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EVAC+CHAIR
ATANSYON!
KOURAN TRE DANZERE
(ZEN POU SEPTANM)
WARNING!
VERY DANGEROUS CURRENTS
(JUNE TO SEPTEMBER)
ATTENTION!
(JUIN A SEPTEMBRE)
ATTENZIONNE!
(GIUGNO FINO A SETTEMBRE)
WARNUNG!
SEHR GEFAHRLICH STROMUNG
(JUNI BIS SEPTEMBER)
Tornado
Shelter
LES DA LA
BIENVENIDA

From Multi-Hazard Early Warning Systems (MHEWS) to All-Vulnerability Warning Systems (AVWS)

Ilan Kelman[1,2,3,4,6,*] and Carina J. Fearnley[1,5]

Summary

Science, policy, and practice have long accepted that disasters occur due to vulnerabilities rather than hazards, yet approaches to warnings still tend to be hazard-focused. Multi-Hazard Early Warning Systems (MHEWS) are meant to provide warnings for many hazards, whether sequential, simultaneous, or cumulative, and even if ostensibly independent. Despite their advantages, MHEWS display the same inherent limitation as most warning systems: they focus on hazards, without sufficient attention given to vulnerabilities. This paper aims to explain and overcome this limitation of hazard-focused warnings and warning systems. Following discussion of the ethos behind, advantages of, and limitations regarding MHEWS including with respect to the United Nation's 'Early Warnings for All' initiative, this article proposes a complement to MHEWS: All-Vulnerability Warning Systems (AVWS). The implications of and further work for implementing AVWS are discussed, highlighting the vision that warning systems as social processes should:

1. Across different people, address vulnerabilities conferring widely varying experiences to the same hazard.
2. For the same people, address vulnerabilities conferring similar difficulties to different hazards.

Disaster risk

Disaster risk, by definition, combines either (i) hazard and vulnerability or (ii) probability of something happening and the consequences of it happening.[1,2] Parallels in the two definitions emerge, in that an earthquake or explosion is not necessarily a hazard unless there are or could be deleterious consequences, which would emerge namely due to vulnerabilities. An axiom of contemporary disaster research is that disasters are caused by vulnerability rather than hazard.[3] The disaster is the deleterious consequences, not the probability of something happening.

To reduce disaster risk, hazards can and should be controlled and modified, provided that further problems do not result. Examples are barriers to block or deflect avalanches,[4] designing a chemical plant to prevent flammable substances from inadvertently encountering heat or sparks,[5] and nudging an asteroid away from the Earth[6]. Targeted weather modification retains high uncertainties,[7] although human-caused climate change is rapidly and substantially altering global weather.[8] Some hazards currently cannot be entirely stopped, such as magma exiting

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volcanoes and tornadoes touching down. Efforts to control others might end up producing more damage, with river floods being notable.[9,10] Irrespective, as Rousseau[11] explained to Voltaire after the 1 November 1755 earthquake and tsunami in Lisbon, Portugal, human constructions must still be damaged for the environment to be problematic. The reason for the disaster is the vulnerability or consequences.[12]

These definitions have variations. The word 'hazard' does not exist in many languages, with examples being Spanish and Norwegian, so terms used instead might be 'threat', 'danger', and 'risk'. Climate change research[8] popularised a third term, exposure, as being separate from vulnerability. As an expression of what exists to be harmed—including but not limited to people, businesses, nature, buildings, energy supplies, and transportation systems—exposure is embraced in many definitions of 'vulnerability'. Hence, vulnerability and exposure can be difficult to separate. In financial sectors including insurance, 'exposure' tends to mean an entity's potential for or susceptibility to specific harm or losses.

Irrespective of these differences, the key aspect remains that actions can and should be taken to reduce, minimise, and eliminate detrimental consequences from threats.[13] When actions are not taken, then disasters can result. Consequently, as per Rousseau[11] and more formalised contemporarily starting in the 1970's,[14] disasters are not caused by nature, such as a hurricane or an earthquake. Sometimes a specific phenomenon ends up in a disaster and sometimes a specific phenomenon with similar parameters does not end up in a disaster. Sometimes, people and places affected by the same specific phenomenon experience widely disparate disaster-related outcomes.

The difference in outcomes occurs due to differing levels of vulnerability, often with poor correlation between hazard magnitude and disaster magnitude.[1,2,3] Since disasters do not come from nature, they are not natural and the term 'natural disaster' is seen as a misnomer which would be best avoided.[14] Hashtags #NoNaturalDisasters and #DisastersAreNotNatural are used to communicate this point.

With disasters resulting from vulnerabilities accruing over the long-term due to societal decisions, another key aspect of disasters that was formalised in contemporary disaster research is that disasters happen slowly.[1,15] Many hazards emerge rapidly, with earthquakes and tornadoes being common examples. No matter what the timescale of a hazard, vulnerabilities must exist for a disaster and these vulnerabilities have taken a long, slow, social process to be built up and maintained. These vulnerabilities are typically societal, being part of structures and institutions, often revealed by hazards as individual vulnerabilities, even though created by the wider, long-term processes. Consequently, disasters are a long, slow, social process; rapid-onset disasters do not occur for the same reasons that natural disasters do not occur.

Since disasters are much more than hazards and come from vulnerabilities over the long-term, the key to reducing disaster risks is to reduce vulnerabilities over the long-term. Nevertheless, many initiatives aimed at tackling disaster risks continue to focus on hazards, sometimes including warnings which is this paper's focus.

This paper aims to explain and overcome the limitations of hazard-focused warnings and warning systems. To achieve this aim, the next section outlines the current tendency to push for Multi-Hazard Early Warning Systems (MHEWS) including within the United Nations' initiative 'Early Warnings for All' (EW4All). Then MHEWS are problematized in order to lead to the following section which proposes the complement of All-Vulnerability Warning Systems

(AVWS). The final two sections, respectively, explore the implications of adopting an AVWS approach and further work needed to pursue it.

Multi-Hazard Early Warning Systems (MHEWS)

MHEWS focus on hazards

One approach highlighted for redressing disaster risk is warnings, often framed as warning systems or early warning systems (EWS). Warnings and affiliated systems have been part of human culture since humans first emerged. People would learn what current weather conditions might portend for coming weather or they would learn that when the nearby mountain shakes, they should move farther away. These systems could not be perfect. Some volcanoes erupt for the first time in human history. Weather forecasting today remains inexact and probability based.

