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Chemical Toxicants in Water: A *GeoHealth* Perspective in the Context of Climate Change

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Key Points:

- Integrating additive and synergistic biological actions of water contaminants can address the issue of chemical exposure and health outcomes
- Environmental injustice can be mitigated by inviting community stakeholders to participate in scientific-based policy decision-making
- Community-engaged research and action can facilitate policy decisions to safeguard drinking water and public health

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Abstract The editorial focuses on four major themes contextualized in a virtual *GeoHealth* workshop that occurred from June 14 to 16, 2021. Topics in that workshop included drinking water and chronic chemical exposure, environmental injustice, public health and drinking water policy, and the fate, transport, and human impact of aqueous contaminants in the context of climate change. The intent of the workshop was to further define the field of *GeoHealth*. This workshop emphasized on chemical toxicants that drive human health. The major calls for action emerged from the workshop include enhancing community engagement, advocating for equity and justice, and training the next generation.

Plain Language Summary In June 2021, a virtual workshop was held that attempted to elucidate four major themes within *GeoHealth*. The four major themes include drinking water and chronic chemical exposure, environmental injustice, public health and drinking water policy, and the fate, transport and human impact of aqueous contaminants in the context of climate change. Common threads throughout the workshop were the importance of community engagement and the interplay between academic scientists and impacted communities. The workshop also highlighted the need to prepare public health agencies regarding chemical toxicants and climate change and its impact on public health through education, monitoring, research, and contribution to public dialog. We propose that carefully constructed communication streams to the public about outcomes from *GeoHealth*-related research can facilitate policy decisions for improved public health outcomes.

1. Introduction

In recent years, there has been an upswell in research that relates earth and environmental sciences to human, agricultural, and environmental health (McEntee, 2016). The field of *GeoHealth* has attracted the attention of many water resource professionals that desire to use large, pre-existing datasets to characterize the water quality and quantity of “waterscapes” (i.e., watersheds, streams, aquifers) as they pertain to ecosystem services and human health (Jordan & Benson, 2015). A three-day *GeoHealth* workshop titled “Chemical Toxicants in Water: A *GeoHealth* Perspective in the Context of Climate Change” was conducted focusing on climate change, environmental health, and science communication in the context of water quality. The workshop was organized by the Center for Health Equity Research at Northern Arizona University, in conjunction with faculty from the University of Idaho, the University of Nebraska Medical Center, and the University of Nebraska–Lincoln, from June 14th to June 16th, 2021. The four major themes of the *GeoHealth* workshop were: drinking water and chronic chemical exposure, environmental injustice, public health and drinking water policy, and the fate, transport and human impact of aqueous contaminants in the context of climate change. The workshop demonstrated the importance of integrating geospatial data with epidemiological research, addressing the long-standing issue surrounding environmental justice, and including approaches to serve communities most impacted by environmental contamination and climate change. This editorial reflects the research intentions that came out of the workshop.

2. Drinking Water and Chronic Chemical Exposure

Clean drinking water quality is of the utmost importance to public health, as almost 10% of the global population does not have access to safe drinking water (World Health Organization, 2015). While contaminated drinking water can result from the presence of microbes, chemical contamination can also lead to several adverse health

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outcomes, including increased cancer incidence, cardio-vascular diseases, and adverse reproductive outcomes (Levallois & Villanueva, 2019; Villanueva et al., 2014; Ward et al., 2018). For instance, Ward et al. (2018) did a meta-analysis of epidemiological studies and found linkages between an increased exposure to nitrates through drinking water and methemoglobinemia, adverse reproductive outcomes, cancer, and thyroid disease in women. Similarly, Jones et al. (2020) demonstrated the negative environmental impacts and human health risks associated with mining activities on unregulated groundwater sources in the Western Navajo Nation. While these case studies were conducted across different regions, all of them identified that populations exposed to high concentrations of chronic chemical contaminants (e.g., arsenic, uranium etc.) may also expect to see an increase in some specific adverse health impacts.

