Journal of the American Medical Informatics Association, 2023, 1–11
https://doi.org/10.1093/jamia/ocad153
Research and Applications

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Evaluating the representation of disaster hazards in SNOMED CT: gaps and opportunities

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ABSTRACT

Objective: Climate change, an underlying risk driver of natural disasters, threatens the environmental sustainability, planetary health, and sustainable development goals. Incorporating disaster-related health impacts into electronic health records helps to comprehend their impact on populations, clinicians, and healthcare systems. This study aims to: (1) map the United Nations Office for Disaster Risk Reduction and International Science Council (UNDRR-ISC) Hazard Information Profiles to SNOMED CT International, a clinical terminology used by clinicians, to manage patients and provide healthcare services; and (2) to determine the extent of clinical terminologies available to capture disaster-related events.

Materials and Methods: Concepts related to disasters were extracted from the UNDRR-ISC's Hazard Information Profiles and mapped to a health terminology using a procedural framework for standardized clinical terminology mapping. The mapping process involved evaluating candidate matches and creating a final list of matches to determine concept coverage.

Results: A total of 226 disaster hazard concepts were identified to adversely impact human health. Chemical and biological disaster hazard concepts had better representation than meteorological, hydrological, extraterrestrial, geohazards, environmental, technical, and societal hazard concepts in SNOMED CT. Heatwave, drought, and geographically unique disaster hazards were not found in SNOMED CT.

Conclusion: To enhance clinical reporting of disaster hazards and climate-sensitive health outcomes, the poorly represented and missing concepts in SNOMED CT must be included. Documenting the impacts of climate change on public health using standardized clinical terminology provides the necessary real time data to capture climate-sensitive outcomes. These data are crucial for building climate-resilient healthcare systems, enhanced public health disaster responses and workflows, tracking individual health outcomes, supporting disaster risk reduction modeling, and aiding in disaster preparedness, response, and recovery efforts.

Key words: standardized terminology, systematized nomenclature of medicine clinical terms (SNOMED CT), climate change, hazards, disasters, disaster nursing

INTRODUCTION

Many extreme weather disasters are driven by climate change, which the United Nations defined as "*a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.*"[1] Since the start of 2023, our planet has experienced several natural disasters, including 2 earthquakes in Turkey and Syria that killed over 45 000 people, floods and landslides in San Paolo, Brazil, West Java in Indonesia and Ecuador, floods in Australia, tropical cyclone Freddy that struck Mauritius, Mozambique, and Madagascar, and another cyclone Gabrielle that struck New Zealand. Other disasters included a cold wave in Lebanon, severe weather in California, USA, and wildfires in Chile. Examples of technological disasters included a coal mine collapse in Inner Mongolia and China and a shipwreck with many migrants dying in Italy.[2]

During 2020, disaster-related events impacted 100 million people globally, costing $US 190 billion of global economic losses.[3] The expected annual losses from pandemic risk were estimated at US$500 billion, equivalent to 0.6% of annual global income.[4] Anthropogenic air pollution was estimated to lead to 5.5 million premature deaths in 2013, costing the global economy US$25 billion in lost labor income.[5] Additional costs are reflected in severe physical damage and destruction to healthcare facilities, loss of service delivery, loss of healthcare workforce, overburdening of healthcare services, and interruption of health programs.[6] Climate change impacts threaten the World Health Organization's

Received: 17 April 2023. **Revised:** 20 July 2023. **Editorial Decision:** 20 July 2023. **Accepted:** 21 July 2023

(WHO) *Triple Billion goals*, which aim to improve the health of billions by 2023 through evidence-based interventions, strengthened information systems, and public health policy.[7]

Climate-driven disaster impacts on the ecosystems in which people live, and biodiversity are not known. While most countries can expect to experience a large-scale disaster emergency response every 5 years,[8] including seasonal returns of cyclones and monsoon floods and disease outbreaks, climate change is exacerbating their frequency, intensity and duration, disproportionately impacting on some countries more than others.[9] Unabated climate change is an underlying disaster risk driver (defined in Table 1) that demands an urgent preparation of the healthcare systems and its workforce to resiliently navigate the management of adverse health impacts on community health, property damage, social and economic disruption, and environmental degradation.[10] To meet this urgency, new strategies are required to make healthcare systems climate and disaster resilient, particularly when there is increased pressure on the healthcare systems due to repeated management of disasters while needing to become more environmentally sustainable, equitable, and effective.[11,12]

In 2021, the United Nations Office for Disaster Risk Reduction International Science Council (UNDRR-ISC) published the Hazard Information Profiles—Supplement to UNDRR-ISC Sendai Hazard Definition and Classification Review—Technical Report, which lists 302 hazards grouped into 8 clusters: meteorological and hydrological hazards, environmental hazards, extraterrestrial hazards, geohazards, chemical hazards, biological hazards, technological hazards, and societal hazards.[14] Each cluster contains a list of defined and described hazard information profiles (HIPs).[14] The UNDRR-ISC Hazard Definition and Classification Review—Technical report[15] and its Supplement[14] support the implementation of disaster risk reduction and risk-informed investment and are aligned with the Sendai Framework for Disaster Risk Reduction 2015–2030,[16] the 2030 Agenda for Sustainable Development Goals of Agenda,[17] the Paris Agreement on Climate Change,[18] and the Addis Ababa Action Agenda on Sustainable Financing, which aligns financing and policies with economic, health, social, and environmental priorities.[19]

