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Review

Review

Digital health for climate change mitigation and response: a scoping review

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ABSTRACT

Objective: Climate change poses a major threat to the operation of global health systems, triggering large scale health events, and disrupting normal system operation. Digital health may have a role in the management of such challenges and in greenhouse gas emission reduction. This scoping review explores recent work on digital health responses and mitigation approaches to climate change.

Materials and Methods: We searched Medline up to February 11, 2022, using terms for digital health and climate change. Included articles were categorized into 3 application domains (mitigation, infectious disease, or environmental health risk management), and 6 technical tasks (data sensing, monitoring, electronic data capture, modeling, decision support, and communication). The review was PRISMA-ScR compliant.

Results: The 142 included publications reported a wide variety of research designs. Publication numbers have grown substantially in recent years, but few come from low- and middle-income countries. Digital health has the potential to reduce health system greenhouse gas emissions, for example by shifting to virtual services. It can assist in managing changing patterns of infectious diseases as well as environmental health events by timely detection, reducing exposure to risk factors, and facilitating the delivery of care to under-resourced areas.

Discussion: While digital health has real potential to help in managing climate change, research remains preliminary with little real-world evaluation.

Conclusion: Significant acceleration in the quality and quantity of digital health climate change research is urgently needed, given the enormity of the global challenge.

Key words: global warming, digital health, scoping review, health informatics

INTRODUCTION

Climate change poses a potentially existential challenge for humanity.[1] Evidence of the specific association between climate change and human health is accumulating rapidly,[2] through multiple direct and indirect pathways.[3,4] The environmental consequences of climate change, from meteorological variability to extreme weather events such as increased droughts, floods, and wildfires, all can impact human health.[5] For example, poor air quality is associated with extended heat events and can exacerbate existing health issues such as asthma.[5] Alteration of rain and drought patterns can impact the range and severity of infectious disease outbreaks associated with vector- and water-borne diseases.[6] A recent overview of 94 systematic reviews examining the health effects of climate change shows that in addition to infectious diseases, extreme events caused by climate change are associated with an increase in mortality, especially for cardiovascular- and respiratory-related diseases, regardless of region and country.[6]

Health systems may consequently be stressed by emergencies triggered by climate change. Events such as extreme weather or infectious disease outbreaks can impact medical supply chains or disrupt normal operation of the health system. The often-heroic responses by health systems to the COVID-19 pandemic are a salutary example of the huge demands that can be made on health systems to respond to a single disease. It also underscores the vital role information and communication technology has had in tackling health emergency responses.[7–9] Disasters create complex information environments with data coming from multiple and disparate organizations.[10] Digital health, the use of information and communication technology to improve human health, healthcare services, and wellness for individuals and populations,[11] can play a critical role in collecting data, monitoring diseases, early risk assessment, initiating investigation and control activities, and providing information for decision-making.[7,12] Communication technologies can facilitate the delivery of care and medical services to remote or resource-limited areas in disasters or provide a platform for community data sharing.[13]

Digital health can also help with global warming mitigation. Healthcare is a major emitter of carbon emissions, contributing to about 10% of greenhouse gas emissions in the United States.[14] Finding ways to reduce those emissions and decarbonize health is, therefore, not a minor matter but critical to our global net-zero ambitions. Major contributors to these emissions include patient and staff travel, heating or cooling of facilities, medicines (such as inhalers), anesthetic gas escape, waste management,[15] and electricity used for computer server farms.[16] Some evidence shows that teleservices can reduce patient and clinical staff travel and so assist with reducing carbon footprints.[13]

There is growing research interest in the role of digital health in climate change. A recent paper highlights the role of digital health in reducing greenhouse gas emissions and in integrating data to generate insights into the human health impacts of climate change.[17] Recent scoping and systematic reviews have examined the role of digital health in climate change in specific areas such as tele-health for urology.[13,18,19] This scoping review aims to take a broad view by summarizing the literature on how digital health can assist in managing health problems triggered by climate change, and how digital health can assist in reducing the emission intensity of health services.

METHODS

Given that the climate change and digital health research literature appears young and heterogeneous, often with quite preliminary results, a scoping review was undertaken to map the literature, characterize typical research methods used, and to give an indication of the volume and focus of the literature.[20] This scoping review was conducted in accordance with PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews).[21,22]

Study selection

Articles on digital health/health informatics tools and approaches to assist with climate change health system responses or emission mitigation activities were included. Articles such as editorials, opinion pieces, or book chapters were also included to help identify key concepts and relevant theoretical frameworks. Table 1 details the inclusion and exclusion criteria.