These approaches, and the standard approach, for warnings and warning systems is to focus on the hazard or hazards, typically aiming to isolate a particular hazard for a specific warning. Table 1 lists some examples. Warning system work can overlap, such as NOAA and USGS in the USA operating some gauges in the same places along the same rivers.

Table 1: Examples of Warning Systems

Organisation	Hazard(s)	One Advantage	One Disadvantage	Website at the Time of Writing
Africa Multi-hazard Early Warning and Action System.	Weather and water.	Aspects of vulnerability are included in warnings.	Limited information is available for the public.	https://au.int/en/pressreleases/20230730/shaping-future-africas-drive-multi-hazard-early-warning-systems
Japan Aerospace Exploration Agency (JAXA) Earth Observation Research Center (EORC) Real-Time Monitoring for Tropical Cyclones.	Tropical Cyclones.	Information is free to access and anyone can sign up for alerts.	The online information is neither user friendly nor geared toward the public.	https://sharaku.eorc.jaxa.jp/cgi-bin/typhoon_rt/main.cgi?lang=en
National Oceanic and Atmospheric Administration (NOAA) in the USA.	Tsunamis.	Information is free to access and anyone can sign up for alerts.	The work is subject to the whims of government funding.	https://www.tsunami.gov
Planetary Defence Office of the European Space Agency (ESA).	Near-Earth objects, such as asteroids and comets which could hit the Earth.	Although funded mainly by European governments, it identifies potential threats to the world.	The Sun obscures any objects heading toward Earth from that direction, meaning that the hazard monitoring is incomplete.	https://www.esa.int/Space_Safety/Planetary_Defence
United Kingdom Government.	Pandemics.	It is purported to be the first in the world, possibly inspiring others.	It focuses on one infection type, respiratory.	https://www.gov.uk/government/news/uk-to-create-world-first-early-warning-system-for-pandemics
United States Geological Survey (USGS).	Earthquakes. Volcanic eruptions.	Information is free to access and anyone can sign up for alerts.	The work is subject to the whims of government funding.	https://www.usgs.gov/programs/VHP/volcano-updates

Simultaneous hazards occur, such as an earthquake during a disease outbreak.[16] Many hazards by definition involve multiple hazard components. A tropical cyclone brings high winds, coastal flooding from storm surge, and flash flooding from rainfall. A volcanic eruption typically has multiple hazards, such as ash-dust clouds flowing down the mountain's slope (pyroclastic density currents), fragments of rock falling from the sky (tephra), and ash injected into the atmosphere which might travel thousands of kilometres.

To recognise the inevitable and usual reality of multiple hazards—often termed compound, cascading, or complex hazards—one frequent theme has been Multi-Hazard Early Warning Systems (MHEWS) in which a warning system aims to cover several hazards.[17] MHEWS are meant to provide warnings for many hazards, whether sequential, simultaneous, or cumulative—including for hazards that are ostensibly independent of each other.[18] An example would be weather watches and weather warnings applying to any type of weather, such as precipitation type, rate, and amount; wind speed and direction for the average and for gusts; and air temperature maximum, minimum, averages, and durations. This approach would contrast with having different warning scales and vocabulary for each type of weather and issuing those warnings separately.

MHEWS need to consider vulnerabilities

MHEWS can be touted as the essential baseline for warnings, focusing on their ethos and advantages, while paying less attention to their limitations and possible alternatives. The main detriment is the focus on hazards rather than highlighting vulnerabilities, given that the reducing the latter is needed to reduce disaster risk.

Certainly, a warning system is not complete simply because many hazards are covered or because multiple data sets are collected. Long-standing lessons from warning system research still apply, with the overarching truism that warnings are for people, not for hazards.[19,20] To achieve this baseline, warnings need to be personalised, so that all recipients understand the messages, recognise the messages as being for them, and are willing and able to act on those messages. Some people can leave their work and home as many times as needed. Others might fear leaving home due to experiences of harassment, assault, or burglary.[21] Some people cannot leave their job, even for a few minutes, because their work is continuously essential such as intensive care nurses and train drivers.

Some people might be fired for abandoning their post, such as some assembly lines. One company was fined, although is appealing, after six workers died in their Kentucky factory on 10 December 2021 when tornado touchdown warnings were issued, but the workers were allegedly not permitted to take shelter.[22] This example would demonstrate structural and institutional vulnerabilities, particularly creating individual vulnerability for low-wage workers in order to serve the profits of the business owners. A suggestion to overcome this vulnerability would be to promulgate, monitor, and enforce labour laws permitting people to evacuate without them losing their jobs. Some countries do so, demonstrating the viability. The US culture would make it far more challenging to redress such societally engrained mechanisms of vulnerability creation.

Consequently, MHEWS require a process involving and serving all of society. No warning message across any hazard or combination of hazards should assume that people are in a familiar environment. People travel to locations with other languages and cultures for work, holiday, visiting friends and family, education, health, and many other reasons. When someone is in the locality where they live, they might be in an unfamiliar part or in a different environment (e.g., their first time skiing, trying a new store, or having just started a new job) when a hazard manifests. Nor should a warning message assume that people have sufficient resources to act. They might know that they have to leave the area, yet do not have a private vehicle and do not have the spare cash for public transport fees or for alternative accommodation. They might be caring for people or animals and so need support for the caring tasks. They might be temporarily impaired, for instance in labour giving birth, under the influence of alcohol or drugs, or exhausted from having just worked a physically gruelling or 36-hour shift.

Overall, no MHEWS should assume a generic human being responding as a perfectly trained, responsive, and competent automaton. Populations change over time, as do individuals. What worked for MHEWS last year or last decade might not work now. An individual might not be in the same condition between minutes or decades.

Early warnings for all

Recognising that everyone in all their circumstances require warnings, in 2022, the United Nations formulated the ambition to reach everyone with EWS by 2027, called 'Early Warnings for All' (EW4All).[23] While the headline is laudable, the details indicate concerns.