The healthcare workforce, including nursing as the largest professional group, is essential to meeting the care needs of the disaster-impacted communities during disaster preparation, response, and recovery.[12] Risk assessment, determining major health priorities, care planning and operational readiness, workforce capacity development, effective communication, and providing healthcare services and assistance where required to meet the community's health needs are essential components of healthcare professionals work. Furthermore, data generated by the healthcare professionals can help define what health indicators will be important in the overall monitoring of health interventions to support communities in disaster mitigation, preparation, response and recovery, and climate change adaptation and mitigation.[20] Clinical data, documented electronically in standardized terminology, can inform planning, implementation and evaluation of the effectiveness, and impact of policies, procedures, and actions, so that timely improvements in the processes can take place in the context of prevention, mitigation, preparation for, responding to, and recovering from disaster events.[21,22] Furthermore, capturing clinical workflow, in a meaningfully structured manner, is essential for providing evidence of the impact of healthcare professionals on care provision and population health outcomes.[21,22]

Nursing work can help define what health indicators will be important in the overall monitoring of health interventions to support communities in disaster mitigation, preparation, response and recovery, and climate change adaptation and mitigation.[20] Nursing data, documented electronically in standardized terminology, can inform planning, implementation and evaluation of the effectiveness, and impact of policies, procedures, and actions, so that timely improvements in the processes can take place in the context of prevention, mitigation, preparation for, responding to, and recovering from disaster events.[21,22] Furthermore, capturing nursing workflow, in a meaningfully structured manner, is essential for providing evidence of the impact of nurses on care provision and population health outcomes.[21,22] To define and code nursing care and share data about nursing, including comparing nursing practice across different settings, the International Council of Nurses (ICN) developed the International Classification for Nursing Practice (ICNP).[23]

In 2021, ICNP content was incorporated into the Systematized Nomenclature of Medicine Clinical Terms (SNOMED CT), which is available in English, Spanish, Danish, and Swedish with ongoing translation by member countries,[24] and released as a reference set by SNOMED.[25] While SNOMED CT provides a common language for healthcare professionals and health systems to accurately document, exchange, and analyze data, little is known about the representation of disaster hazards identified by the UNDRR-ISC Hazard Definition and Classification Review—Technical report[15] and its Supplement[14] as hazardous to human health. With recent work to define and extend hazard information profiles (HIPs) through UNDRR-ISC,[14,15] an opportunity exists for researchers to consider this document as an evaluation source based on standardized clinical terminologies.[25] The aim of this research was to: (1) map the United Nations Office for Disaster Risk Reduction and International Science Council (UNDRR-ISC) Hazard Information Profiles to SNOMED CT International and (2) to determine the extent of clinical terminologies available to capture disaster hazard-related events.

MATERIALS AND METHODS

This study employed a descriptive concept mapping approach using a procedural framework for standardized clinical terminology mapping[26,27] to identify hazards concepts representation in SNOMED CT.

Ethical statement

Ethics permission to conduct the mapping research was not required as the information collected is publicly available through published reports. Patients and the public were not involved in this research's design, conduct, reporting, or dissemination. Due to the nature of the study, patient consent for publication was not required.

Source concepts

The UNDRR-ISC Hazard Information Profiles—Supplement to UNDRR-ISC Hazard Definition & Classification Review—Technical Report which describes 302 HIPs was used as the source reference material for the concept extraction.[14] In this document, the hazards are grouped into meteorological and hydrological, extraterrestrial, geohazards, environmental,

Table 1. Definitions of disaster risk reduction terminology according to UNDRR's Sendai Framework Terminology on Disaster Risk Reduction Online glossary[13]

Term	Definition
Disaster	"A serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic, and environmental losses and impacts."
Disaster impact	"The total effect, including negative effects (eg, economic losses) and positive effects (eg, economic gains), of a hazardous event or a disaster. The term includes economic, human, and environmental impacts, and may include death, injuries, disease, and other negative effects on human physical, mental, and social well-being."
Disaster risk	"The potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society, or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability, and capacity."
Hazard	"A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption, or environmental degradation."
Hazardous event	"The manifestation of a hazard in a particular place during a particular period of time."
Underlying disaster risk drivers	"Processes or conditions, often development-related, that influence the level of disaster risk by increasing levels of exposure and vulnerability or reducing capacity."

chemical, biological, technological, and societal clusters. The focus was on hazards in each cluster described in this document as adversely impacting human health.[14]

Source concept extraction protocol

One researcher (ZL-T) reviewed all 302 HIPs to extract concepts, definitions, and synonyms from the UNDRR-ISC Hazard Information Profiles—Supplement to UNDRR-ISC Hazard Definition & Classification Review—Technical Report.[14] From 302 HIPs, 226 (74.8%) HIPs were described to have an adverse impact on human health. These 226 concepts were then manually mapped by 2 researchers (ZL-T and L-MP) to SNOMED CT. Their mapping was manually checked by another 2 researchers working independently (SD and CER) to find an agreement. After that, the research team met to verify completeness and accuracy and resolve discrepancies through discussion until consensus was achieved.

During the mapping process, the researchers reviewed the assigned concepts, identified clinical concept(s), categorized the concepts into a domain type (conceptual modeling) according to SNOMED CT,[28] and added possible synonyms or extensions that may not have been covered by UNDRR-ISC report as interpreted by their clinical knowledge and expertise. For example, the researchers assigned domain type(s) to facilitate an understanding of the orientation and descriptive meaning of the extracted concepts (eg, the extracted concept was "earthquake" and the domain type was "event").

Target terminology

The target terminology was SNOMED CT International Edition (2022-09-30 version). All the extracted source concepts were prepared for SNOMED CT mapping.