Search strategy

Due to the time sensitivity of the topic and the recent rapid growth in publications, we conducted a scoping review to provide a timely snapshot of the evidence using only Medline, which was searched from inception (1947) to February 11, 2022. The search strategy was partially adapted from previous systematic literature reviews on digital health[23] and climate change,[24,25] and further modified after reviewing the titles/abstracts of the initial 50 records and discussion with a librarian. Supplementary Table S1 provides the final search strategy.

Study selection was completed with a 2-step screening process using Rayyan.[26] Two reviewers (HR-A and SH) independently screened titles/abstracts for 50% of retrieved articles. Any disagreements were resolved by reviewing the full text and discussion amongst reviewers. One reviewer (HR-A) assessed the remaining titles/abstracts and full text to identify eligible articles. Any uncertainty was discussed with the third author (EC). Eligible articles identified by hand search were also included.

Data extraction

One author (HR-A) extracted data from the included articles. The extracted data included authors, year of publication, study area, study design, population, and outcomes. In addition, information about study aims and digital methodology was collated. Study areas were classified by the country they were conducted in, using categories for low to upper-middle-income countries and high-income countries from the United Nation's definition.[27]

Summarizing and reporting findings

To analyze the contribution of digital technology to climate change, we developed a classification framework that firstly reflected the specific problem being addressed and secondly identified the methodological approach taken. The high-level framework was synthesized from recent related reviews[13,28] and pre-existing classifications[29,30] and was extended and modified using an inductive approach as articles were analyzed.[13,28–30] Three high-level problem domains were identified:

1. Mitigation of the impact of health services on climate change (where digital health contributes to a reduction of greenhouse gas emissions from the health system);
2. Management of climate change-triggered infectious diseases (where digital health assists in managing infectious disease problems triggered by climate change); and
3. Management of climate change-triggered environmental health risks (where digital health assists with managing environmental health risks triggered by climate change, for example heat stress).

Developing a framework to analyze the methodological approaches in these 3 domains was challenging because they are typically a bundle of different technology classes (eg, an interruptive prompt on a mobile phone, developed using machine learning on electronic health records [EHRs]) and are often selected from a large number of technical options (eg, machine learning using deep learning or support vector machines or linear regression). As a result of this heterogeneity, we elected to take a technology neutral and generic approach to classify interventions into 6 distinct technical tasks.[30]

1. *Data sensing* includes any technology that measures health or environmental factors related to climate change, such as diagnostic tests developed by bioinformatics methods;
2. *Monitoring* when temporal processing was involved in data analysis to examine patterns over time, such as analysis of medical data to detect outbreaks of diseases;

Table 1. Inclusion and exclusion criteria

Component	Included	Excluded
Participants	Human	Animal studies
Intervention/exposure	Any digital health/health informatics tools or assessments used to assist health systems with climate change, both response and mitigation, such as decision-making support tools (eg, alerts, warning), self-service, digital data gathering, modeling, and monitoring	
Comparator	Not applicable	Not applicable
Study design	• Peer-reviewed • Any design and publication type including commentary, editorial, opinion piece and protocol, review	• Non peer-reviewed • Conference abstracts
Outcomes	• Health outcomes, for example infectious disease rate or transmission risk • Environmental health risk factors, such as heat stress, vector prevalence, identifying geographic area at risk, pollen presence • Environmental outcomes (for mitigation), such as carbon emission	Any outcome which does not directly relate to health or climate change, such as waste management, air quality improvement, food and water safety or behavioral change (eg, diet)
Language	English	Other languages

3. *Electronic data capture* when electronic data capture was utilized to support studies or provide basic infrastructure, for example integrating climate and health data for a dashboard;
4. *Modeling* where digital tools incorporate computational models, for example to predict climate change-related health or environmental outcomes;
5. *Decision support* when digital tools provide targeted assessments to support decision-making, such as alerts for potential heat events. Decision support was further sub-classified into *Screening, Diagnosis, Treatment, Prognosis/Risk assessment, Planning, and Control*;
6. *Communication* when a technology such as teleconferencing was used within health services, such as telehealth tools (virtual-consultations, e-prescriptions etc.) or tele-education.[30]

Articles could be assigned to multiple categories.

