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Review article

Climate change and health care facilities: A risk analysis framework through a mapping review

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ABSTRACT

Introduction: Climate change (CC) has been identified as the biggest global health threat of the 21st century. Although health care facilities (HCF) play a central role in the care of populations, there has been no comprehensive assessment of the impact of CC on HCF. The objective of our study was to highlight the components of HCFs affected by CC through a mapping review of the literature.

Methods: To meet our objective, we first assessed the place of HCFs in relation to CC in the scientific literature and in the Intergovernmental Panel on Climate Change (IPCC) reports. Bibliometric data from the PubMed database were analyzed between 1979 and 2021 to assess the penetration of keywords on CC alone, and in relation to health and HCF in particular. Second, we analyzed the changes in HCF keywords in the IPCC reports. Finally, we conducted a mapping review in five databases, of the international scientific literature published between 1979 and 2019, and identified the components of HCF affected by CC using the Ishikawa diagram.

Results: From the 2000s, the number of publications on CC and HCF increased gradually with 137 articles in 2005, and even more sharply since 2008 with 358 articles published and 813 in 2021. Even though CC is only recently present in the biomedical literature, all climatic events (warming and heatwaves, droughts, wildfires, storms, hurricanes and cyclones, floods and sea-level rise, and other indirect effects) have had an impact on at least one component of HCF.

Conclusion: HCFs are already impacted, in all their components, by CC. By enhancing our understanding of the impacts of CC on HCF, this work could contribute to the engagement of health professionals in the implementation of mitigation and adaptation actions, thereby limiting the consequences of CC on patient care.

1. Introduction

Due to the massive increase in the emission of greenhouse gases in the atmosphere generated by human activities (e.g., transportation, agriculture and land use, industry, buildings, energy, healthcare systems), climate change (CC) affects the world through four mechanisms, known as climate drivers: increased mean temperature of the atmosphere and the oceans, rising sea level, ocean acidification, and more frequent and more devastating extreme weather events (e.g., floods, storms, wildfires, drought) (IPCC, 2013; World Meteorological

Organization, 2020a). Between 1995 and 2015, 90% of disasters were caused by weather-related events, leading to more than 600,000 deaths and 4.1 billion people injured or in need of medical assistance (UNISDR, 2015).

As a result, CC has been identified as the biggest global health threat of the 21st century (Costello et al., 2009), which makes it one of the greatest challenges of our time (WHO Chan, 2008). CC already has a negative impact on the ability of many countries to meet one of the UN's Sustainable Development Goals (SDGs) (World Meteorological Organization, 2020b). It has the potential to reverse the health and

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development gains of the last decades through three different pathways: i) direct impacts such as injuries or illnesses caused by extreme weather events including hurricanes or floods, ii) effects mediated through natural systems such as air pollution or vector-borne disease, and iii) effects heavily mediated by human systems such as mental stress or undernutrition (Watts et al., 2015; IPCC, 2014). The adverse effects on health are numerous and could cause illness at all ages, including during development (Salas and Solomon, 2019; Bekkar et al., 2020). CC could also exacerbate environmental problems that directly or indirectly amplify health risks such as heat-related illnesses, asthma and chronic respiratory disorders or mental health disorders (Salas and Solomon, 2019). In the future, climate-caused natural hazards are predicted to rise in frequency and severity (IPCC, 2013). Exposure of individuals in all countries has increased more rapidly than vulnerability has decreased, thereby leading to new risks and a rise in disaster-related losses (UNDRR, 2015). Infectious disease outbreaks (e.g., water-, food-, vector-, and rodent-borne) due to the degradation of environmental media and CC will lead to even greater health risks (World Meteorological Organization, 2019; Chersich et al., 2018). With this in mind, the addressing of CC could represent the greatest global health opportunity, which may be associated with the health-related co-benefits of CC response, interventions designed to mitigate and adapt to CC can in themselves improve health and reduce risk and vulnerability (Watts et al., 2015).

There has been substantial research on the links between CC and health (Watts et al., 2015; World Meteorological Organization, 2019; Watts et al., 2019), and as of late, more studies are being conducted on the impacts of CC on health care facilities (HCF). HCFs play a central role in health systems through health-specific infrastructure and specialized medical equipment in buildings and thanks to trained and qualified staff taking care of patients with increasingly complex pathologies and growing challenges such as antibiotic resistance (Laxminarayan et al., 2013). Emergency departments attached to HCFs are tasked with reaching vulnerable populations as quickly as possible, in the event of need for urgent care. They are on the front line of responses to natural disasters or climate change-related events (World Health Organization and Regional Office for the Western Pacific, 2010). As a result, they can reduce health impacts from CC not only by treating illnesses and injuries and caring for patients during and after disasters but also by reducing the impact of climate itself, through mitigation actions (Loosemore et al., 2011).

In 2005, in recognition of the importance of “making hospitals safe from disasters”, it was stipulated by the UNISDR that all new hospitals should be built “with a level of resilience that strengthens their capacity to remain functional in the event of a disaster and to implement mitigation measures to strengthen existing health facilities, particularly those providing primary health care” (UNISDR, 2008).

However, emergencies and crises continue to render HCFs unable to function, and a significant number of health facilities are still being built in areas highly prone to disasters (World Health Organization et al., 2013a). A number of climate-related phenomena pose significant threats to HCF operations. While HCFs are most of the time at full capacity and regularly overcrowded, the system will be further tested as population health is adversely affected by increased climate-related disease. HCFs are highly dependent on community services that are vulnerable to power supply (Kile et al., 2005; Rand et al., 2005), or supply chain disruptions (Appelbaum, 1999). And through the Covid-19 health crisis, we have observed the fragility of the current system in different countries (Khullar et al., 2020; White and Lo, 2020; Supady et al., 2021; Rosenbaum, 2020; Herreros et al., 2020). Health institutions and health systems have not responded well to these diversified challenges. In the future, with increasing frequency and severity and probably with long-lasting impacts, climate-related health issues will not necessarily just follow one another (e.g. heatwaves, droughts, storms), and will in all likelihood become additive (IPCC. *Global Warming of 1.5 ° C Matthews, 2018; Golechha and Panigrahy, 2020*). And since each additional

degree of warming will be proportionally more destructive, some countries are now making CC a national security priority (The White House, 2021).