Mapping

The following mapping procedures were applied:

- Mapping coordination: Precoordination, whereby each source concept was mapped to a completed concept in SNOMED CT.
- Mapping style: Manual mapping in SNOMED CT.
- Hierarchical mapping awareness: All extracted concepts had potential alignment to existing concepts' hierarchies in SNOMED CT and were, therefore, candidates for SNOMED CT mapping.
- Systematic search strategy: See below for description.
- Cardinality: See below for description.

Systematic search strategy

Using the SNOMED CT online browsers, the researchers undertook a systematic process of manual searching as presented in Figure 1. These methods were chosen to minimize selection bias.[29–31] During the manual mapping phase, extracted concepts were uploaded into an Excel spreadsheet and divided among 2 researchers, where each concept was independently manually mapped 2 times. The following protocol was used in each terminology online browser:

Cardinality

The types of mapping matches were defined as follows:

- Direct match means that the concept matches precisely to the concept found in SNOMED CT.
- Broader than match means that the concept found in SNOMED CT was conceptually broader (encompasses a wider range of related concepts) than in the source concept list. It represents a higher level in the hierarchical structure of clinical concepts. For example, a general disease category (for example, infectious diseases) is broader category encompassing many infectious diseases.
- Narrower than match means SNOMED CT was conceptually narrower (more specific) than the concept found in the source concept list. It represents a lower level in the hierarchical structure as it allows for the detailed description and classification of specific diseases or conditions. For example, a specific disease is conceptually narrower because it represents a specific condition.
- No match means there were no matches in the target SNOMED CT terminology.

Evaluation

As part of additional quality assurance, the manually mapped 226 candidate HIPs concepts, definitions, and synonyms derived from the UNDRR-ISC Hazard Information Profiles—Supplement to UNDRR-ISC Hazard Definition & Classification Review—Technical Report[14] were presented to 2 additional researchers who were not part of the manual mapping phases. The researchers reviewed the extracted concept and candidate

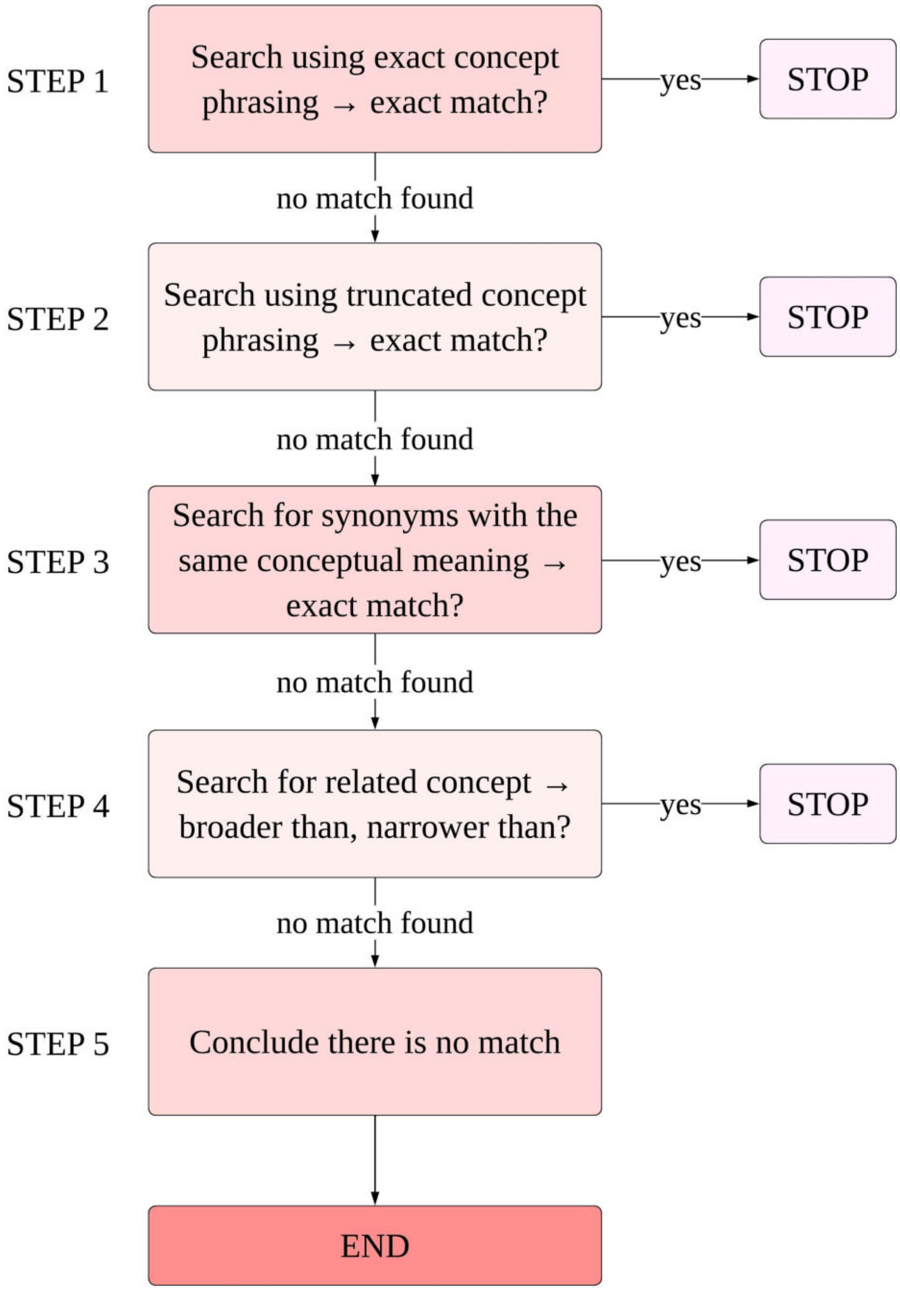

Figure 1. Representation of a systematic SNOMED CT search protocol.

mapping matches and then choose the "best" fit (ie, broader than, narrower than, no match, or exact match as described in "Materials and Methods" section) mapping and cardinality match(es). The 2 researchers noted any concepts or mapping matches that required further review. All members of the researcher group then reviewed the results of this work over 4 meetings, where results, alignment, and ambiguity were discussed. This discussion led to iterated, refined, and verified final mapping list. Furthermore, the results were compared for consensus agreement.