RESULTS

The initial searches identified 661 records; 482 of these did not meet eligibility criteria and were excluded at the title/abstract screening stage. The full text of 182 articles was reviewed, and 142 articles were included (Figure 1).

Of the included articles, 89 were empirical (57 ecological, 15 cross-sectional, 12 cohorts, 4 qualitative and mixed-method, and 1 case series); 39 articles were an editorial, opinion piece, commentary, or literature review; 2 articles were systematic or scoping reviews; and there were 12 case studies, prototype descriptions, or protocols.

Overall, the articles came from 30 countries, 9 came from more than one country and 2 were global. The majority of studies ($n = 113$, 79%) came from high-income countries, specifically the United States ($n = 42$), Canada ($n = 19$), and the United Kingdom ($n = 18$) (Figure 2). Most articles were published recently, with half appearing in the last 5 years (Figure 3).

This review identified 33 articles related to the mitigation of health system contributions to climate change, 65 to the management of climate change-triggered infectious diseases, and 71 to the management of climate change-triggered environmental health risks. The topic of mitigation of health system greenhouse emissions has become a particular recent focus, with the highest rise (a 5-fold increase) in the last 3 years. For a summary of included articles, see Supplementary Table S2. Tables 2–4 provide references to all the included articles, classified according to 3 problem domains and 6 technical tasks. For each article, aims and technical methods adopted are described.

Mitigation of contributors to climate change

Most articles that discussed mitigation of health system contributions to climate change ($n = 31/33$) explored the use of communication services such as telehealth to reduce patient or staff travel (Table 2).

Monitoring

One article suggested using monitoring tools for CO_2 emissions.[31]

Electronic data capture

EHRs, electronic prescriptions and referrals can help digitize work process, thus save energy and decarbonize health services.[35] Five of the 33 articles in this group provide some early evidence that this can contribute to a reduction in greenhouse gas emissions.

Decision support

Optimizing energy use in hospital buildings using information technology, for example to better control air conditioning[13,35] and lighting,[36] was discussed in 3 articles.

Communication

Virtual services such as telecare for patients or telework between clinicians such as teleradiology[13] are seen as alternatives to traditional face-to-face interactions that can reduce greenhouse gas emissions. A recent systematic review of 18 articles shows that a virtual consultation could lead to a carbon reduction of 0.7 to 4.35 metric