While some publications have studied the impact of CC on health, few have focused on HCFs and the ways in which CC will impact health care delivery, and some of the impacts already experienced have not been analyzed. There has been no comprehensive assessment of the impact of CC on HCF operations and the potential dysfunctions that could occur. That much said, climate change and HCF is increasingly under discussion. Recently, international institutions such as the WHO, the Canadian Coalition for Green Health Care, and Health Care Without Harm have been working on the topic and have published reports (World Health Organization, 2020; Health Care Without Harm, 2017). In 2020, the WHO proposed a framework through which HCFs might implement appropriate interventions (World Health Organization, 2020). By the same token, different organizations have proposed tools to assess climate vulnerabilities and implement related interventions (The Health Care Facility Climate, 2022; U.S. Climate Resilience Toolkit, 2021; World Health Organization, 2021a). In view of assessing the climate risks in each HCF and subsequently adapting their infrastructure and processes, the objective of our study was to highlight the components of HCF that are affected by CC through a mapping review of the literature.

2. Material and methods

2.1. Study design

To meet the objective of our study, we proceeded in three stages. First, bibliometric data from the PubMed database between 1979 and 2021 were analyzed to assess the penetration of keywords on CC alone, and in relation to health and HCFs. Second, we analyzed changes in HCF keywords in the Intergovernmental Panel on Climate Change (IPCC) reports. Finally, we conducted a mapping review in five databases, of international scientific literature published between 1979 and 2019, and identified the HCF components affected by CC using the Ishikawa diagram, a validated risk analysis method (Picarillo, 2018; Nathan and Kaplan, 2017).

2.2. Search strategy and selection criteria to assess the penetration of keywords on CC alone, and in relation to health and HCF

We compared, the number of articles published in the PubMed database between 1979, when the first World Climate Conference was held in Geneva (Switzerland), and 2021, based on the three themes of: CC alone, CC and health, and CC and HCF. Regarding CC, we used the keywords “climate change”, “global warming”, “climate variability”, and “greenhouse effect”, and for CC and health, the same keywords were used with the addition of “health”, “disease”, “mortality”, and “morbidity”, based on a previous study (Verner et al., 2016). Finally, the keywords used for the topic of CC and HCFs are those detailed in the PubMed database section in Table 1. In the search equation, MeSH terms were used, and we consequently added an additional column in Table 1 to indicate the keywords included in the searches we conducted (e.g., “extreme weather”, “storm” or “heatwave”).

2.3. Identification of keywords related to HCF in IPCC reports

The occurrences of the HCF-related keywords in the six IPCC assessment reports (1990–2022) were counted. The keywords searched for were: hospital(s), health care facility(ies), hospitalization, and hospitalized. Another team member verified the research by re-counting the occurrences. To allow for meaningful comparison between the various IPCC reports, which have become increasingly voluminous over the years, and to take into account the increased number of words in the reports, we standardized the number of occurrences of HCF-related

Table 1
Research equations including the climate hazards and the five categories (manpower, material, medium, method, and management) used in each database.

Database	Equation	Examples of keywords included
PubMed	1) "climatic processes" [MeSH Terms] OR ("climatic processes" [MeSH Terms] AND "weather" [MeSH Terms]) 2) ("built environment" [MeSH Terms] AND health [Title/Abstract]) OR ("structure collapse" [MeSH Terms] AND health [Title/Abstract]) OR "health facilities" [MeSH Terms] OR "health services accessibility" [MeSH Terms] 3) "disease transmission, infectious" [MeSH Terms] OR "health resources " [MeSH Terms] OR "capacity building" [MeSH Terms] OR "health services " [MeSH Terms] OR "health services needs and demand" [MeSH Terms] OR "hospital rapid response team" [MeSH Terms] 4) "health personnel " [MeSH Terms] OR "health workforce" [MeSH Terms] OR "alert fatigue, health personnel " [MeSH Terms] (1 AND 2) OR (1 AND 3) OR (1 AND 4)	Climate change, global warming, sea level rise, cyclonic storms, droughts, floods, greenhouse effect, snow, tidal waves, rain, wind, temperature, sunlight, extreme heat, extreme weather, health, hospitals, medical schools, community health centers, outpatient clinics, bed occupancy, biological specimen banks, dental clinics, dental offices, hospital design and construction, intensive car units, operating rooms, mobile health units, laboratories, pharmacies, poison control centers, nursing homes, nurses, pharmacists, physicians, emergency medical services, mental health services, patient care
Scopus	(TITLE-ABS-KEY ("climate change")) AND (TITLE-ABS-KEY ("health resources")) OR TITLE-ABS-KEY ("health services") OR (TITLE-ABS-KEY ("capacity building")) AND TITLE-ABS-KEY (hospit*) OR TITLE-ABS-KEY (hospital*) OR TITLE-ABS-KEY ("health personnel") OR TITLE-ABS-KEY ("health care personnel") OR (TITLE-ABS-KEY (admission*) AND TITLE-ABS-KEY (hospit*)) OR TITLE-ABS-KEY ("health facility") OR TITLE-ABS-KEY ("health facilities") OR TITLE-ABS-KEY ("health care facilities") OR TITLE-ABS-KEY ("health care facility"))	Climate change, hospital, hospitals, hospitalized, hospitalization, admission, health care facility, health care facilities, health resources, health services, health care personnel, health facility, health facilities
Science Direct (English)	("Climate change" OR weather OR "natural disasters") AND (hospitals OR "health facilities" OR "health facility" OR "health services")	Climate change, weather, extreme weather, extreme weather events, natural disasters, hospitals, health facility, health facilities, health services,
Science Direct (French)	In Title, abstract or keywords ("catastrophes naturelles" OR "changements climatiques") AND (ressources OR services OR Hopital OR Hopitaux OR soins OR batiment OR personnels) In Title, abstract or keywords	Catastrophes naturelles, changements climatiques, changement climatique, hôpital, hôpitaux, soins, ressources, services, bâtiment, personnels
GreenFile	("natural disasters" or tsunamis or floods or drought or wildfire or earthquake or tornado or hurricane or snowstorm or "climate change" or "global warming" or heatwave or "greenhouse effect" or "climatic changes" or weather) AND ("built environment" and (health or hospital) or "health	Natural disasters, tsunamis, floods, drought, wildfire, earthquake, tornado, hurricane, snowstorm, climate change, global warming, heatwave, greenhouse effect, climatic changes, weather, extreme weather, health, hospital, healthcare, health care, health