Data analysis

The data analysis was organized to reflect the UNDRR-ISC Hazard Information Profiles—Supplement to UNDRR-ISC Hazard Definition & Classification Review—Technical Report hazard grouping into meteorological and hydrological, extraterrestrial, geohazards, environmental, chemical, biological, technological, and societal clusters.[14] For each cluster, the overall findings were summarized using frequencies and percentages.

RESULTS

From 302 HIPs described in the UNDRR-ISC Hazard Information Profiles—Supplement to UNDRR-ISC Hazard Definition & Classification Review—Technical Report,[14] 226 HIPs (74.8%) were identified to contain a reference to adversely impacting human health in some form. Therefore, a total of 226 indicators and their concepts and synonyms were extracted (Supplementary Table S1). These were used as

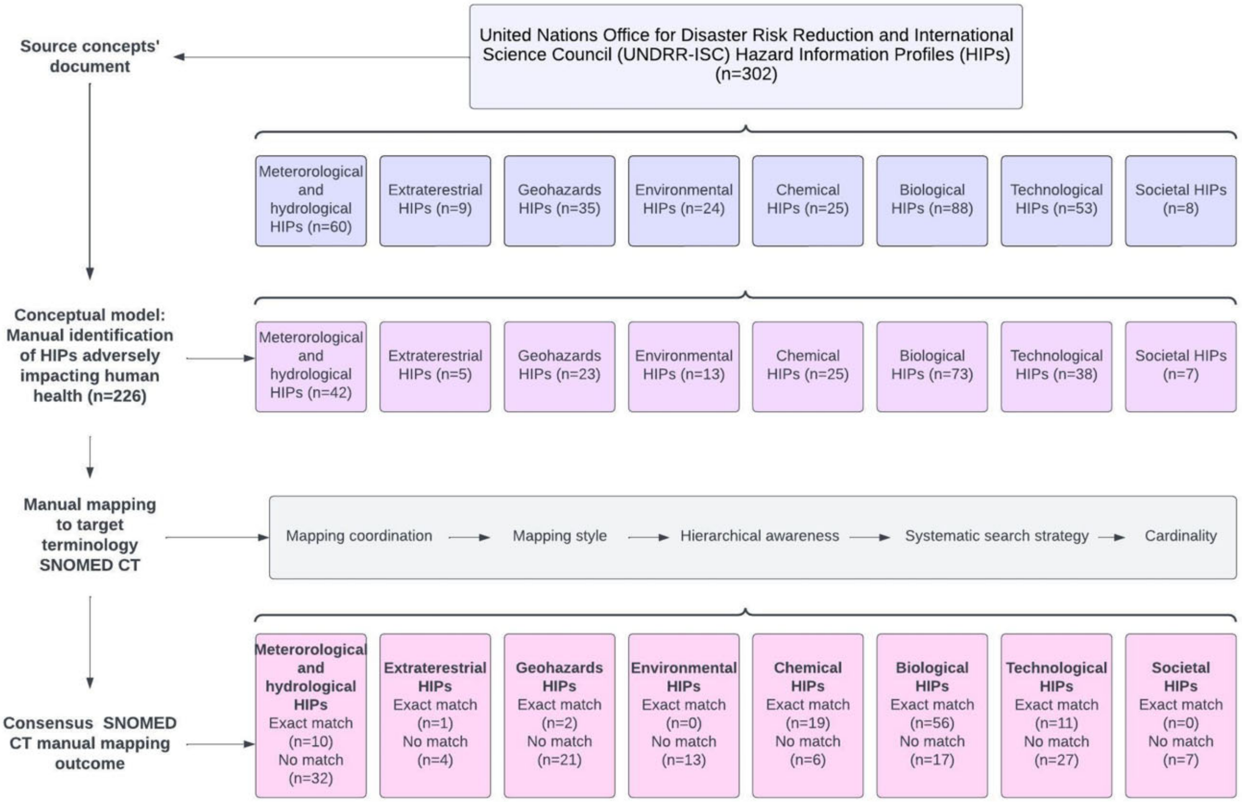

Figure 2. Procedural framework for standardized terminology mapping towards consensus outcome. The order of the concepts presented in this table reflects the grouping of hazards information profiles represented by the UNDRR-ISC Hazard Information Profiles—Supplement to UNDRR-ISC Hazard Definition & Classification Review—Technical Report.[14]

source concept candidates for SNOMED CT mapping. To support the ease of comparison to the source document, the cluster results are presented in the same order as listed in the source document: meteorological and hydrological, extraterrestrial, geohazards, environmental, chemical, biological, technological, and societal clusters.

From the total of 226 HIPs identified to impact human health, 42 HIPs belonged to the meteorological and hydrological cluster, 5 HIPs belonged to the extraterrestrial cluster, 23 HIPs belonged to the geohazards cluster, 13 HIPs belonged to the environmental cluster, 25 HIPs belonged to the chemical cluster, 74 HIPs belonged to the biological cluster, 38 HIPs belonged to the technical cluster, while 7 HIPs belonged to the societal cluster (Figure 2). All concept definitions and synonyms are documented in Supplementary Table S1.