The stated aim is 'to ensure universal protection from hazardous hydrometeorological, climatological and related environmental events through life-saving multi-hazard early warning systems, anticipatory action and resilience efforts'.[23] The immediate scoping to some hazard categories undermines the ethos of MHEWS. Focusing on 'events' means that long-term environmental processes are excluded. Examples are drought and subsidence, but a major surprise is that climate change is ostensibly not part of EW4All. Weather changed by climate change, such as tropical cyclones decreasing in frequency and increasing in intensity,[24] are included, without also covering Ice Ages from natural climate change or ocean acidification from human-caused climate change.[8]

Finally, highlighting 'protection' implies separating people and the environment, rather than accepting their inseparability. Alternatively, 'living with' environmental phenomena—both processes and events, including weather, climate, and all of nature's other offerings—has been an established baseline for dealing with disaster risk.[25] Rather than viewing the environment as inherently hazardous so that everyone needs protection from it, 'living with risk' means considering how to reduce risk through living with the environment. Sometimes, protection through separating people from the environment is necessary. Being in the middle of a pyroclastic density current or a vegetation fire is almost unsurvivable without a barrier between the people and, respectively, the heat/ash and heat/smoke.

Conversely, some levels of cold air temperatures and wind speed (together, termed 'wind chill') are easily survivable with appropriate clothing rather than staying indoors with artificial heating. Some levels of hot air temperatures and humidity (together, termed 'humidex') are easily survivable with appropriate clothing and drinking plenty of water, rather than staying indoors with artificial cooling. At points, protection from high or low air temperatures is needed through artificial temperature control.

This example leads toward the importance of vulnerabilities. Not everyone can afford to purchase appropriate clothing or has access to sufficient drinking water, so they might die whereas others live. Even in countries such as the UK, thousands of people die every year because they cannot afford to heat or cool their home properly.[26] These situations are not about the individuals per se, but rather are about governance, resource allocation, and political power creating structural and societal vulnerabilities emerging as individuals suffering from this 'fuel poverty'. This prevalence of vulnerability, leading to mortality in easily survivable circumstances, means that information about cold weather or hot weather warnings could reach everyone as a warning, without much that some people could do. EW4All is not satisfied since 'anticipatory action and resilience efforts' cannot be taken irrespective of the 'multi-hazard early warning systems'. In fact, viewing the former as being separate from the latter immediately limits the scope of what a MHEWS is presumed to be.

The context of a set of hazards can change the warning needs as well. To understand how and why this context impacts warnings, disaster studies frequently use scenarios, speculation, counterfactuals, and hypotheticals for indicating what could happen or what could have happened.[5,7] Then, actions can be taken in order to avoid the disaster, which is the point of reducing vulnerabilities.[1,2,3] The point of disaster research, policy, and practice is ultimately to prevent casualties, damage, and disruption, which can best be achieved by not having a disaster.

One example is that a thunderstorm moving over a roofless stadium requires a different warning for when the stadium is empty compared to when an event is starting/ending (so people are arriving and leaving) or is ongoing (so people are in place in the stadium). If a flash flood or tornado warning indicates the need to evacuate to shelters, the context is different during a pandemic with expectations for face coverings, use of hand sanitiser before touching a door handle, and/or physical distancing from others. Some storms bring the threat of flash floods requiring evacuation to upper storeys simultaneously with the threat of tornadoes requiring evacuation to basements. MHEWS should be able to deal with both, in addition to possibilities for hail which might discourage outdoor movement toward a tornado shelter or up slopes away from a river.

Consequently, in addition to warnings being personalised for vulnerabilities in order to achieve EW4All, MHEWS must be localised for any given situation and contextualised so that everyone is covered. Covering one subset of hazards, as in EW4All's 'hazardous hydrometeorological, climatological and related environmental events', does not suffice for MHEWS, let alone for all warning needs.

Problematizing MHEWS

To be fully effective, a warning system should somehow embrace considerations beyond specifically known or apparent hazards, being creative and imaginative in order to prepare for unknown hazards alongside uncertainties in hazard estimations and projections. This statement is, in effect, a contradiction: being ready for something without knowing what it is. Creativity, initiative, and imagination can input into such actions, yet could never overcome the inherent contradiction in this requirement. Consequently, MHEWS will inevitably have major gaps due to the impossibility of being complete regarding all (possible or expected) hazards.

On 18 May 1980, Mount St Helens in the northwest USA was known to be ready for an eruption. Magma movement produced a small earthquake, triggering a landslide on the volcano's flank which removed enough material to permit the pressure building up inside the volcano to be released in an explosive lateral eruption in which 57 people perished. On 17 June 2017, the Karrat Fjord on the western side of Kalaallit Nunaat (Greenland) experienced a massive tsunami which propagated down the coastline, flooding Nuugaatsiaq village with up to 1.5 metres of water and killing at least four people. The tsunami was caused by a rock fall or other form of slide which might have been triggered by ice melting in (or longer-term freeze-thaw cycles affected by) higher air temperatures linked to human-caused climate change. In these instances, a MHEWS might or might not consider all the named hazards and the complete sequences which led to the fatalities. Alternatively, perhaps a single-hazard warning system would be preferable in order to focus on the damaging final phenomenon. Perhaps a combination would be suitable.

Whether or not any particular MHEWS should cover all (possible or expected) hazards and hazard combinations (simultaneously, sequentially, and cumulatively) continues to be discussed. Monitoring and evaluating the effectiveness of MHEWS would help with comparing them, keeping in mind the eternal question about how to quantitatively and qualitatively analyse the effectiveness of MHEWS.

If an accurate and precise message indicates that a Sturzstrom, storm surge, or lahar is impending, but the specific word is not known or not understood, then the warning system might not be classifiable as being highly effective. As noted earlier, many languages do not have the word 'hazard' leading to problems with the basics of MHEWS. They end up more troublesome when languages, cultures, or individuals do not have the words for or understand the phrases of specific hazards.