Table 1 (continued)

Database	Equation	Examples of keywords included
Cairn	resources" or "health workforce" or "health personnel" or healthcare or "health care" or hospital or "health services" or "health facilities") ("réchauffement climatique" OU chaleur* OU tempête* OU température* OU pluie* OU inondation* OU catastrophe* OU "changement climatique" OU "changements climatiques" OU climat* OU météo*) ET (urgence* OU santé OU hôpit*OU "établissement de santé" OU "établissements de santé" OU hospitalization* OU soinn* OU malad* OU pathologi* OU trouble*)	facilities, health resources, health workforce Réchauffement climatique, chaleur, tempête, température, pluie, inondation, catastrophe, changement climatique, climat, météo, météorologique, urgence, santé, hôpital, hôpitaux, établissement de santé, hospitalization, soin, malade, maladie, pathologie, trouble

keywords in relation to the number of pages in each report.

2.4. Search strategy and selection criteria for the mapping review and the 5M Ishikawa diagram

We conducted a mapping review of the overall observed global effects of CC on HCFs worldwide. Without an international validated guideline, the mapping review was structured and adapted from other validated checklists and guidelines (Grant and Booth, 2009; Moher et al., 2009; Tricco et al., 2017).

2.4.1. 5M Ishikawa diagram

The study of HCFs, like other complex organizations, is possible using the 5M Ishikawa diagram, a validated risk analysis method (Picarillo, 2018; Nathan and Kaplan, 2017). Initially developed in manufacturing and industry and still used today, this generic and broad template for quality is simple to use, easy to interpret and apt to resolve problems in health care (Arvanitoyannis and Varzakas, 2007; Picarillo, 2018; Coughlin and Posencheg, 2019). Based on the usual "5M" categories, the study of HCF could be divided into the following 5 categories: Manpower, Material, Medium, Method, and Management (Picarillo, 2018; Nathan and Kaplan, 2017).

2.4.2. 5M Ishikawa diagram applied to HCF

Translated into the field of health and applied to HCF, the manpower (or people) category included not only the staff working in HCFs, but also all the patients who could be cared for. The material (or equipment) category included all equipment used or required during patient care, such as drugs, medical devices, beds, medical equipment, communication devices, and vehicles. The medium (or environment) category included all elements of the building, its location, infrastructure and services enabling access to HCFs and the various environmental media (air quality, water quality and supply, soil). The method category included all procedures and protocols applied in the institutions (evacuation plan, communication systems in case of power failure ...). The management part included the elements of decision-making, steering, financing, and management of the institutions. As there is no specific screening standard, three authors (JG, SAT, VM) have consensually classified the specific content in each component of the 5M Ishikawa diagram. For example, some specific content of each component of the 5M Ishikawa diagram, are available in the Supplementary Table 1. The 5M Ishikawa diagram started from climate hazards and the effect studied was HCF dysfunction.

2.4.3. Construction and stratification of the 5M Ishikawa diagram by climate hazards

The risk analysis was carried out for each climate hazard. To consider

CC in its entirety, the choice of climate stressors was made according to the IPCC definition, which defines CC hazard as “the potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources” (IPCC. *Global Warming of 1.5 °C Matthews, 2018*). Climate hazards are usually distinguished according to whether they cause direct (e.g., storms, drought, flood, heatwave, or wildfires) or indirect (e.g., changing patterns of disease, water quality, air pollution, or land use change) effects on health (Watts et al., 2015, 2018). In line with this classification, we included the following climate hazards: warming, heatwaves, wildfires, floods, droughts, storms, tornadoes, hurricanes and sea-level rise (Salas and Solomon, 2019; Watts et al., 2019; Mora et al., 2018). Given the purpose of our study and the relevance of distinguishing hazards such as storms and wildfires, we grouped other hazards with similar consequences, such as floods and sea level rise. In the risk analysis using the 5M Ishikawa diagrams, climate hazards were ordered into 6 groups: i) warming and heatwaves, ii) wildfires, iii) floods and sea level rise, iv) droughts, v) storms, tornadoes and hurricanes, and vi) other indirect effects [such as alteration of the environmental media (air quality, water quality and supply, soil), or vector-borne diseases].

2.4.4. Selection of databases and articles

Databases including PubMed (medical), Scopus (life sciences), Science Direct (health), Cairn (humanities and social sciences) and GreenFile (environment) were used to retrieve papers published between January 1, 1979, and December 31, 2019. By adapting to the specifics of each database, keywords were sought out in several English-language reference medical dictionaries by a reviewer (JG) and selected by the team members (JG, VM and SAT) once a consensus had been reached, after a series of pilot tests. Search equations for each database are detailed in Table 1. To complete the research, grey literature including reports from international organizations (WHO, World Meteorological Organization, and IPCC) and learned societies were screened.