Meteorological and hydrological cluster

In the meteorological and hydrological cluster, out of 42 HIPs, 10 items were an exact match (23.8%), and 32 HIPs had no exact match (76.2%). Out of these , 12 HIPs (28.6%) were identified as broader than, 3 (7.1%) were narrower than and 17 (40.5%) had no match. Details of the mapping of the meteorological and hydrological cluster are shown in Table 2 and Supplementary Table S1.

Extraterrestrial cluster

In the extraterrestrial cluster, 5 HIPs were identified as potentially harming human health. Of these 5 HIPs, only one (20%) had an exact match. Of the remaining 4 (80%), that had no exact match, 1 HIP (20%) had a narrower than and 3 (60%) had no match cardinality. Details of the mapping of extraterrestrial cluster are shown in Supplementary Table S1.

Geohazards cluster

In the geohazards cluster, out of 23 HIPs identified to potentially impact human health, 2 (8.7%) HIPs had an exact match. Of the remaining 21 (91.3%), 6 (26.1%) HIPs were broader than, 8 (34.8%) were narrower than, and 7 (30.4%) had no match. Details of the mapping of the geohazards cluster are shown in Table 3 and Supplementary Table S1.

Environmental cluster

In the environmental cluster, 13 HIPs were identified with the potential to harm human health. No HIPs were identified to have an exact match in SNOMED CT. Instead, 3 (23.1%) HIPs were broader than, 1 (7.7%) HIP was narrower than, and 9 (69.2%) had no match. Details of the mapping of the environmental cluster are shown in Table 4.

Chemical cluster

In the chemical hazards cluster, 25 HIPs were identified to potentially harm human health. Nineteen (76.0%) of these HIPs had an exact match. Of the remaining 6 (24%) HIPs that had no exact match, 2 (8.0%) were broader than, 1 (4.0%) was narrower than, and 3 (12.0%) had no match. Details of the chemical cluster mapping are shown in Supplementary Table S1.

Table 2. Manual mapping of the meteorological and hydrological HIPs from the UNDRR-ISC Hazard Information Profiles—Supplement to UNDRR-ISC Hazard Definition & Classification Review—Technical Report[14]

Extracted concept	Consensus SNOMED CT manual mapping results	SNOMED-CT cardinality
Downburst	No match	No match
Lightning (electrical storm)	Lightning (event); SCTID: 5193003	Exact match
Coastal flood	Flood (event); SCTID: 111056004	Broader than
Estuarine (coastal) flood	Flood (event); SCTID: 111056004	Broader than
Flash flood	Flash flood (event); SCTID: 111056004	Exact match
Fluvial (riverine) flood	Flood (event); SCTID: 111056004	Broader than
Groundwater flood	Flood (event); SCTID: 111056004	Broader than
Ice-jam flood including debris	Flood (event); SCTID: 111056004	Broader than
Ponding (drainage) flood	Flood (event); SCTID: 111056004	Broader than
Snowmelt flood	Flood (event); SCTID: 111056004	Broader than
Surface water flooding	Flood (event); SCTID: 111056004	Broader than
Glacial lake outburst flood	Flood (event); SCTID: 111056004	Broader than
Black carbon (brown clouds)	Carbon black (substance); SCTID: 3849002	Exact match
Dust storm or sandstorm	No match	No match
Polluted air	Air pollution (event); SCTID: 102413006	Exact match
Sand haze	No match	No match
Smoke	No match	No match)
Seiche	No match	No match
Tsunami	Accident caused by tsunami (event); SCTID: 217743009	Narrower than
Depression or cyclone (low pressure area)	Cyclone (event); SCTID: 48071004	Exact match
Subtropical cyclone	Cyclone (event); SCTID: 48071004	Broader than
Acid rain	No match	No match
Blizzard	Blizzard (event); SCTID: 49113003	Exact match
Drought	No match	No match
Hail	Accident due to striking by hailstones (event); SCTID: 217644006	Narrower than
Ice storm	No match	No match)
Snow	Snow (substance); SCTID: 263874004	Exact match
Snow storm	Snowstorm (event); SCTID: 59262002	Exact match
Cold wave	No match	No match
Dzud	No match	No match
Freezing rain (supercooled rain)	No match	No match
Heatwave	No match	No match
Icing (including ice)	No match	No match
Thaw	No Match	No match
Rock slide	Landslide (event); SCTID: 49061008	Broader than
Derecho	No match	No match
Gale (strong gale)	Wind (event); SCTID: 90569008	Narrower than
Squall	No match	No match
Subtropical storm	No match	No match
Tropical cyclone (cyclonic wind, rain [storm] surge)	Cyclone (event); SCTID: 48071004	Broader than
Tornado	Tornado (event); SCTID: 88644004	Exact match
Wind	Wind (event); SCTID: 90569008	Exact match

Biological cluster

In the biological cluster, 73 HIPs were described as harming human health. Of these, 56 HIPs (76.7%) had an exact match. Of the remaining 17 (23.3%) HIPs that had no exact match, 1 HIP (1.3%) was broader than, 8 (11.0%) were narrower than, and 8 (11.0%) had no match. Details of the biological cluster mapping are shown in the Supplementary Table S1.

Technological cluster

In the technological cluster, 38 HIPs were identified with the potential to harm human health, of which 11 (28.9%) HIPs had an exact match. Of the remaining 27 (71.1%) HIPs with no exact match, 6 (15.8%) HIPs had broader than, 6 (15.8%) had narrower than, and 15 (39.5%) had no match. Details of the technological cluster mapping are shown in the Supplementary Table S1.

Societal cluster

In the societal cluster, 7 HIPs were identified to harm human health. None of these had an exact match in SNOMED CT, and only one (14.3%) had a narrower than match. The remaining 6 HIPs (85.7%) had no match. Details of the manual mapping of the societal hazard cluster are shown in Supplementary Table S1.