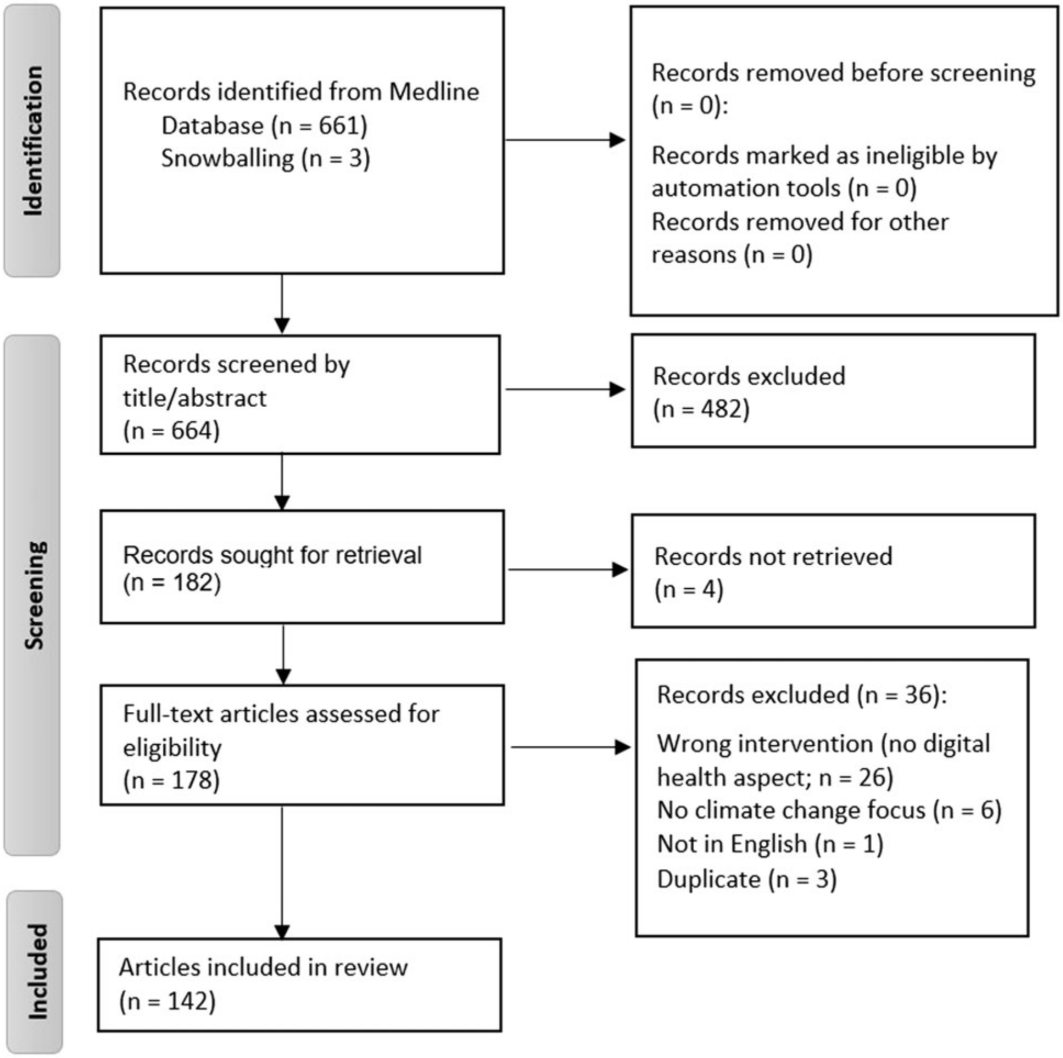

Figure 1. PRISMA flow diagram.

tons, depending on the mode of travel used.[19] Studies that took travel mode and type of fuel into account[41,45,55] or focused on remote areas where there is a need for long-distance travel to receive care[47–49] all reported that virtual care can reduce greenhouse gas emissions.[37,42,46,49] Tele-education can reduce travel by health professionals when engaging in training[59] or medical education,[13] as well as reduce paper usage associated with face-to-face events.[35]

To quantify environmental impact, some studies[32,33,58] used life-cycle assessment (LCA). LCA extends beyond energy consumed for travel to consider environmental impacts of a product over its entire life cycle (inputs and outputs). Life cycle costs could include energy saved from digitization of work, building operations, and the energy used by digital health tools, such as energy used to cool computer servers. Studies using LCA show that digital health tools, such as electronic data recording systems and teleconferencing produce 40–70 times less CO_2 emissions, depending on the type and purpose of tools.

Communication tools may also be able to increase awareness and preparedness of health professionals of the impacts of health systems on climate change. One study showed that an online forum effectively increased nurse awareness of health system sustainability issues.[60]

Management of climate change-triggered infectious diseases

Most of the articles that explored the role of digital health in addressing climate-related infectious diseases (Table 3) focused on modeling applications ($n = 34/65$) such as disease risk mapping ($n = 28/65$) and monitoring infectious disease outbreaks ($n = 21/65$).

Data sensing

One article suggested that bioinformatics data sensing tools could be developed for diagnostic tests to detect climate-related changes in infectious diseases,[61] although no empirical study was performed.

Monitoring

Timely detection of infectious disease outbreaks can be supported by monitoring for changes in the patterns of disease symptoms. For instance, a syndromic surveillance system can monitor EHR data to detect unusual increases in malaria cases, potentially in near-real-time.[62] The majority of articles discussing syndromic surveillance ($n = 8/11$) were not empirical studies. Validation and evaluation studies ($n = 3/11$) reported that syndromic surveillance methods

Figure 2. Geographical distribution of articles included. Articles such as reviews and editorials are not included in the figure. Two articles that considered global data are not included in the figure.