In 1985, impressive hazard maps had been produced and communicated regarding threats from Nevado del Ruiz volcano in Colombia. On 13 November, over 20,000 people died despite warning messages being issued which would have permitted timely evacuation. One of the many problems was people not fully understanding what a lahar is or its possible impacts, with one contribution to the misapprehensions being that the word used in Spanish was (inaccurately) 'avalanche'.[27] In November 2013, Super Typhoon Yolanda (Typhoon Haiyan) killed over 6,000 people in the Philippines. One major factor identified in people not heeding warnings for evacuation was using the term 'storm surge' which was new to them, whereas survivors indicated that they would have understood and responded better to the (inaccurate) word 'tsunami'.[28]

Where warning messages are accurate and precise, but people make informed and resourced decisions not to heed the advice, the meaning of 'effectiveness' requires further analysis. The effectiveness of MHEWS would also be affected by close calls / near misses and false alarms. Where some hazards are not considered in MHEWS for justifiable resource constraints or reasonable trade-offs, 'effectiveness' might refer to only the hazards covered.

These questions remain subjects of ongoing research, segueing into understandings of current limitations of MHEWS. A significant limitation relates to vulnerabilities: how people would engage with warnings and warning systems when they cannot afford to do so financially or socially. Lack of financial affordability could be not having money to evacuate or being in danger of losing a job by being absent, irrespective of the dangers of being present. Lack of social affordability could relate to having disabilities, caring responsibilities, or local statuses which do not make it easy to leave one's home, irrespective of dangers. Even when people receive perfect information and know exactly what to do within MHEWS, some people might still not be able to act due to vulnerabilities foisted on them by long-term societal processes, often articulated with terms such as poverty, injustice, marginalisation, discrimination, and oppression. Drawing on the citations provided throughout this paper, Table 2 summarises many aspects of vulnerabilities. It offers merely an illustrative overview rather than a comprehensive or definitive summary. It is deliberately generic and superficial in order to instil particular lines of thought in those dealing with warnings, rather than expecting every set of circumstances to parallel the specific examples and evidence in citations throughout this paper.

Table 2: Illustrative Vulnerabilities

Vulnerability Type	Example
Individual demographics	Adults have sometimes had more years of education than most children, meaning that those adults can access and process information about hazards and hazard mitigation better than many children.
Population demographics	Specific needs of a variety of groups of people with disabilities are typically neglected, meaning that they have fewer options for informing themselves about, and redressing potential impacts from, hazards.
World views	Where people believe that a deity or deities should and do decide their fate, then some groups become less inclined to implement measures to avoid disasters.
Financial	Where jobs serving society such as teachers and nurses are paid orders of magnitude less than people leading for-profit organisations, then the skills most essential post-disaster will be less available, since people with those skills can be the most affected by the disaster.
Governmental	Where government is corrupt, then money is siphoned away from improving and maintaining infrastructure.
Societal structures	Where a specific demographic is expected to take on family caring responsibilities, then that group and those cared for tend to be slower at preparing and evacuating, since not everyone in the family contributes their knowledge and skills.
Discrimination	Where a specific gender or sexuality is outlawed, then that group tends to be listened to less regarding preparedness needs.
Oppression	Where people of a particular caste are presumed by those in power to deserve their living situation, then less societal help tends to be available for making their homes and workplaces safer.
Marginalisation	Where people are forced to live in dangerous locations due to finances or demographics, then they typically experience the worst hazard impacts.

Toward All-Vulnerability Warning Systems (AVWS)

The questions raised about MHEWS and EW4All lack systematic research to offer answers with confidence. In particular, a solid theory or conceptualisation of MHEWS remains a gap. While these topics are important for research and development of MHEWS, possibilities exist for overcoming some identified difficulties of MHEWS by returning to the baseline of disaster risk science. In particular, the focus of MHEWS on hazards diverges from the baseline ethos of disaster-related work that disasters are not caused by hazards. Since a disaster is a process caused by vulnerabilities over the long-term and warning systems are social and societal processes that need to be developed and implemented over the long-term, warning systems could be reframed to focus on vulnerabilities.

Highlighting vulnerabilities in and for warning systems would build on the current focus on hazards through MHEWS in order to move toward All-Vulnerability Warning Systems (AVWS). This suggestion neither abandons nor denigrates a multi-hazard approach, instead incorporating it into understanding and redressing vulnerabilities through warning systems. That is, AVWS complement and incorporate, rather than contrast with, MHEWS. Then, ‘warnings for all’ through AVWS serves everyone on their own terms irrespective of hazards and multi-hazards. Two key aspects from disaster risk science[1,2,3] support the move toward AVWS:

1. Across different people, vulnerabilities confer widely varying experiences to the same hazard.
2. For the same people, vulnerabilities confer similar difficulties to different hazards (for the same people.

Different people experience the same hazard differently

On the first point, vulnerabilities giving different people widely varying experiences to the same hazard can be physical and social.[1,2,3] Physical aspects can emerge from individual characteristics. Children[29] and elderly[30] do not thermoregulate as well as others, plus children have a higher ratio of body surface area to body volume, so these age groups are typically affected most during heat waves.

Other vulnerability factors affect mortality and morbidity during heat waves. Outdoor workers such as agricultural labourers, construction workers, and deliverers experience heat more than many workers who can stay inside,[31] as long as the indoor workers have sufficient cooling and ventilation—which garment workers, for example, typically lack.[32] Many of these workers might not get paid or might lose their job if they take a break from work, leading to incentives for them to continue working irrespective of heat waves.

These aspects are social conditions foisting expectations on certain groups of individuals, thereby creating vulnerabilities to a particular hazard and suggesting that warnings ought to involve employers as much as employees. Consequently, vulnerabilities are not just about physical and social characteristics and circumstances of individuals. Vulnerabilities are very much created and perpetuated by social conditions.[1,2,3] People are forced into poverty and kept there. They have few livelihood options, so they must remain as an agricultural labourer or garment worker with little possibility for advocating for improved working conditions. They have few choices regarding where they live, meaning limited possibility to stay cool at home during heat waves, few resources or permissions to seismically retrofit their property in an earthquake zone, and must continue living in a floodplain without flood resistant dwellings or viable evacuation routes. Vulnerabilities are systemic, societal, and generally forced on people by those who could choose otherwise.[1,2,3]

Another heat-related vulnerability is based on gender, exemplifying the social aspects and the creation of vulnerabilities by society, rather than by the people who experience the vulnerabilities.[33] In most places, it is more acceptable for men than women to wear fewer clothes and to urinate in public. Consequently, irrespective of physiological differences, women would wear more clothes and would drink less water when outdoors in heat waves, leading to higher heat and humidity mortality and morbidity for women than for men—although men, in taking off more clothes, might experience more sunburn. If society does not wish to change to support gender-equitable vulnerability reduction, for males and females, then heat-related warnings might wish to include messaging that specifically tackles these gender-differentiated vulnerability aspects.

