greater risk of hospitalization for toxicological

emergencies, trauma, and skin rashes in children<sup>69</sup>. A survey in Detroit found recurrent flooding to be common and household factors (eg, roof condition, foundation structure), particularly in rental units, to be important predictors of asthma<sup>70</sup>. A meta-analysis found flooding significantly increased risk of bacillary dysentery in China<sup>71</sup>. A systematic review of floods and mental health in LMICs found an association with post-traumatic stress disorder<sup>72</sup>, while a comprehensive review found a more than 90% likelihood of experiencing any psychosocial impact from all EWEs, particularly for those involving property damage and losses<sup>73</sup>. The widespread catastrophic flooding in populous areas of China, the Eastern United States, and North-Central Europe—including the low share of damages insured—suggest dozens of millions of people may have been exposed to risk of mental health effects, in addition to injury, asthma and other respiratory illness, gastrointestinal and skin infections, and pregnancy complications.

### **Drought: “The Next Pandemic”**

Today, drought is already widespread, affecting 19% of the global land surface<sup>19</sup>. Without more intentional water and land management, “drought will be the next pandemic,” according to the United Nations<sup>74</sup>. In 2021, drought on the Colorado River, which supplies water to 40 million people across seven U.S. states and Mexico, may have become the most severe in the last millennium; in August, the United States declared a water shortage on this lifeblood tributary of the American West, triggering mandatory water cuts<sup>75</sup>. A similar situation evolved in the Paraná River Basin, which provides water to 40 million people in Argentina, Brazil, and Paraguay<sup>76</sup>, with the latter particularly hard-hit due to its dependence on the river for its export-led agriculture<sup>77</sup>. Megacities such as São Paulo are promoting conservation to avoid crisis and rationing<sup>78</sup>. But droughts in low-income countries carry a higher burden: In Southern Madagascar, lack of rain this year may create the world’s first climate famine, as more than 1.1 million subsist on foraged locusts, termites, and cactus leaves<sup>79</sup>; *Médecins Sans Frontières* has reported tens of thousands of malnourished children with bilharzia, malaria, and respiratory infections<sup>80</sup>. In Cameroon, in the Lake Chad region, conflict over water has erupted between herders and farmers in an area plagued by drought for decades<sup>81</sup>. In China, the worst sandstorm in a decade reached Beijing from Mongolia in March, worsening air quality and forcing residents indoors<sup>82</sup>.

In 2021, rural and agricultural populations felt drought effects most acutely. In a review of health effects of drought in high-income countries, associations included water- and vector-borne disease, respiratory disease from air-borne dust, and mental health effects<sup>83</sup>. For example, farmers in the United States facing drought felt that job strain increased substantially, driven by psychosocial stress factors<sup>84</sup>. On the other hand, a review of drought impacts

on health in Africa found increased anemia, cholera, scabies, dengue fever, and child nutrition-related disabilities, including stunting and wasting<sup>85</sup>. Drought was associated with lower odds of completing childhood BCG, DPT, and polio vaccines, suggesting risk of future disease outbreaks<sup>86</sup>. In a systematic review, during droughts in India, the work burden on women and children increased, along with malnutrition and anemia<sup>87</sup>. Meanwhile, a review of experimental studies found a likely harmful effect of desert dust on asthma and respiratory infections, suggesting dust may be a platform for other chemicals that enhance its pulmonary toxicity<sup>88</sup>. Mega-droughts in the Colorado and Paraná River basins are bringing mental health-affecting water shortages to farming communities and threat of water rationing to urban dwellers, impacting 80 million people. Droughts in Madagascar, East Africa, and Lake Chad add millions to those likely exposed to risk of malnutrition and anemia, respiratory illness, infectious and vector-borne disease, and the dangers of armed conflict. The China sandstorm exposed millions to enhanced risk from respiratory illnesses.