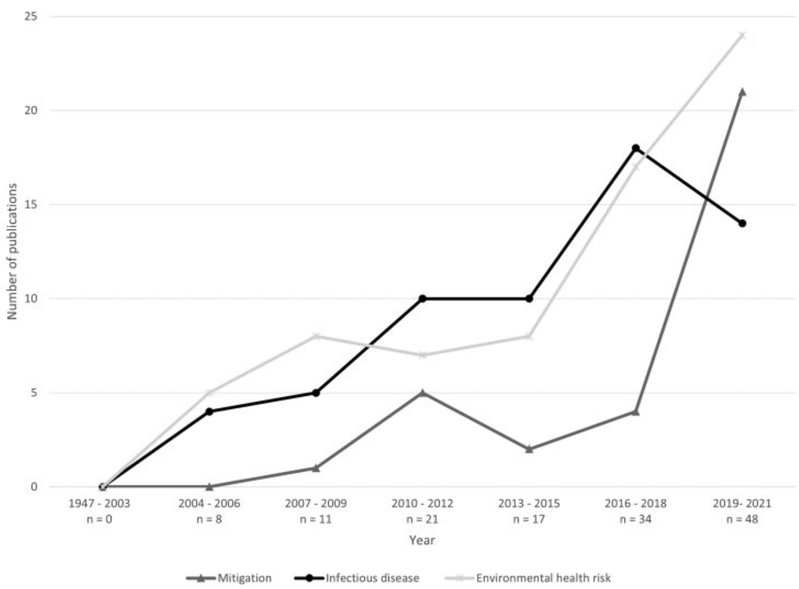

Figure 3. Publication trend by year for each climate change domain. Some studies included more than one domain; *n*, total number of publications

could detect daily changes in disease symptoms, mortality, and morbidity.[62,68]

Data mining of community data found in social media or search engine queries has also been proposed to assist with disease monitoring.[8,28,31] One study used Twitter data to detect dengue fever.[72] Another monitored disease vectors using community data collected by a mobile application that allows users to upload mosquito images and tag them geographically. These photos were later validated and classified by experts.[74] This approach has the potential to detect the appearance of vectors in new territory, where traditional surveillance methods are usually limited.

Electronic data capture

Electronic data capture can support novel discoveries about relationships between environmental factors and infectious diseases. For example, collecting and fusing environmental data (eg, precipitation,

Table 2. Classification of included articles that focused on mitigation of health system contributions to greenhouse gas emissions ($n = 33$)

Technical task	Aim	Technical method	Identified articles
Data sensing			
Monitoring	Reduce energy consumption	Carbon emission monitoring software	Emission assessment software[31]
Electronic data capture	Digitalization of work process	Digital workflows	Electronic prescriptions and referral[13,32–35]
Modeling			
Decision support			
Screening			
Diagnosis			
Treatment			
Prognosis/risk assessment			
Planning			
Control	Reduce energy consumption	Computer-aided optimization of energy use	Smart hospital[13,35,36]
Communication	Reduce travel Digitalization of work process	Tele-services	Virtual patient visits[18,19,32,34,37–55]; virtual visitor visits[34]; computer supported collaborative work[35,56]; patient support[57]; and remote staff education[35,56,58,59]
	Improve health professionals' preparedness on health system sustainability	Social media for interaction	Discussion forum[60]

temperature) and health data (eg, malaria incidence) can support the discovery of geographic differences and changes.[81–83]

Modeling

Many articles reported methods for predicting or identifying areas at risk of infectious disease ($n = 28$) using geospatial data and processing tools such as geographical information systems (GIS).[93]

Three articles used GIS to identify which environmental factors contributed the most to an infectious disease outbreak.[80,111,114] Machine learning[112,114] (eg, using feature importance analysis[112] or TreeNet-based simulation[70]) were used to identify environmental factors with the most impact on infectious diseases.

Decision support system

Decision support systems mainly generated alerts or warnings when outbreaks were identified, for example by syndromic surveillance systems. Four studies evaluated surveillance systems for mortality and morbidity outcomes associated with infectious diseases like influenza and bronchiolitis using quantitative[62,68] or qualitative[63] methods. A decision support system for detecting the presence of disease vectors with a reported 98% accuracy was developed using machine learning on images of vectors and reduced the need for human experts to classify images by 80%.[75] Another paper reported a protocol using decision analysis tools for prioritizing emerging infectious diseases using decision tree-based weighting methods on characteristics and the local status of pathogens.[117] A retrospective cohort study of a flu surveillance system assessed a novel color-coded interface for displaying alerts.[67]

Multiple ideas to solve public health challenges related to climate change and infectious disease outbreaks were developed as part of a hackathon held alongside the International Meeting on Emerging Diseases and Surveillance.[31] The 12 projects described include proposals to support populations, minimize carbon footprints, track environmental variables, and disease vectors.[31]

Communication

Communication technologies can be employed to enhance community awareness of infectious disease outbreaks. One proposal described a community-based data sharing platform, connecting community users to each other (eg, sharing an image of environmental risk) or with experts to receive feedback on concerning infectious disease risks (eg, sick farm animals).[31,73] Tele-services can also facilitate the delivery of care and education during disasters to out-of-reach areas,[43,119] including virtual consultation and home care.[118]

Management of climate change-triggered environmental health risks

Studies related to the management of climate change-triggered environmental health risks (Table 4) largely described the monitoring of environmental health events ($n = 24/71$), decision support tools for risk assessments ($n = 20/71$), and modeling ($n = 17/71$), such as environmental health risk mapping.