Similarly, people with pre-existing breathing ailments, such as asthma, are far more affected by smoke from vegetation fires than people without such pre-existing conditions.[34] The hazard can lead to widely varying outcomes from mild irritation, possibly avoidable by wearing a mask and goggles, through to death. These outcomes depend on vulnerabilities and so AVWS for vegetation fire smoke would account for these differences.

The same people experience different hazards similarly

On the second point introducing this subsection, vulnerabilities give people similar difficulties to different hazards. People who have mobility restrictions, whether from arthritis or using a wheelchair or crutches, typically cannot evacuate as fast as others irrespective of the hazard.[35] An earthquake warning system might offer 20 or 40 seconds between the P-waves and S-waves, which suffices for many people to get underneath a sturdy piece of furniture and hold on, followed by carefully exiting the building once the shaking stops, as long as it is safe to do so.[36] A tornado warning system might offer 10-20 minutes that people should go to basements or to shelters. These timeframes might not suit people with physical movement restrictions or who are bedridden.

The unsuitability of many earthquake and tornado warning timeframes for people with mobility restrictions is not the fault of the individuals. Nor could the timeframes be improved much, given the current state of knowledge regarding the hazards. Instead, society has decided that infrastructure—including evacuation routes and shelters—is designed, built, and maintained assuming that people are mobile enough to get to safety for earthquakes and tornadoes. Society has determined who is advantaged and disadvantaged by the warning system for hazards which are regular, typical, and with known approximate timeframes.

Recognising how these vulnerabilities are created by society's decisions on warning systems, decisions on warning systems could change. Earthquake warning systems ought to include information on how people can act within the earthquake warning timeframe if they are unable to 'drop, cover, and hold'. Tornado warning systems ought to include support for people with various mobility abilities to help themselves reach safe locations. Expecting instead that someone else would be around to assist others reinforces dependency and makes assumptions about personal relationships, thereby continuing to foster vulnerabilities for a certain group of people—those who simply have different mobilities than others.

A parallel example is that people who are colour-blind would be disadvantaged when visuals from warning systems including MHEWS use a traffic light approach, namely green-amber/orange/yellow-red to represent, respectively, safe-caution-danger.[37] Colour-blindness by itself does not confer, create, or exacerbate vulnerability. Choices for warning systems, which would include AVWS, to not account for colour-blindness creates the vulnerability by making interpretation more difficult for a certain group. Vulnerability as a societal process, rather than being inherent to the individual, is again demonstrated.

As another class of examples, evacuation and sheltering are inhibited by fear of harassment and assault,[38] lack of hygiene and privacy,[39] and wishing to protect one's property.[21] These reasons manifest irrespective of the hazard(s), being the same vulnerabilities to all hazards and multi-hazards. AVWS would recognise why some people might not respond to impending hazards. Before a hazard appears, the AVWS process would work with people to determine what they would need to overcome the challenges—in effect, 'warnings for all'.

How far AVWS can go to account for everyone's ever-changing needs remains an open research and practice question. Individuals and groups vary in vulnerabilities, depending on the amount of sleep, stressors in lives, and any impacts from substance intake such as alcohol, caffeine, medications, and drugs. Individuals and groups also vary in vulnerabilities depending on their chosen and unchosen roles in society, how cultural structures place them and treat them according to their demographic characteristics, and societal structures including livelihoods, violences, marginalisations, discriminations, oppressions, injustices, governments, and governance.

Over the decades of contemporary vulnerability research,[1,2,3] extensive efforts have sought to produce tables, infographics, schematics, and frameworks to distinguish various types and sources of vulnerabilities while demonstrating their interactions and feedbacks. No single approach has proved to be satisfactory.[40] To fully express and communicate in different forms the depth and interlacing of vulnerabilities, particularly their root causes and feedbacks, vulnerability theories require further advances. One notable step is getting past the retrogressions that climate change has brought, such as the aforementioned separation of exposure from vulnerability.

'Warnings for all' means for everyone at any time in any circumstances. Further work is needed for dynamic AVWS, serving everyone as their hourly, daily, annual, and other conditions change, through individual, collective, and societal decisions and lack of opportunities to make decisions. Steps toward achieving this challenge are explored in the next section.

Implications of All-Vulnerability Warning Systems

Highlighting vulnerabilities as the baseline cause of disasters accepts why disasters happen and hence how they should be tackled. The implications of taking an AVWS approach offers lessons for warnings.

Focusing on people and vulnerabilities suggests moving away from the paradigm of 'the last mile' (or 'the last metre') of warnings and toward 'the first mile' (or 'the first metre').[41] The last mile is set up as overcoming the final step of warning systems, articulated as being that not everyone is reached by warnings. Closing this gap between warnings and everyone who needs them—which is actually all of us—is seen as the last action for completing a warning system. This argument is difficult to defend since a warning system cannot exist unless the people who need it are part of the system. Consequently, the first mile of warnings ensures that people are placed first, often termed 'people-centred warning systems'.[42] From the first notion of developing a warning system, it is for and about people, as a long-term social process. It involves and learns from people throughout the warning process to confirm that their warning needs are being met or else it adjusts to ensure that gaps are closed.

Language and vocabulary were discussed earlier. The dilemma between using correct but not understood vocabulary compared to incorrect but understood words is easily resolved by implementing a warning system long before a hazard emerges. Focusing on vulnerabilities through AVWS would identify and redress gaps in knowledge, language, vocabulary, connotation, and interpretation.

Advice within MHEWS on responding to a particular hazard or set of hazards could also be problematic. Consider instructions to evacuate to a shelter at a school to stay safe,[43] yet those who are meant to evacuate are regularly bullied, harassed, and assaulted along the evacuation route or at that school.[44] The evacuation and shelter would not seem to be safe due to focusing on hazard(s) rather than on vulnerabilities.