## Conclusion and Recommendation

The total reported economic cost of the 30 major 2021 EWEs was \$215 billion, less than half of which was likely insured. However, cost estimates were lacking for multiple EWEs, mainly those in low-income countries. In terms of human toll, nearly 3,500 deaths were reported, although this figure is likely underestimated for these events and represents only a fraction of probable deaths from all EWEs during the year. Displacement of approximately 4.5 million people was reported for the 30 EWEs, although data were missing for many. A like figure for all EWEs during the year would be closer to 20–30 million, based on previous year's reporting<sup>28,29</sup>. The morbidity risks associated with the four hazards reviewed (wildfire smoke, extreme cold, precipitation-related flooding, and drought) included injuries and CO poisoning, respiratory illness, water- and food-borne infectious diseases, vector-borne diseases, mental illness, cognitive decline, adverse birth outcomes, and malnutrition (including anemia, stunting, and wasting). Added to the morbidity due to heat-related illness from heatwaves<sup>89,90</sup> and other hazard pathways not covered here, it seems likely the population exposed to injury and illness for the 30 EWEs reached dozens of millions. Based on various agency reports, an estimated 319 million were affected by weather disasters in 66 countries during 2018–2020<sup>27</sup>; more than 57 million were affected by weather disasters in Asia Pacific in 2021<sup>91</sup>; 40% of the U.S. population (approximately 130 million) lived in counties affected by weather disasters in 2021<sup>92</sup>; and 1.8 billion people experienced their country's hottest year on record in 2021<sup>93</sup>. Thus, when considering the full number and range of extreme weather hazards globally, several hundred million or more may have been exposed to morbidity risks in 2021.

Notably, all four of the EWE-morbidity pathways explored led to increased risk of respiratory illness. Given the current COVID-19 pandemic—and evidence suggesting interaction in the case of both wildfire smoke and cold exposure—attention to risk of respiratory illness in association with EWEs may be an important and compelling message. Such messaging may also be complementary with the WHO campaign on PM<sub>2.5</sub> air pollution contributing to millions of annual deaths<sup>5</sup>. Also noteworthy were increased risks across most EWE pathways of the “hidden costs”<sup>94</sup> of mental illness; this is especially acute considering the modest share of losses that are reportedly insured. Injuries were a third common cause of mortality across EWEs. Of concern, as previous studies have highlighted<sup>95</sup>, both data and studies were lacking for LMICs. Finally, the focus of this review was harm and risk associated with EWEs; however, success was also observed. For example, new flood defenses may have helped Manchester, United Kingdom, manage the impact of spring flooding<sup>96</sup>; the Netherlands was not as severely impacted by torrential summer rains as Germany due to its centuries-old water management infrastructure and a culture of preparedness<sup>97</sup>. Examining these experiences was beyond the scope of this review, but the topic warrants greater exploration and dissemination within the health frame.

The EWEs experienced in 2021 place society in uncharted territory. Across events and countries, those affected expressed shock at the extent, intensity, and rapidity of EWEs, even in situations where early warnings had been provided. However, lack of adequate warning and preparation was evident in many events. Distinguishing 2021 were unprecedented temperature extremes in opposing direction to prevailing seasonal weather patterns; as expressed by a former UK climate science advisor, it seems “nowhere is safe”<sup>98</sup>. The human toll of EWEs is likely to increase<sup>99</sup>. Agencies that disseminate data on EWEs provide an essential public service. To contribute to needed urgent public and policymaker action on the climate crisis—as well as to educate the public on how to prepare for continued and often catastrophic change—will require more consistent, regular data on the full human toll of EWEs. This is likely to involve greater cross-collaboration of meteorological, disaster management, public health, health care, and other agencies at local, national, and international levels. Such an effort provides an opportunity for public health agencies, which could take on leadership for coordination of such work. Localities are increasingly concerned about tracking and risk communication on morbidity<sup>100</sup>; efforts to build local climate and health surveillance in New York and Barcelona provide encouraging examples<sup>101,101</sup>.

There is need for a global annual report on EWE morbidity. A report of this type would complement existing EWE annual reporting and could help ensure a fuller picture of human impacts. Such a report could discuss major drivers of morbidity by hazard, update epidemiological findings,

provide estimates of population exposures and likely risks, and provide actual morbidity outcomes when available. Sharing its findings via the media could contribute to a more comprehensive public understanding of climate change-related risks. In this way, the public health frame may be further harnessed to bolster evidence for the broader, promising frame of urgency and agency for climate change action.


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### Supplemental Material

Supplemental material for this article is available online.

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