We did not restrict our scope to a specific health facility. Indeed, in our search equations, we have included MeSH terms, such as “health facilities”, “health services” or “health workforce”, allowing us to include many facilities, including academic medical centers, ambulatory care facilities, biological specimen banks, birthing centers, dental facilities, fertility clinics, hospitals, laboratories, pharmacies, poison control centers, rehabilitation centers, as well as the various health services and the many health professionals.

Studies were included if they met the following criteria: i) studies published between January 01, 1979 and December 31, 2019, and ii) studies that identified the presence of at least one effect on one of the HCF components by one of the climate drivers. We also examined papers identified from the reference lists of included papers to make sure that relevant papers were included.

We excluded papers, if i) papers were published in languages other than English, French or German, ii) the date of publication of the article was outside the period 1979–2019, iii) the papers did not identify consequences on HCF by climate drivers, and iv) grey literature outside key internationally recognized organizations. We did not specify any population or geographic location restriction.

2.4.5. Analysis to build the 5M Ishikawa diagram

To enable the distribution and categorization of the various risks identified from the literature in the 5M Ishikawa diagrams, two reviewers, health workers in HCFs (JG, SAT) independently read the selected articles to classify them according to the terms related to each of the 5Ms. For example, we classified in the material category, articles that reported unavailability of drugs, of beds, or the non-operation of medical devices, and in the medium category, we placed articles that reported structural damage or HCF access issues. A third reviewer (VM) mediated when consensus was not reached. The relevant selected

articles described the impact on the different elements of each component of the 5M Ishikawa diagram. As we went along, we retained the articles that contributed complementary elements to the 5M Ishikawa diagram. After including the relevant articles with regard to the 5M components and climate hazards, we highlighted them according to the impacted WHO regions (Africa, the Americas, Eastern Mediterranean, Europe, South-East Asia, and Western Pacific), as a complementary illustration. The references of the relevant articles included in the mapping review, organized by type of climate hazard, and impacted HCF component, and with the illustration of impacted WHO regions, enabled construction of the 5M Ishikawa diagram, and are available in the [Supplementary Table 2](#).

3. Results

The number of articles published in PubMed database between 1979 and 2021 on CC, CC and health, and CC and HCFs, and contextualized with major international conferences, decisions, and reports are summarized in Fig. 1. For CC, the number of scientific articles published was stable at less than 10 per year until 1987. Since 1988, when the IPCC was created, the number of published articles gradually increased until 1999 (108 articles), and more pronouncedly until 2021 (10,304 articles). Concerning CC and health, it was only in 1989 that more than 5 articles were published after which the number continued to increase, with an acceleration publications in the mid-2000s (458 articles in 2008 and 3731 in 2021). Finally, regarding CC and HCFs, the number of articles published was much lower (59 articles in 2005), but then increased (216 articles in 2013 and 323 in 2020). The milestone of 300 articles published per year was reached for CC, CC and health, and CC and HCFs in 2001, 2008 and 2019 respectively.

The number of scientific publications related to CC and HCF found in the databases searched between 1979 and 2021 are detailed in Fig. 2. In 1979, 24 articles were published. During the 16 years that followed, the number of articles per year never exceeded this number. For example, in 1988, when the IPCC was established, the number of articles published was 12 and in 1992, when the United Nations Framework Convention on Climate Change was negotiated and signed, 23 articles were published. From the 2000s, the number of publications increased gradually with 137 articles in 2005, when the Kyoto Protocol came into force, and even more sharply since 2008 (358 articles published) and in 2021 (813).

During the period of 1990 and 2022, the occurrences of keywords defining HCF appearing in various IPCC reports were counted (Fig. 2). Before the 2000s, CC linked to HCFs was not a real concern, with only one occurrence (“medical care facilities”) in the first IPCC assessment report (AR1) in 1990, and 2 keywords in all AR2, in 1995, (Fig. 2). In the third IPCC assessment report (2001) and the fourth (2007), keywords on HCF appeared 26 times. In the fifth IPCC assessment report, the number of occurrences was 44. Finally, in the latest full report (AR6, 2022), keywords on HCF appeared 84 times (Table 2). The progression of occurrences has been growing and constant over time, as has been the case for published articles.

The place of HCF-related keywords in the various IPCC working group reports are detailed in Table 2. In the assessment reports, the theme is absent from all working group (WG) I reports. Overall, most occurrences on impacts, adaptation and vulnerability were found in WG II. With 2 occurrences in WG II of the AR2 (1995), 24 in AR3 (2001), and 43 in AR5 (2014), the topic has become even more important with 77 occurrences in AR6 (2022). As regards the WG3 reports, the number of occurrences remains low with 2, 4, 1 and 6 occurrences in AR3, AR4, AR5, and AR6, respectively. Between AR3 and AR4, while the total number of keywords remained the same, more terms were found in WG III, on CC mitigation. Despite a considerable increase over the years in the total number of occurrences of HCF-related terms, in proportion to the increase in the number of pages of the reports we noted, a stabilization of the number of keywords per 1000 pages, which has ranged since 2001 from 9.1 to 9.7 (Table 2).