As another example, manuals as part of wider warning systems advise stockpiling several days of supplies including non-perishable food and bottled water.[45] This advice could be suitable for most hazards, yet does not address the vulnerability of many people not being able to afford enough food each day, let alone stockpiling for several days. Plus, in some places, if it is known that someone has stockpiled, then they might become a magnet for robbery.

Another paradigm within warning systems emerging from MHEWS is the 'end-to-end' warning system, implying a clear starting point followed by a linear, step-by-step approach to reach a clear ending point. Warning systems as societal processes do not function fully by adopting this structure. Instead, warning systems require multiple, continuous inputs from a diversity of sources, followed by many pathways interacting and feeding back into each other to produce an ever-evolving warning system adjusting to people's changing needs. Starting with the latter is 'the first mile', with the warning system's components converging and branching according to expressed and identified needs—notably about identifying and reducing vulnerabilities. The warning system's process never really ends, as it must continue to be connected to and integrated into people's daily and decadal lives, always demonstrating the improvements from the warning system such as by overcoming vulnerabilities. Beyond 'end-to-end', warning systems become end-to-end-to-end-to-end-to-end-to-end-to-end-to-end… also including nodes as node-to-node-to-node-to-node…

These multiple interactions, connections, feedbacks, and adjustments cover all time scales and all space scales. Warning systems can be global such as for near-Earth objects on a collision course with our planet[46] or can be suitable for a single household requiring much more evacuation time for a vegetation fire than nearby households.[47] As above, specific warning messages can be short-fuse for earthquakes[36] offering less than a minute to act or could be decades-long, as seen for human-caused climate change.[8]

Given these varying scales, 'early warning systems' are only part of the warning system process. With all time scales being important, 'medium-term warning systems' and 'late warning systems' are part of the warning process. They provide a diverse repertoire to cover the timeliness required for various vulnerabilities to various hazards. In any case, the terms 'early', 'medium-term', and 'late' are subjective, as seen for earthquakes.[48] For a specific location, the maximum possible earthquake warning time might be five seconds or for a flash flood might be five minutes. These timeframes could give sufficient time for some people to act in some circumstances, yet the label 'early' could induce a false sense of security—particularly for people who could never act within these timeframes.

AVWS indicate that these time-based labels could not proffer the full scope of a warning system. Possible timelines are often limited by the hazard, such as for an earthquake or a flash flood, demonstrating that MHEWS still have a place and should not be abandoned. Knowing vulnerabilities and addressing them through warning systems would indicate the full scope of what the warning systems need to achieve. With those goals, long-term plans could be developed to achieve them, thereby reducing all vulnerabilities to all hazards. MHEWS, where useful, sit within AVWS.

In particular, reducing all vulnerabilities to all hazards with warning systems focusing on vulnerabilities would support the wider ethos within avoiding disasters and reducing disaster impacts of living with risk[25] and living with change.[49] The former was detailed earlier. The latter refers to environmental changes of which human-caused climate change is a major influence[8] and social changes of which mobile phones and the internet have both had huge influences on warning systems.[50] Living with change must also refer to individual changes which could range from new financial circumstances—for instance, losing or gaining a job which impacts evacuation and sheltering possibilities—through to new health circumstances, whether being pregnant or having given birth, receiving a clinical diagnosis requiring treatment and medication, or having reduced vision, hearing, or mobility.

An illustration is reduced cancer diagnosis and treatment in the UK due to inadequate preparation for the COVID-19 pandemic.[51] Aside from pandemic warnings not being fully acted on in the UK,[52] focusing on vulnerabilities such as cancer diagnosis and treatment within the warning system could have helped planning to support people's medical needs amid pandemic-related restrictions. Rather than manufacturing an apparent and false trade-off between COVID-19 deaths and cancer deaths, a vulnerability-focused pandemic warning system would have incorporated the need for lockdown-related measures without compromising the health of people requiring medical treatment or the medical and non-medical staff (e.g., janitors) needed for diagnosing and treating them. A specific recommendation is to ensure that everyone has enough personal protective equipment (PPE), which the UK lacked[53] even though this gap was known in the UK long before COVID-19.[54]

AVWS can account for changing hazards, since vulnerabilities are treated as dynamic with actions always required to identify and reduce vulnerabilities in order to live with all ongoing changes. For instance, flood and drought parameters change with factors including reservoir construction and climate variabilities.[10,55] Rather than a new reservoir requiring that MHEWS change from slow-rise floods to flash floods, or change from meteorological drought to agricultural drought,[55] AVWS remain consistent in focusing on people's vulnerabilities and aiming to reduce them to all hazards and hazard changes.

Moving forward

No warning system is or could be a panacea. Warning systems contribute to efforts to redress disaster risk within wider contexts of other risks, perils, and concerns, seeking safer and health lives and livelihoods. Much remains undocumented or unverified regarding warning systems, including the history of the concept and the reality of warning systems alongside a comprehensive theory. Many glimpses into the history are offered by specific examples, such as a 1900 hurricane[56] and nineteenth century discussions of volcano warnings.[57] Meanwhile, others have offered contemporary overviews of warning systems.[58,59,60] This material provides a helpful baseline for developing a theory which would combine with existing conceptualisations of specific aspects, such as false alarms, near misses, and close calls.[61] Investigations into MHEWS remain limited on all such aspects, with AVWS never before having been considered.

The next step in moving forward might be to work through different frameworks for AVWS to determine whether or not an overarching form does exist and would be useful. If so, then a specific framework could provide a starting point for all warning systems, assisting with comparisons and ensuring that any AVWS achieves its purpose. A variety of frameworks is available for warning systems including MHEWS. None is agreed upon and all are heavily critiqued, at times with an alternative proposed[62] yet not adopted. A single, universal framework for AVWS, or indeed for MHEWS, might not be feasible or might not be appropriate to pursue, instead focusing on contextual approaches.

In parallel, a schematic, visual, or diagram could help to communicate the components and processes of an AVWS or a suite of them. The main challenge in visualising is making the figure simple enough to be understood across contexts without being so simplistic that it misleads.[63] Many MHEWS diagrams simplify the warning process to a linear chain, which mispresents the system. Conversely, adding in all the steps, connections, and feedbacks could alienate audiences due to the complexity—or could backfire by diminishing key components of inclusivity.[64] As per the adage, a picture should be worth a thousand words rather than requiring a thousand words to explain it. Similarly to a framework, some form of elegant visualisation might be justifiable in principle, while being counterproductive in practice.