DISCUSSION

Unabated climate change, an underlying risk driver of natural disasters, poses a significant threat to global environmental sustainability, planetary health, population health, and sustainable development goals.[32] However, real-time data demonstrating the adverse impact of climate-change related events on populations, healthcare workforce, and healthcare systems, including natural disasters at the point of care, is

Table 3. Manual mapping of the geohazard cluster hazards from the UNDRR-ISC Hazard Information Profiles—Supplement to UNDRR-ISC Hazard Definition & Classification Review—Technical Report[14]

Extracted concept	Consensus SNOMED CT manual mapping results	SNOMED CT cardinality
Earthquake	Earthquake (event); SCTID: 8766005	Exact match
Tsunami (Earthquake Trigger)	Accident caused by tsunami (event); SCTID: 217743009	Narrower than
Landslide or Debris Flow (Earthquake Trigger)	Landslide (event); SCTID: 49061008	Exact match
Ground Gases (Seismogenic)	Accident caused by gases evolved in volcanic eruption (event); SCTID: 217744003	Broader than
Lava Flows (Lava Domes)	Accident caused by lava flow (event); SCTID: 242562009	Narrower than
Ash/Tephra Fall (Physical and Chemical)	No match	No match
Ballistics (Volcanic)	No match	No match
Pyroclastic Density Current	No Match	No match
Debris Flow/Lahars/Floods	Debris (substance); SCTID: 257159000	Broader than
Landslide (Volcanic Trigger)	Landslide (event); SCTID: 49061008	Broader than
Volcanic Gases and Aerosols	Accident caused by gases evolved in volcanic eruption (event); SCTID: 242563004	Narrower than
Tsunami (Volcanic Trigger)	No match	No match
Lightning (Volcanic Trigger)	Lightning (event); SCTID: 5193003	Broader than
Urban Fire (During/Following Volcanic Eruption)	No match	No match
Liquefaction (Groundwater Trigger)	Liquefaction time (property) (qualifier value); SCTID: 733999003	Narrower than
Ground Fissuring	No match	No match
Sinkhole	Sinking (event); SCTID: 47044002	Narrower than
Ground Gases (CH4, Rn)	Accident caused by gases evolved in volcanic eruption (event); SCTID: 242563004	Narrower than
Riverbank Erosion	No match	No match
Submarine Landslide	Accident caused by landslide (event); SCTID: 217740007	Broader than
Rockfall	Accident caused by rockfall (event); SCTID: 242560001	Narrower than
Sediment Rock Avalanche	Accident caused by rockfall (event); SCTID: 242560001	Broader than
Tsunami (Submarine Landslide Trigger)	Accident caused by tsunami (event); SCTID: 217743009	Narrower than

Table 4. Manual mapping of the environmental cluster hazards from the UNDRR-ISC Hazard Information Profiles—Supplement to UNDRR-ISC Hazard Definition & Classification Review—Technical Report[14]

Extracted concept	Consensus SNOMED CT manual mapping results	SNOMED CT cardinality
Household air pollution	Air pollution (event); SCTID: 102413006	Broader than
Air pollution (Point Source)	No match	No match
Ambient (Outdoor) Air Pollution	Air pollution (event); SCTID: 102413006	Broader than
Land Degradation	No match	No match
Soil Degradation	No match	No match
Runoff/Nonpoint Source Pollution	Water pollution (event); SCTID: 102414000	Broader than
Salinity	No match	No match
Biodiversity loss	No match	No match
Wildfires	Uncontrolled fire in forest (event); SCTID: 217486005	Narrower than
Desertification	No match	No match
Loss of mangroves	No match	No match
Wetlands loss/Degradation	No match	No match
Permafrost loss	No match	No match

lacking. This is primarily due to absence of relevant concepts in standardized clinical terminologies used for electronic data documentation to capture climate-sensitive cause and outcome events. This study aimed to address this gap by mapping the UNDRR-ISC HIPs to SNOMED CT International, evaluating the extent of clinical terminologies available for capturing disaster hazard-related events. The findings of the study have identified the gaps in clinical terminologies available to healthcare professionals when delivering healthcare services during disaster-related events. By highlighting these gaps, the study sheds light on the limitations faced by healthcare providers in accurately documenting and analyzing the impact of climate-related events on health outcomes. The study also offers opportunities to expand SNOMED CT International to support climate change adaptation efforts.

The manual mapping of the UNDRR-ISC HIPs to SNOMED CT showed that while most of the hazards classified as biological (76.7%) and chemical (76.0%) were precisely mapped to SNOMED CT International, the meteorological and hydrological (23.8%), extraterrestrial (20%), geohazard (8.7%) environmental (0%), technological (28.9%), and societal (0%) hazards were poorly mapped. The substantial coverage of chemical and biological clusters in SNOMED CT International may be related to more wellestablished diagnosis content reflecting the link between many chemicals and biological organisms on population health.[33] Interestingly, hazards that had no exact match in SNOMED CT International, but were clustered in the biochemical and chemical hazard cluster, tended to represent events that impacted the environment, such as "hazardous pesticide contamination in soil" or "microplastics," found in the chemical cluster. Other examples are "harmful algal bloom," "insect pest infestation," "invasive species," and "human-wildlife conflict," which are clustered into the biological cluster.