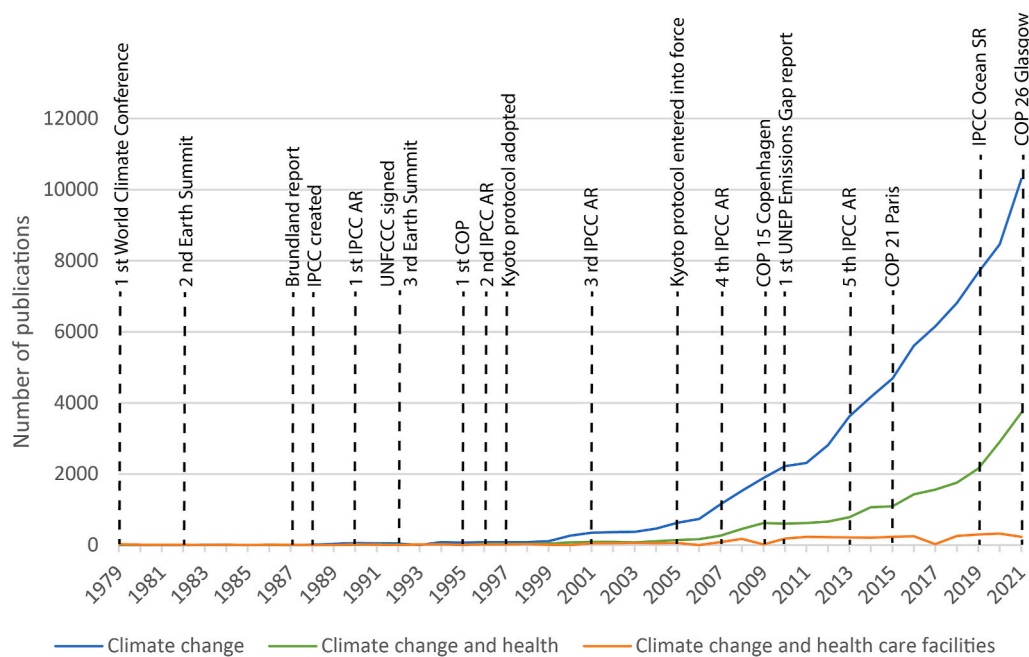


Fig. 1. Publications on ‘climate change’, ‘climate change and health’, and ‘climate change and health care facilities’ by year indexed in PubMed database between January 1, 1979 and December 31, 2021. IPCC: Intergovernmental panel on climate change, UNFCCC: United Nations Framework Convention on Climate Change, COP: Conference of Parties, AR: Assessment report, UNEP: United Nations Environment Programme, SR: Special report.

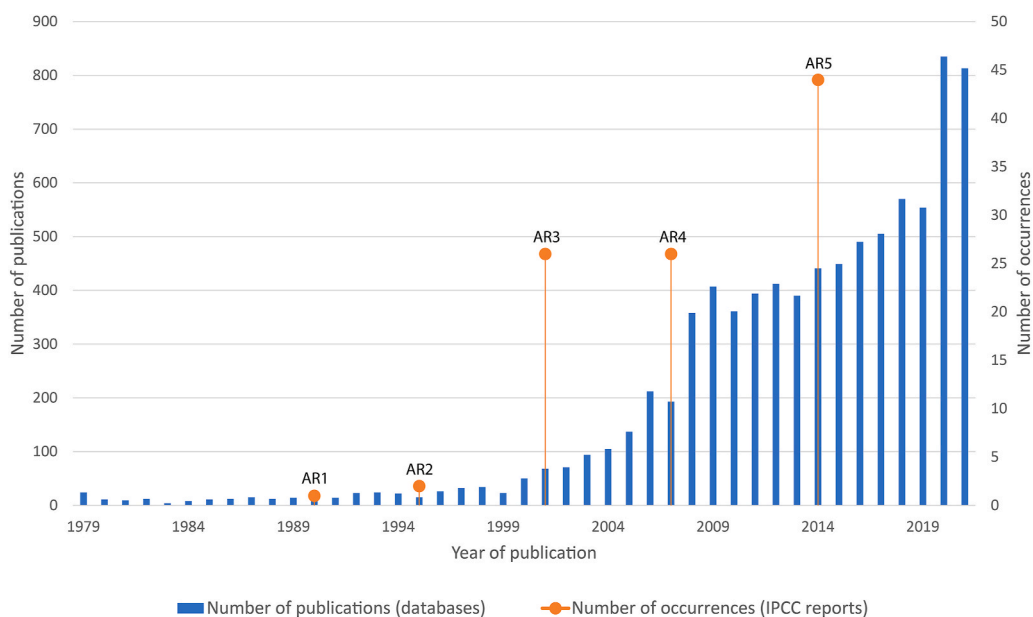


Fig. 2. Evolution of the number of articles published on climate change and health care facilities from Cairn, GreenFile, PubMed, Science Direct and Scopus databases between January 1, 1979 and December 31, 2021 and the number of occurrences in IPCC reports (1990–2014) of health care facilities keywords.

Based on the Ishikawa diagram, a recognized and validated risk assessment tool, we have detailed, according to the international literature, the risks that HCFs have faced in the context of CC and classified them into six groups of climate hazards (Fig. 3).

All climatic events had an impact on at least one category of HCF. Some climate hazards, such as warming and heatwaves (Fig. 3A), storms, hurricanes, and cyclones (Fig. 3D), and floods and sea-level rise (Fig. 3E) have been described as impacting all components of HCF: people, methods, environment, materials, and management. Other climate hazards such as droughts (Fig. 3B), wildfires (Fig. 3C), and other indirect effects (Fig. 3F) have been described as affecting several, but not all, components. Indirect effects such as soil, air and water alterations or vector-borne disease changes were described as affecting the people and environment categories. The different impacts observed on one or more

categories led to HCF dysfunctions for all the climate hazards presented.

4. Discussion

To our knowledge, for the first time, this study has identified the HCF components affected by CC through a mapping review of the literature, between 1979 and 2019. In addition, we compared the level of penetration of keywords of CC alone and linked to health and HCF in a medical database between 1979 and 2021, and in the IPCC reports. The subject of CC was long absent from the PubMed medical database. It was not until the early 2000s that the subject gained in visibility. This increase took place a few years after the initiation of the Yokohama Strategy and Plan of Action for a Safer World, adopted following the World Conference on Natural Disaster Reduction in 1994, which

Table 2

Distribution of occurrences of keywords related to health care facilities in the various IPCC working group reports of each six assessment reports (1990–2022), by number and percentages.