Data sensing

Sensors such as wearable devices or remote sensing tools that measuring an individual's health and environment can reduce exposure to environmental health risks.[73,120–124] Six protocols and prototypes were identified but there were no empirical studies. Three papers reported sensing of environmental hazards such as desert dust[120,121] or personal variables such as body temperature using wearable devices.[122] The SMARTICE system measured sea ice thickness via stationary sensors and then notifies community users.[73]

Monitoring

EHRs may help with the timely detection of health risks triggered by environmental changes such as heat syndrome.[7,64,66,126,127] Empirical studies ($n = 4$) evaluated and assessed the efficacy of existing syndromic surveillance systems[62,68,128,129] and showed these successfully detected early outbreaks of heat-related mortality and

Table 3. Classification of included articles that focused on the management of climate change-triggered infectious diseases ($n = 65$)

Technical task	Aim	Technical method	Identified articles
Data sensing	Detect presence of infectious disease	Bioinformatics development of diagnostic tests	Develop diagnostic test[61]
Monitoring	Detect outbreak of infectious disease	Medical data monitoring system	Syndromic surveillance system[7,62–71]
		Community-based monitoring of symptoms	Social media data mining[8,28,31,72]
		Community-based monitoring of vector	Apps for data collection by community participation[28,31,73,74]; image analysis by community participation data[75,76]
Electronic data capture	Support observational studies	Linking data	EHR[77,78,79]; GIS-based[80]
	Software for infrastructure	Processing and displaying data	Cloud program for environmental data[81–83]
Modeling	To predict/identify area at risk	Disease risk mapping	GIS based disease mapping[8,28,64,84–108]; genome-based monitoring[70,109,110]
	To identify environmental factors contributing to infectious disease	Model environmental features/impact related to infectious disease transmission	GIS-based analysis[111]; machine learning-based modeling[112,113]; detect ecological niche[114]
Decision support			
Screening			
Diagnosis	Diagnosis of patients	Mobile apps	Mobile-based survey tools[31]
Treatment			
Prognosis/risk assessment	Alerts for outbreak of infectious disease	Early risk assessment warning	Syndromic surveillance system embedded alerts[7,31,62–66,68,69,83,92,98,109,115,116]; Disease prioritizing[117]; vector images identification[75]
Planning	Assist with choosing the best plan	Cost-effectiveness analysis of models	Cost-effectiveness toolkits[31]
Control			
Communication	Reduce exposure to vector-borne and zoonotic diseases	Share information across the community with educational programs	Interactive education and connecting to the network of professionals for feedback[31,73]
	Deliver care to high-risk and/or remote area	Tele-services	Telehealth[31,43,118,119]; tele-education[43,118]

EHR: electronic health records; GIS: geographical information system.

morbidity. GIS can additionally analyze spatial and temporal data,[62] for example linking climatic variability and emergency calls.[69,71,126]

A novel application of unsupervised machine learning[67] for the early detection of environmental health events. The algorithm was validated on historical data where it detected heatwave events unnoticed by a previous surveillance system. This study used a visual representation of the symptoms and developed color-code-based alerts.[67]

In addition to data from EHRs, environmental and health data collected from individuals, either via sensors[120–122] or user-entered data[130] can be used for monitoring. Monitoring symptoms using web data such as search engine queries and social media posts[8,28,76,131–135] or data collected by applications specifically designed for community participation[28] have been proposed. Five ecological studies showed that data mining of social media[131,133–135] and/or search engine queries[132,133] could predict environmental health events. One study found a significant positive association between tweets that mentioned words such as heat or air conditioner and heat-related cases at emergency departments.[133] Another paper suggested integrating multiple sources of data, such as social media and mobile phone mobility data to monitor environmental risk factors (eg, air pollution) using deep learning.[76]

Electronic data capture

EHRs[77,115,136,137,139–141] and GIS[143–145] can support observational studies exploring associations between environmental changes and diseases, including mental health problems.[139] Integrating data from various sources in a GIS can support data processing and visualization of data.[81,82]

Modeling

GIS-based models can assist in identifying areas at higher risk of health problems such as injury and skin diseases triggered by climate changes.[64,97,100,147–152,154–157] For example, Liss et al[146] used unsupervised machine learning to classified geographic regions into areas at risk by identifying climatic factors that were highly associated with hospitalization due to extreme weather. GIS can also help identify the location of resources such as cooling centers[158] to inform those high at risk in a community.