Regarding mapping the environmental cluster to SNOMED CT International, the most surprising findings are that hazards such as "heatwave" and "drought" were not found in SNOMED CT. Considering that climate change has already exacerbated the intensity, frequency, and duration of heatwaves and droughts, leading to significant impacts on human health, migration patterns, and armed conflict situations globally,[32] there is an urgency to correct this deficit in SNOMED CT to capture these events as causative factors of many health-related issues. Furthermore, despite SNOMED CT International being designed as a clinical terminology to record clinical information at the point of care internationally, our data show that SNOMED CT International did not capture hazards identified in our UNDRR-ISC source to reflect diverse geographies prone to varied climate change impacts to enrich distinctions within narrower categories. For example, dzud/zud, a Mongolian term describing severe winter conditions[14] was not found in SNOMED CT. This inequity reflects the need to diversify human agents driving input into SNOMED CT terminology. Alternatively, it is essential to establish systems that support stakeholders globally to contribute to ongoing updating of SNOMED CT to better reflect global health needs.

From global population health, it is essential to recognize inequities across nations' health information systems infrastructures. The disproportionate impacts of climate change on areas where health systems infrastructures lack the capacity or capability to use standardized terminologies, like SNOMED CT, translates to the absence of standardized data collection, thereby representing a critical gap in data and knowledge. Compounding this data gap is that these health systems already face the challenges of providing basic care for vulnerable populations in resource-limited settings. In global healthcare, the lack of collection of such data impacts workforce planning and education, predicting impacts on health services demands, and developing interventions supportive of sustainable healthcare.[34,35] Furthermore, lack of standardized clinical terminology to capture the impacts of climate change and disasters on individual and population health hinders our ability to deliver care effectively or plan interventions that can support healthcare systems in delivering care during disasters. Thus, further work to expand concept coverage to include unique geographical and regional hazard contexts disproportionately experienced in the countries most affected by climate change, is needed. Having a global, interdisciplinary understanding, for example integrating technical and health professional expertise, and ability to codify disaster hazards, disaster events, and environmental and health impact data, is also essential when utilizing such data in analytics and artificial intelligence applications (eg, Machine Learning to predict the impacts of specific hazards on population health).[36]

Another barrier for countries and regions to increase a unique content representation in SNOMED CT may occur through the requirement that additions or changes must be managed by a Member National Release Center or by an individual from an international group identified as providing specialist content.[37,38] A National Release Center is a point of contact between SNOMED International and a Member Country, which can facilitate the required processes to support the SNOMED CT content change. While country membership of SNOMED CT is expansive, notable gaps exist throughout Africa, the Middle East, Central America, and South Asia.[39] The 2022 World Risk Report identifies the Philippines, India, Indonesia, Colombia, Mexico, Myanmar, Mozambique, China, Bangladesh, and Pakistan as countries at the highest risk for global disaster.[36] Of these, only India, Indonesia, and China are SNOMED International members.[39] While other options to increase content coverage outside of National Release Centres exist, such as being a member of an "identified" International Group, concept representation and the ability to request expansion remains an important point when considering the codification of disaster hazard concepts in SNOMED CT. One method for future consideration could be for member countries to host crowd-sourcing events,[40] where the purposeful and intentional mapping of unique hazard concepts is done with high-risk, nonmember countries. Member countries could then leverage existing National Release Centre processes to advance the representation of these concepts.

Concerning the technological cluster, a power supply failure is one of the most significant hazards absent from SNOMED CT. Extreme weather events may adversely impact critical infrastructure, including power supply.[41] As all healthcare settings, including home care, are increasingly dependent on technologies to provide safe, quality care, such as patient ventilation equipment, electronic health records, electronic prescribing, or infusion pumps, which depend on the power supply.[42] Critical access to electronic data and exchanging electronic information during disasters is essential to informed decisions and emergency management efforts.[20,23,43] Hospitals that support other hospitals during a disaster identify power supply as the most critical infrastructure to support their capacity to provide this support.[44] Securing power supply to cope with disaster events is essential to interventions that reduce health risks associated with disaster events.[44]

During the manual mapping process, we also encountered ambiguity when examining specific concepts. For example, UNDRR-ISC defines "smoke" as "a suspension in the air of small particles produced by combustion."[14] However, in SNOMED CT, "smoke" refers to cigarette and tobacco smoke (SCTID: 64197008) with the ontological parent, "gaseous substance." Furthermore, when examined in SNOMED CT as an event, term "smoke" refers either to "exposure to second-hand tobacco smoke (SCTID: 16090371000119103)," "occupational exposure to environmental tobacco smoke (SCTID: 16090771000119104)," or "an accident caused by smoke from the public building (SCTID: 242437007), private dwelling (SCTID: 242430009), or commercial premises (SCTID: 242451007)." Both "exposure to second-hand tobacco smoke (SCTID: 16090371000119103)" and "occupational exposure to environmental tobacco smoke (SCTID: 16090771000119104)" come under the parent of "Exposure to potentially harmful entity (event)."

Another concept was that of "icing" whereby UNDRR-ISC referred to "any deposit or coating of ice on an object caused by the impact of liquid hydrometeors, usually supercooled,"[14] whereas in SNOMED CT concept of "icing (substance) SCTID: 229871004" referred to a different type of food icing. Similarly, concept "Flood (event) SCTID: 111056004," whose parent is "Environmental event" appears to be broader than many flood-related hazards[14] and would benefit from the inclusion of other flood-related events such as coastal flood, estuarine flood, fluvial flood, groundwater flood, ice-jam flood, ponding (drainage) flood, snowmelt flood, and glacial lake outburst flood.[14] These ambiguities highlight a need for a more transparent and standardized decision-making process of how concept definitions are created and how they are mapped so that the potential for misinterpretation can be reduced. Ongoing research work to expand, develop, and test these representations will be required to strengthen rigor and expand the conceptual nuances of this topic in these codified knowledge systems. With respect to implementation of the results of this study, the priority for implementation would be geographically driven although the concepts linked to meteorological cluster, such as heatwaves, floods, and droughts, dominate the priority list. These phenomena will intensify as global warming continues and have the greatest impact on human health across the lifespan.[32]

In addition to capturing real-time global data on climate-related impacts on health, the availability of global codified terminology, such as SNOMED CT, provides clinicians, public health officials, and health informaticians with the opportunity to manage large volumes of clinical data that can be retrieved, analyzed, and contextualized specifically to the situation from which it was obtained (ie, heatwaves, floods, earthquakes). This capability allows for the generation of evidence for the most effective interventions to protect public health and identify climate-resilient practices. Researchers can use this data to determine the risk and scale of climate-related threats and develop surveillance systems to predict future impacts and demands, including the economic implications of climate-driven events.