	AR1 (1990)	AR2 (1995)	AR3 (2001)	AR4 (2007)	AR5 (2014)	AR6 (2022)
WG I: The Physical Science basis	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (1%)
WG II: Impacts, adaptation, and vulnerability	1 (100%)	2 (100%)	24 (92%)	22 (84%)	43 (98%)	77 (92%)
WG III: Mitigation of climate change	0 (0%)	0 (0%)	2 (8%)	4 (16%)	1 (2%)	6 (7%)
Total	1	2	26	26	44	84
Number of pages, full report	1042	1917	2689	2857	4852	8949
Number of occurrences, per 1000 pages	1.0	1.0	9.7	9.1	9.1	9.4

AR: Assessment report, WG: Working group.

provided landmark guidance on disaster risk reduction ([International Decade for Natural Disaster Reduction, 1994](#)). Major challenges were identified for the coming years such as the need to implement more systematic actions to address disaster risks in the context of sustainable

development and to strengthen resilience strategies to better manage these risks. CC was identified as a major factor in the increase of disasters and of severe consequences on people’s health. To reduce the consequences of CC, the Kyoto Protocol, which was signed in 1997 and came into force in 2005, was accompanied by the Hyogo Framework for Action, which aimed to build the resilience to disasters of nations and communities ([United Nations and International Strategy for Disaster Reduction, 2005](#)). And so, CC is a latecomer to the field of health and only in the 2000s became a topic in the scientific literature. Through another database, Science Direct, the same observation was made by Verner et al. on CC and health publications between 1990 and 2014 ([Verner et al., 2016](#)). Not only did health-related publications represent a minority of all CC publications, but it would certainly take years to catch up with the research gap. Through its numerous works, reports, and tools, along with other organizations the WHO has been closing the gap, producing guidance for systematic risk assessment and monitoring ([World Health Organization, 2015, 2022a](#)). In its 2021 report, the Lancet Countdown also showed, in another database, Embase, the recent but significant increase on health-related CC ([Romanello et al., 2021](#)). Moreover, as in our study, this report concluded that in terms of absolute number of articles, the topic of health-related CC included far fewer publications than CC alone ([Romanello et al., 2021](#)). This could be explained by the fact that i) CC has been perceived rather weakly by health professionals, or not strongly enough for them to take up the issue, ii) despite a stated willingness of health professionals, there are still many obstacles preventing commitment and action, particularly the lack of time, iii) health professionals do not feel sufficiently prepared for the challenges of CC, and iv) some health education institutions do not address the issue of CC in the teaching of health students ([Kotcher et al.,](#)