Decision support

Embedding alerts in surveillance systems may assist in the early detection of changes in morbidity and mortality due to environmental events.[7,64,129] A syndromic surveillance system monitoring malaise associated with hot days had a reported sensitivity and specificity of

Table 4. Classification of included articles focusing on the management of climate change-triggered environmental health risks ($n = 71$)

Technical task	Aim	Technical method	Identified articles
Data sensing	To detect/reduce individual exposure to environmental risks	Wearable sensors and GPS	Reduce exposure to dust[120]; poor air[121]; heat[122]; ice thinness[73]; GPS based[123,124]
Monitoring	Detect outbreak of disease	Medical data monitoring system	EHR[125,126]; syndromic surveillance system[7,62,64,66–68,96,127–129]
		Environmental-based monitoring	Individualized monitoring[120–122,130]; environmental by image analysis[76]
		Community-based monitoring of symptoms	Social media data mining[8,28,131–135]; images analysis by community participation[73]
Electronic data capture	Supporting observational studies	Linking data	EHR[77,115,136–141]; GIS collected data[92,142–145]
	Software for infrastructure	Processing and displaying data	Cloud program for environmental data[81,82]
Modeling	To predict/identify impact of environmental change on health	Climatic classification	Unsupervised machine learning[146]
		Risk mapping	GIS-based mapping[8,64,97,100,147–153]
	To identify environmental factors contributing to outbreak	Risk mapping	GIS-based mapping[152,154–157]
	Identify locations of resources	Resource mapping	Cooling center mapping[158]; external facilities mapping[124]
Decision support			
Screening			
Diagnosis			
Treatment			
Prognosis/risk assessment	Alert for environmental risk	Early risk assessment warning	Water-contamination[159] heatwave[127,160]; automating detection of pollen[161]; heat[122]
	Alerts for outbreak of environmental-related disease	Early risk assessment warning	[7,64–66,69,71,116,123,126,129,150,162]
	Alert to reduce exposure to environmental risk	Personalized notification	Alert for dust[120]; air quality and pollen[121,163]; heat[122]
Planning			
Control			
Communication	Deliver care to high-risk and/or remote area	Tele-services	Telehealth[43,119]; tele-education[43]
	To manage resources in outbreaks	Tele-service	Tele-cardiology for tirage[164]
	Reduce exposure to health risk	Share information across community with educational programs	Online community platform for sharing experience[73]

EHR: electronic health records; GIS: geographical information system.

0.69 (confidence interval [CI] 0.60–0.79) and 0.73 (CI 0.64–0.82) and showed that the total numbers of malaise cases during on-alert periods were significantly higher than off-alert ($P < .001$).[129] Another system was able to detect and classify pollens with 96.2% recall and 96.1% precision and would assist in warning about heightened asthma risks.[161] A case study evaluated a system to provide warnings about drinking water contaminants using factors such as rainfall and drought that can change levels of water solids or toxins produced by algal growth.[159] Four studies reported early explorations of methods using an individual's GPS location data linked to environmental data to reduce environment exposures, including to heat[122] using wearable temperature biosensors, to dust[120] and to poor air quality, including smoke and pollen.[121,163]

Communication

As with infectious disease management, communication technologies can facilitate the delivery of care to high-risk or remote areas during climate events.[43,119] Tele-health tools can also support resource management by supporting communicating between health professionals. One study found that using telecardiology to triage patients at a local hub before referring them to a central hospital reduced the burden on the health system during a heatwave.[164] Community-level data sharing of environmental health risks is another way to respond to climate change. A review of approaches to community data sharing identified applications such as the Siku Atlas, which allowed stories and data about sea ice safety to be shared in the form of maps, audio, picture, and text across Nunavut in Canada.[73] Further, a case report described how tele-services assisted in 3 acute emergency care cases to remote areas where extreme weather conditions made it impossible for medical evacuation, reporting that patients received accurate and timely diagnoses.[119]

DISCUSSION

Overall, 142 studies were identified connecting digital health and climate change. While the number and growth in publications is promising, studies were often at a preliminary stage, for example observational studies. Studies examining efficacy were thus lacking.