By linking and mapping standardized data from sources such as electronic medical records, researchers can conduct geospatial and temporal analyses[45] to better quantify the connection between more intense and frequent weather events and specific health conditions or to identify communities that are most at risk from the impact from climate-related extremes and therefore require additional supports to adapt to climate change. This data can also be utilized by health informaticians to develop algorithms, models, and tools that enhance data analysis and knowledge discovery. Ultimately, this leads to the development of new climate- and disaster-resilient models of care and the ability to predict demands on healthcare services during natural disasters and allocate resources accordingly to meet increased demand while delivering value-based care. The evidence derived from these analyses would serve as valuable information for policymakers and government leaders, assisting them in making informed decisions regarding climate change mitigation and adaptation strategies.

Limitations

One limitation is that the UNDRR-ISC HIPs template document did not clearly identify disaster hazards where climate change was the underlying risk driver. In addition, the impact of some disaster hazards on human health was only sometimes explicitly described. Instead, the same generic description was provided, for example, in different types of floods. In some instances where HIPs without an exact match were mapped, it was often difficult to decide whether the classification should be "narrower than" or "broader than." For example, when reviewing HIP for "foodborne viruses," the closest cardinality was "foodborne transmission" (qualifier value). Furthermore, some concepts such as "leaks and spills," "vaccine preventable diseases," neglected tropical diseases, foodborne virus/microbial hazards, antimicrobial resistance are too broad and would require more research to establish the levels of granularity in order to increase the depth and extent of terminology.[14] We also encounter ambiguity with some terms in SNOMED CT requiring individual rather than standardized interpretation, which was addressed through group discussion in this study. In the term mapping of tsunami, several event causes (eg, earthquake trigger, volcanic trigger) were identified in the source document. Our mapping found these source concepts were narrower than what was available in SNOMED CT. Improving the representation of this concept and building it out with hierarchical depth could address this gap and support the precise documentation of this hazard. For example, adding a parent concept of Tsunami (event) with child concepts of Tsunami earthquake trigger (event) and Tsunami volcanic trigger (event), which collectively had a transitive relationship to a Geohazard (event) concept. An additional limitation of the manual mapping was of how the team interpreted "narrower than" and "broader than" concepts at individual levels requiring consensus decision for a final outcome was required to decide the outcome. For example, when discussing "Oil Pollution" the match of "Oil Spill (event) SCTID: 57371001," was considered by some team members to be narrower than "Oil pollution" whereas others considered it to be an "exact match." Further research is required to refine the manual mapping methodology to standardize the decision-making process towards increased rigor in the mapping process.

CONCLUSION

With increased climate change impacts on the frequency, intensity, and duration of extreme weather events, the world will experience more natural disasters. Tracking and assessing these disasters' impacts on the human population's health and wellbeing and tracking progress on health interventions addressing these challenges is essential to healthcare systems and community's climate change adaptation and mitigation. The value of "all hazards" approach mapping to SNOMED CT suggests that the integration of these hazards into SNOMED CT International and their subsequent use in health information systems will enable standardized collection of the public health impacts of disasters data that can be shared at local, national, and international levels. In turn, data sharing makes possible for health informatics research community to develop predictive models built on real-time clinical data that can enhance health system and community emergency management, monitoring and resilience to natural disasters. Sound data foundations and data sharing can enable, for example, the use of advancements in artificial intelligence to estimate future demands on services, impacts on human health and the local environment, and healthcare workforce needs. Thus, emergency management and global organizations, such as the WHO, can draw upon real-time data that is geographically unique to assess the impacts of hazards on global health outcomes to model and predict where investments and resources to develop more resilient healthcare and community systems are needed. For this to occur, there needs to be a conscious decision by clinical terminology systems to preserve social justice, equity, and diversity by being responsive to geographically specific pressures and reflective of specific environmental hazards that threaten human health. The next step for the work reported here is the application to SNOMED CT to integrate our findings into SNOMED CT International.

FUNDING

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

AUTHOR CONTRIBUTIONS

The initial project idea was conceived, managed, and supervised by ZL-T. All authors then contributed to the refinement of the idea and to the formal analysis of the results. ZL-T drafted the first version of the manuscript. All authors contributed to discussions on the direction of the manuscript, and subsequent manuscript revisions and all agreed to the final manuscript version. AI-assisted technologies were not used in the production of submitted work.

SUPPLEMENTARY MATERIAL

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

CONFLICT OF INTEREST STATEMENT

ZL-T is a member of Climate and Health Alliance, Alliance of Nurses for Healthy Environments, World Health Organisation Global Community of Practice for Nursing and Midwifery specific to Climate Change, Climate Reality Leadership Corps, and Australian College of Nursing Emission Reduction Policy Chapter. The remaining authors report no conflict of interest. All authors are members of the International Medical Informatics Association (IMIA).

DATA AVAILABILITY

The data available are presented in this article and in its Supplementary Material. Access to EndNote library available on request.

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