Table 3 reviews the disasters mentioned in this paper before this subsection, with one point regarding what might be relevant to consider for an AVWS in this context. In this context, it is important not to judge what happened in each example without fully understanding what was known at the times and analysing the politics swirling around and within each situation.

Table 3: Applying AVWS to Disasters Mentioned in This Paper

Date	Location	Hazard(s)	Warning notes	An AVWS suggestion
18 May 1980.	Washington, USA.	Explosive volcanic eruption.	Warnings were reasonably technically accurate for the time.	Finding ways for people to fully recognise their vulnerabilities, since many who perished were in the exclusion zone.
13 November 1985.	Nevado del Ruiz, Colombia.	Lahars.	Warnings were impressively technically accurate.	Addressing differences in language, vocabulary, and understandings between scientists and people in affected locations.
5-10 November 2013	Central Philippines.	Typhoon.	Warnings were impressively technically accurate.	Recognising some people's limited evacuation and sheltering options.
17 June 2017.	Western Kalaallit Nunaat.	Tsunami.	Little pre-hazard work had been completed.	Informing on the wide variety of tsunami sources and potential outcomes, so anyone near water

				needs to know actions to take.
10 December 2021.	Kentucky, USA.	Tornadoes.	Warnings were impressively technically accurate.	Being able to evacuate and shelter without fear of losing jobs.
11 March 2020 – 5 May 2023, although ongoing and long-term.	Worldwide.	COVID-19 pandemic.	Key warnings were issued soon after the new virus and new disease were identified.	Expressing better and earlier possible measures and their implications for different population groups.
Ongoing, long-term.	Worldwide.	Human-caused climate change.	Key warnings were first issued at high political levels during the 1980s.	Highlighting the benefits of stopping human-caused climate change.

Once frameworks and schematics have been established and accepted, or completing these tasks is determined to be infeasible and inappropriate, then the next step would be to explore the relevance, impact, advantages, and limitations of AVWS. One technique could be an analysis of AVWS' strengths, weaknesses or limitations, opportunities, and threats or constraints (common acronyms for the technique are SWOT and SWOC). This analysis would connect to and embrace the context of other warning approaches, notably MHEWS. Doing so would mean seeking, as much as possible, systematic, historical, and verifiable evidence regarding three principal points.

First, AVWS need to be consistently costed in terms of the resources required to set up and maintain them compared to the benefits accrued from them. Cost-benefit analyses are used to demonstrate monetary savings from addressing disaster risks.[65] Some examples of these financial analyses exist for warning systems[66,67] with the need remaining for more systematic approaches.

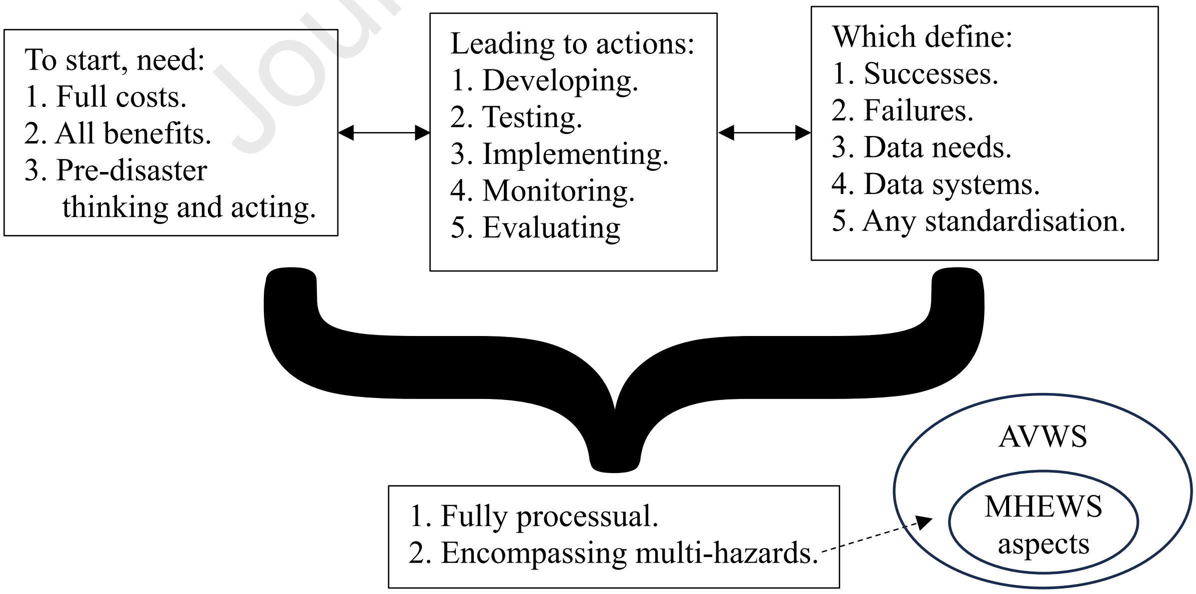
Second, warning systems are not just about saving money, but are also about saving lives and livelihoods, with cyclones in Bangladesh being a typical example.[68] From tens of thousands of deaths in cyclones in 1970 (before independence), 1985, and 1991, deaths per cyclone in Bangladesh have dropped orders of magnitude in recent years, being in the dozens or hundreds due to a comprehensive education, preparedness, warning, evacuation, and sheltering programme focusing on vulnerabilities.[68] This knowledge is now being applied to a landslide EWS for the country,[69] noting that despite the vulnerability baseline, the focus remains on hazard-specific warning systems. Bangladesh is further covered by the Indian Ocean Tsunami Warning System,[70] again being hazard-specific. Non-monetary cost-benefit analyses for warning systems are needed, with earthquakes being an exemplar.[36]

Third, as with Bangladesh, a warning system is often enacted or upgraded after a disaster. AVWS assist in thinking ahead of a disaster to develop, maintain, and adjust warning systems without disasters occurring—and therefore preventing disasters.