Only 2 randomized controlled trials[165,166] were identified in a systematic review included for the mitigation domain.[19] Further, the regions studied were mainly high-income countries. Studies from middle- and low-income counties are lacking, despite the fact that these nations are likely to experience the highest negative impact from global warming.[167]

Mitigation of contributors to climate change

Identified studies suggested that digital health could be a game-changer for climate change mitigation by reducing travel, digitizing work processes, and optimizing health system energy use. Among the digital approaches reported, tele-services to date appear to have had the highest impact on emissions. There is a concern however that a mode of travel has not always been considered by studies estimating the amount of carbon reduction.[168] Further, digital health can itself contribute to greenhouse gas emissions, for example through the use of non-renewable energy is used to run these technologies. Promisingly, some studies are now utilizing the LCA approach, taking into account all energy consumed and emissions produced, and reporting a 40- to 70-fold reduction in emissions compared to the traditional estimates.[18]

For this research field to progress, studies will need to adopt more rigorous designs, moving from observational analyses to formal trials. A more holistic approach such as LCA considering energy consumed is particularly needed.[169] Much more empirical work is needed to find mechanisms to optimize energy use in health facility buildings. Digital health also has an as yet little examined role in managing and minimizing the environmental consequences of decisions about other sources of greenhouse gas, such as inhaler medicines, anesthetic gases,[17] medical waste, and medical devices.[170]

Management of climate change-triggered infectious diseases

Some case studies in this review showed that disease monitoring systems with embedded alerts[62,63,68] can help detect infectious disease outbreaks. While some near-real-time surveillance tools (within 24 h) were reported, we may need to develop systems with near live data processing potential, for example to assist with rapid case finding or urgent resource allocation. Monitoring community-based data such as social media data provides a promising low-cost alternative for tracking disease symptomatology[72] in regions with poor public health data systems.

In the studies identified, the use of decision support system for diagnosis and planning was little examined. The use of communication tools such as social media or chatbots to deliver information to the public were also not found, although they appear to be obvious areas for investigation and deployment.

Management of climate change-triggered environmental health risks

Syndromic surveillance systems appear to have the potential to identify environmental health events in a timely manner. GIS can contribute both to identifying regions high at risk of climate events, as well as mapping the locations of resources that can assist the population during such events, such as cooling centers. Community-based data mining may be a useful alternative for environmental health risks detection in low-resourced areas, as it is for infectious diseases.[132] We did not identify any studies exploring the management of non-communicable conditions worsened by climate change such as malnutrition.

Limitations

This scoping review provides a timely snapshot of the current evidence. We searched only one database and included only English publications. It is a possibility that some areas of study may have been missed. Future reviews will be needed to update the current search, expanding to a wider set of databases, and asking more targeted questions. Search terms for the current review were specifically developed for climate change, and so publications discussing natural disasters or climate change-related factors, for example air pollution, may not have been captured.

Future studies will be needed to explore the nexus between digital health and other health-significant problems indirectly related to climate change, such as waste management, food and water safety, social cohesion, and human population movement.

CONCLUSION

The literature on digital health and climate change response and mitigation is promising but still very immature. Digital health may have the potential to mitigate greenhouse gas emissions and can also assist with managing diseases related to climate change by timely detection of outbreaks, reducing exposure to environmental risk factors, identifying environmental risks, and facilitating the delivery of care to under-resourced areas. We expect this area of research to grow rapidly over the next few years, expanding in scope, and increasing both in the quality and quantity of studies to help us deal with one of the most significant challenges yet faced by humanity.

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AUTHOR CONTRIBUTIONS

Conceptualization: EC; methodology: EC, HR-A, and FM; database search: HR-A; screening: HR-A and EC; data extraction and synthesis: HR-A; writing—original draft preparation: HR-A; writing—review and editing, all authors; project administration: HR-A; funding acquisition: E.C. All authors have read and agreed to the published version of the manuscript.

SUPPLEMENTARY MATERIAL

Supplementary material is available at *Journal of the American Medical Informatics Association* online.

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CONFLICT OF INTEREST STATEMENT

None declared.

DATA AVAILABILITY

There are no new data associated with this article.

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