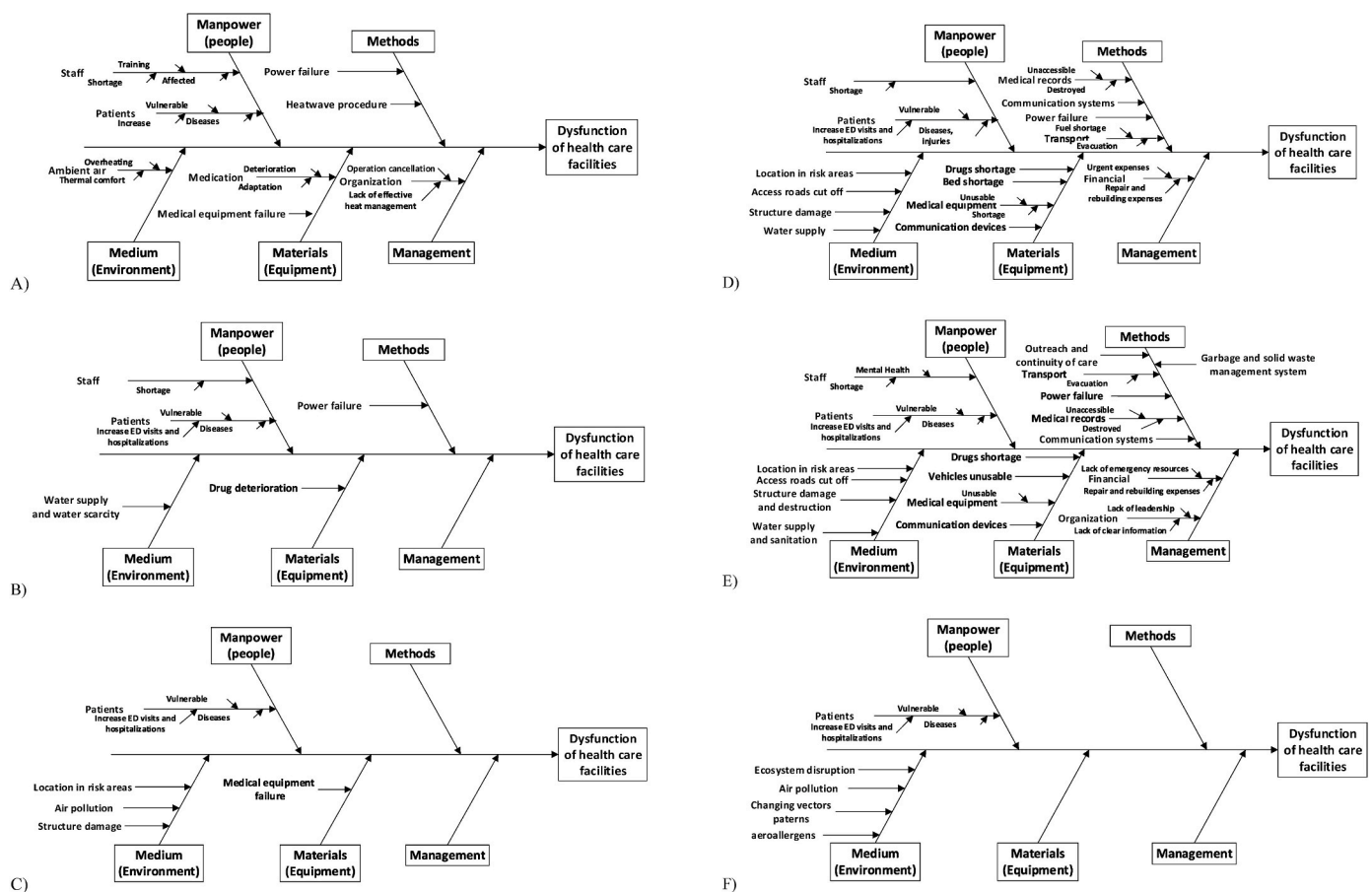


Fig. 3. Ishikawa diagrams of root causes of dysfunctions of health care facilities (1979–2019), according to the climate hazards, ordered in 6 groups A) Warming and heatwaves, B) Droughts, C) Wildfires, D) Storms, hurricanes and cyclones, E) Floods and sea-level rise, and F) Other indirect effects. Relevant references available in supplementary table.

2021; Hathaway and Maibach, 2018; Shea et al., 2020; Omrani et al., 2020). However, health professionals feel increasingly responsible for climate advocacy, associated with an increased willingness to participate in advocacy on climate policies (Lee et al., 2021). Health is also a late entrant in the field of CC, and it has taken many efforts of groups of scientists such as the Lancet Countdown to mainstream health into international discussions on CC by informing on the effects of CC on health and providing recommendations (Costello et al., 2009; Watts et al., 2015). However, the subject was raised at COP 26, following which more than 50 countries committed to adapting their health systems and developing climate-smart health care (The Lancet Planetary Health, 2021; World Health Organization, 2021b).

The subject of CC in relation to HCF did not emerge until the end of the 2000s. In our study, a more in-depth search of five medical, biomedical, life sciences, and environmental databases revealed a visible progression from 2005 onwards: this remained marginal in relation to the total number of publications. In their study, Adelaide et al. did not find sufficient data and detailed studies to properly assess the increase in emergency room and hospital visits expected as a result of CC (Adelaide et al., 2017). In fact, fewer than 600 articles dealt with CC in relation to HCF in 2019.

The relatively small number of publications does not mean, however, that HCFs or their components are not affected by CC. It is more likely that health professionals and others studying healthcare did not consider CC effects on HCF as a topic of scientific interest. It is likely that the actual link between the extreme weather events under consideration and CC has not been well-understood by policymakers, managers, and healthcare workers. In the event of a natural disaster, medical facilities and medical staff have many contingency plans, but CC has not been mentioned in the past when developing and implementing them. Moreover, analyzing the effects of CC on HCF requires both precise knowledge of how a health care facility operates and a global vision of the complex health care system (Raffoul et al., 2019; Lawson et al., 2019). This intersectoral approach is of interest in the analysis of other complex problems related to CC (Valente et al., 2022). It can be difficult to have this double reading and analysis when one is a medical specialist, a scientist, or a physician, who probably represent a significant proportion of the authors who publish in journals linked to biomedical and medical databases, or when the authors are mainly outside the health sector, as in environmental databases. We are probably confronted with a publication bias that is characterized by: i) compartmentalization of hospital activities that prevents authors from having a global vision of the impacts of CC on HCF, ii) a lack of knowledge about CC by health care professionals, and iii) the idea that the subject of CC would not arouse scientific interest with regard to a medical journal in which the existing system impels us to publish.

Comparing the increased number of articles published in the databases used in the study, the number of occurrences of HCF-related keywords increased in a similar way in the five IPCC assessment reports analyzed. Before the 2000s, CC linked to HCF was not a real concern. Since one of IPCC's missions is to review scientific literature, this joint evolution between the number of publications and the number of occurrences reinforces the interest of the five databases used in our study. The increase of published articles was even more marked from 2009 onwards, following the 61st World Health Assembly, which recognized in its 19th resolution that the effects of CC on human health were already observable, and which set out commitments on CC, health, the health sector, and the promotion of research on these issues, the objective being to assess and strengthen health systems (World Health Organization, 2008).

We have further investigated focus on HCFs by counting the number of occurrences of keywords and their location in the three different working group (WG) reports that make up each IPCC assessment report (AR), as Verner et al. proceeded with health (Verner et al., 2016). We found that keywords related to HCF were not present in the WG1 reports. This result was expected as WG1 was specifically concerned with

the physical science underpinning CC (IPCC, 2021). Concerning the WG2 reports, which address impacts, adaptation and vulnerabilities, the topic of HCF became more visible. These results show that HCFs are integrated as vulnerable facilities. However, despite the growing presence of HCF in WG2 reports, few papers have been written to promote the adaptation of HCFs to CC. As for the limited presence of HCF in WG3 reports, it did not allow the proposal of mitigation action for HCFs (IPCC, 2021a).

It will be interesting to measure the impact of the 6th IPCC AR on the number of publications on HCF and CC in 2022.