An ongoing example relates to near-Earth objects. Although it is highly likely that people were killed in previous meteorite strikes, prominently the 1908 Tunguska explosion[71] and the Kaali crater from several millennia ago,[72] no human fatalities from near-Earth object strikes have yet been confirmed. Long-standing efforts at near-Earth object warning systems exist,[46] including under the banner of 'planetary defence',[73] which were in place even before the first confirmed human injuries during the 2013 Chelyabinsk meteor.[74] Similarly, warning systems exist for many active volcanoes which have not been involved in a known disaster[75] with the hope of evacuating people in time should rumbling begin. As always, these examples are hazard-focused.

These three points, brought together in a schematic in Figure 1, direct evidence to be compiled for developing, testing, and implementing AVWS. Simultaneously, monitoring and evaluation mechanisms would be developed, tested, and implemented. One question emerging from Figure 1 is the standard governance query regarding who should be responsible for the work. The answer is the usual baseline within any services and actions deemed to be for society (for instance, health care, education, transport, drinking water, and rubbish collection and disposal): It depends on political ideology/ies. Some believe that the private sector is always better than any government; some believe that governments' primary role is to take responsibility for society; some prefer not-for-profit entities to lead businesses and governments; and some seek a balanced mix. Moreover, governments, businesses, and not-for-profit entities come in an enormous variety, so there is no homogeneity within these sectors. Different choices are inevitably made in terms of the evidence basis desired and required for moving forward, the roles of scientists from across sectors, and inputs from a variety of knowledge and wisdom forms. Such differences of viewpoints and actions, based in ideology/ies, have always permeated warning systems research, policy, and practice, with no agreement and no single approach accepted or shown to succeed (however success is defined) in all circumstances[1,2,13,75,76,77] (which is the same conclusion for all other services and actions deemed to be for society).

Figure 1: Moving Forward with AVWS: A Schematic for Critique



Any warning system faces the standard challenge of defining success and failure.[59,61,78,79] When a warning message is issued and then it might not have been needed, no agreed evaluation approach exists to determine the balance of success and failure during these so-called 'false alarms'. When a warning message is not issued or is somewhat incorrect, so a disaster could have happened based on poor warning messaging, but for other reasons a disaster did not happen, no agreed evaluation approach exists to determine the balance of success and failure during these so-called 'close calls' and 'near misses'. A priority agenda item for further work on warnings and warning systems, especially to establish the effectiveness and limitations of AVWS, is delineating monitoring and evaluation measures and metrics.

To fulfil this agenda item, methods, systems, and resource requirements would be needed for data collection, maintenance, and analysis. Despite the calls for MHEWS, this information is unavailable. Nor are there standardised requirements, expectations, or vocabulary for theorising, designing, creating, implementing, maintaining, monitoring, evaluating, and decommissioning MHEWS. In fact, standardising them and forcing them on everyone for all contexts might be counterproductive.

Emphasising that AVWS complement and encompass, but do not entirely replace, MHEWS means that pursuing these elements can be done in tandem with AVWS and MHEWS. An open question remains about whether or not standardised and systematic approaches for universal data and requirements would be advantageous, given the contextuality of warnings and warning systems. Irrespective, data are both qualitative and quantitative, as well as being instrumental and personal including through the variety and richness of local knowledges and wisdoms. Localised approaches do not preclude comparisons, but do mean approaching them with caution, since baselines can legitimately diverge.

All these elements indicate the importance of warnings and warning systems as processes, being part of the efforts to counter the processes of disaster and vulnerability. In contrast to Figure 1, warning systems are not stand-alone structures, operated and managed by groups separate from the people who need and use the systems (which is all of us). They are most effective when integrated into and contributing to daily life and livelihoods—thereby being effective 'for all' provided that everyone is involved, is contributing, and has their warning needs met.

While never denying that hazards can contribute to disasters, indicating that MHEWS are enfolded within the warning process, the key cause of disasters remains vulnerabilities. Consequently, AVWS would be the most appropriate direction to achieve the goal of 'Creating Effective Warnings for All'.

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Declaration of interests

The authors declare no competing interests.

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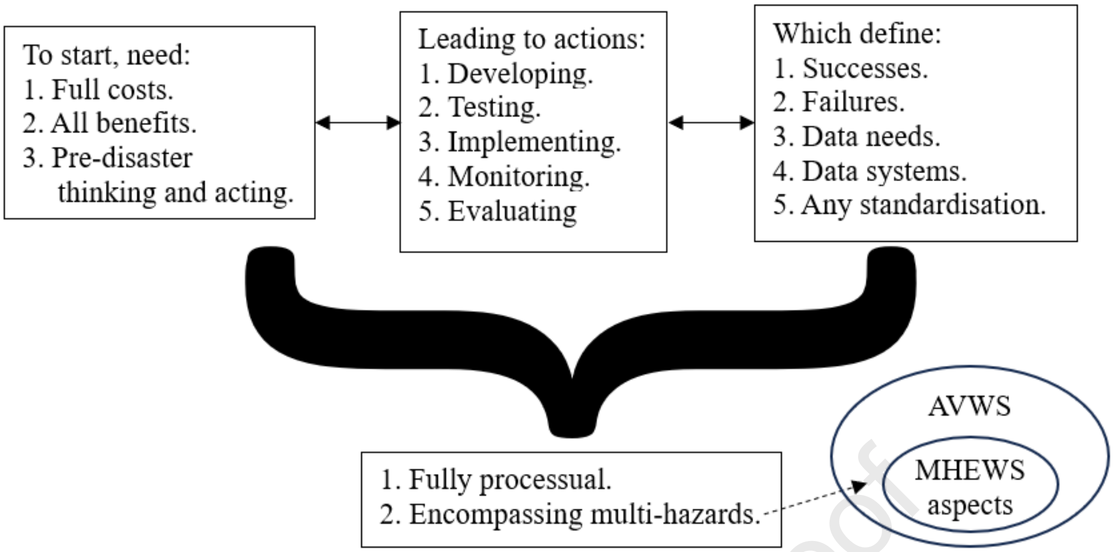
To start, need:
1. Full costs.
2. All benefits.
3. Pre-disaster thinking and acting.
Leading to actions:
1. Developing.
2. Testing.
3. Implementing.
4. Monitoring.
5. Evaluating
Which define:
1. Successes.
2. Failures.
3. Data needs.
4. Data systems.
5. Any standardisation.
1. Fully processual.
2. Encompassing multi-hazards.
AVWS
MHEWS aspects