Risk analysis tools related to climate hazards have been developed in recent years, such as the Canadian Health Care Facility Climate Change Resiliency Toolkit, the U.S. Sustainable and Climate Resilient Health Care Facilities Toolkit and the PAHO SMART hospital toolkit (The Health Care Facility Climate, 2022; U.S. Climate Resilience Toolkit, 2021; Pan American Health Organization, 2021). These tools can provide a starting point for raising awareness in the health sector. However, in the comparative study by Balbus et al., one barrier to effective use of these tools is that health care staff need training and educational opportunities (Balbus et al., 2016). As a complementary approach, to analysis of a complex organization, the 5M Ishikawa diagram (or cause-effect diagram), an essential tool in quality control and total quality management, is commonly used (Ishikawa, 1991). It allows the potential causes of a problem to be categorized in a successive and detailed manner in view of identifying the root cause (Picarillo, 2018). Adapted to any context, it can be easily integrated into the health care facility risk management process. Since it is not specific to a given risk, it is particularly practical in a global risk assessment process. It is increasingly used to improve health care and can support the quality approach of HCF (Picarillo, 2018). Because this broad template for quality is simple to use, easy to interpret, and very useful as a means of solving quality and safety problems in health care, the Ishikawa diagram can guide clinicians to improve patient outcomes (Picarillo, 2018; Coughlin and Posencheg, 2019). Through graphical representation, it also provides a broad view of the components of HCF that are affected by CC and allows management to have a better understanding of the impact of CC in HCFs.

The cause-effect diagrams showed that all climate hazards have impacted HCF. In each of its aspects, CC has induced completely different responses and dysfunctions in HCFs, particularly due to increased patient admissions. Above and beyond extreme events, CC necessitates enhanced community health management, with regard to infectious disease outbreaks and chronic diseases, the most vulnerable (the elderly, people with infections, or chronic diseases, children, and pregnant women) are at increased risk of health issues. Moreover, CC-induced responses and dysfunctions such as sheltering, destruction and evacuation, which may be chaotic and disorganized, are liable to affect HCFs (Hutchinson et al., 2018; Post et al., 2008; Bernard and Mathews, 2008; Hoffman et al., 2018). Processes for patient prioritization, tracking and transport have been characterized as inconsistent (King et al., 2016). In addition, the accessibility of medical care remains a major issue (Ruskin et al., 2018).

For climate hazards such as storms, hurricanes, and cyclones, as well as floods and sea-level rise, the impacts on buildings have been widely described (Tran et al., 2009; Curtis et al., 2017), rendering it easier to understand that the damage is comprehensive and that other components of the system could also be affected (Burki, 2015).

With regard to warming and heatwaves, while health care facilities play a major role in caring for the population in the event of a disaster and are essential assets for the community, hazards such as heatwaves impact HCFs at all levels causing a setback to the health care system during these heat waves (World Health Organization, 2009, 2013b), despite the introduction of specific health policies (e.g., heatwave plan) and their implementation in HCF operations, including management, methods, and procedures (Abrahamson and Raine, 2009; Boyson et al., 2014).

The 5M Ishikawa diagrams showed that the management component was impacted for numerous climate hazard groups: warming and heatwaves, storms, hurricanes and cyclones, and floods and sea-level rise. And despite a lack of visibility, as we have just shown it remains an issue for the other hazards. It is likely that the topic is not visible to the authors, or that they do are unable to measure the impact of CC on this component, in a health care system defined as complex (Raffoul et al., 2019; Lawson et al., 2019). This category would therefore be underestimated as the authors are most often not managers, but health professionals.

Conversely, the manpower and medium categories were systematically cited regardless of the climatic hazards. Several hypotheses can be advanced: i) as we have just seen, the first may be linked to the authors, as these two categories were more visible to health professionals, and ii) the lack of a systemic vision on the part of health professionals fostered greater emphasis on the most visible effects of CC on HCFs.

With regard to the method component, reported difficulties were either a lack of procedures and protocols or procedures not adapted to real-life situations (King et al., 2016). In the cases where the method component was not involved, there may have been a lack of real CC impact or else, this component was not cited as being impacted.

In this study, we proposed a risk assessment method for HCFs, which are parts of health systems, and impacts of CC are more global. While our study included components of the health system, it would also be interesting to consider whether other impacts of CC specifically affect the health system in general (Curtis et al., 2017; Ebi and Boyer, 2019).

The use of 5M Ishikawa diagrams and focus on areas of improvement facilitates our understanding of the different interactions and will enable the implementation of effective and efficient actions in HCFs (Tague, 2005). Based on these findings, a complete and utter assessment will have to be carried out for each HCF, which have different exposures to these climate risks. This analysis could assess the criticality of the different impacts, according to frequency and severity. The articles we have selected are mainly from the Americas and Europe. However, we know that all regions of the world are impacted by CC, particularly Africa, South-East Asia, and the Eastern Mediterranean (World Health Organization, 2022b). It is therefore essential to consider all regions as being impacted by climate risk and to understand all health systems must adapt and establish action plans for HCFs to cope with CC. Sharing previously implemented actions already would make the action plans to mitigate and adapt to CC more effective.

5. Conclusions

Identified as “the defining issue of our time”, climate change represents a major challenge for the health sector in the coming decades (UNDRR, 2021). There is a need to increase awareness and training of all health actors (decision-makers, purchasers, health professionals, health students, technicians, logisticians, etc.) on CC, its challenges and actions to minimize the impacts of HCFs on climate, notably by reducing greenhouse gas emissions (Shea et al., 2020; Omrani et al., 2020).

Until recently, health and HCF were not the focus of scientific research regarding CC. However, HCFs are now fully impacted by CC, in all their components.

Through better understanding of the impacts of CC on HCFs, this work could help to contribute to foster the engagement of health professionals in the implementation of mitigation and adaptation actions. Following this study, one of the perspectives would be to collate the recommended solutions identified in the scientific literature in view of closing the adaptation gap.

6. Contributors

JG conceived and designed the study, developed the search strategy for the review, did the initial search and collected the articles, and drafted and revised the paper. SAT supervised the research, monitored

data collection, analyzed the data, and drafted and revised the paper. SR drafted and revised the paper. AD drafted and revised the paper. VM supervised the research, monitored data collection, and drafted and revised the paper. All authors provided comments to draft versions, and read and approved the final version for submission.

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Declaration of competing interest

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

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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