While many countries monitor drinking water quality, there is a need for a virtually continuous updating of methodologies and safe water quality standards, as advances in water quality quantification and emerging public health concerns lead to the identification of previously unregulated contaminants (Levallois & Villanueva, 2019). Furthermore, while focusing on an individual contaminant and its public health impact is beneficial (Almberg et al., 2018; Richard et al., 2014), there is also a need to shift toward focusing on synergistic interactions between contaminant mixtures (Joseph et al., 2022; Lagunas-Rangel et al., 2022; Villanueva & Levallois, 2015).

3. Environmental Injustice

Environmental injustice (Cook et al., 2021; Mathiarasan & Hüls, 2021) is a long-standing reality in which disadvantaged communities often bear a disproportional burden with respect to environmental contamination and subsequent adverse health impacts (Diaz, 2016). For example, several studies have identified that families living in socio-economic deprived areas are disproportionately exposed to environmental threats resulting in higher susceptibility to adverse health outcomes (Bashir, 2002; Evans, 2004; Rosen & Imus, 2007). However, on a community level, their collective voices are typically not heard, and they are rarely incorporated into decision-making processes (Diaz, 2016).

While environmental injustice undoubtedly occurs, it can be more complicated than it appears at first blush (Butler et al., 2016; Edwards et al., 2009; Wines & Schwartz, 2016). Occasionally, community members may not be receptive to information about environmental contamination and management within their community (e.g., Bennett and Dearden (2014); Gehrig et al. (2018)), particularly when authorities or residents prioritize economic impacts over environmental ones (Al-Emadi et al., 2022; Prayag et al., 2021). This can be attributed to not wanting to lose access to convenience, property value depreciation, the fear of an increased tax burden to support new or improved infrastructure, and the tendency of communities to favor short-term gains over longer-term issues. One way to dampen community resistance is to engage the community in as many science and science communication steps as possible (Gray, 2018). This strategy builds trust and provides citizens with the appropriate information to make decisions that fit within their community framework (Altman et al., 2008; Nyström et al., 2018). Examples where this has been effective, identified that the approach of two-way communication between citizens and scientists fosters collaborative work, relationship building, and learning (Mercer & Littleton, 2007; Riesch & Potter, 2014; Roche et al., 2020).

While the *GeoHealth* field promotes integrated science, there is a need to improve efforts to produce open science to ensure environmental justice (Barnard et al., 2022). Adopting open science strategies such as ICON (Integrated, Coordinated Open Network) throughout the research lifecycle helps alleviate this environmental injustice problem to an extent by empowering populations that are disproportionately marginalized (Acharya et al., 2022; Arora et al., 2022; Barnard et al., 2022; Dwivedi et al., 2022; Salman et al., 2022; Sharma et al., 2022). ICON science principles aim to (a) integrate science across physical, chemical, biological, and social attributes; (b) coordinate the use of consistent protocols across systems and researchers; (c) provide for an open exchange of ideas, data, and models throughout the research lifecycle, and (d) create a platform for multiple stakeholders to network (Barnard et al., 2022; Goldman et al., 2022).

While cohesion between scientists and the community is laudable, its impact on environmental health can be eroded if the driving force underlying the cohesion is the short-term acquisition of funding (e.g., Fanini et al. (2019)). Community members are, by definition, in it for the long term, not for the length of a 3–5 years Federal grant (Gralton et al., 2004). Consequently, these partnerships need to extend beyond the life of a single project and focus on building sustained relationships (Lindenmayer et al., 2012). Funding schemes must be

constructed to provide long-term support for ecological issues. Likewise, integrating community stakeholders into all facets of the program can provide opportunities for sustainability and the continuation of the project beyond the initial funding mechanism (Holmes, 2011; Lindenmayer et al., 2012).

4. Public Health and Drinking Water Policy

Underrepresented communities, particularly those with low-income status, are at a disproportionate risk of consuming poor drinking water (American Public Health Association, 2001). For instance, drinking water violations were more prevalent in Black and Hispanic mid-sized communities in the United States when poverty levels exceeded 40% (McDonald & Jones, 2018; Switzer & Teodoro, 2017). Furthermore, low-income communities have a greater tendency to have their drinking water delivered through aging infrastructure. In the U.S. alone, the American Society of Civil Engineers reported that aging water systems pose a substantial risk to public health from water piping deterioration, leading to leaching contaminant loads into potable water sources (Grigg, 2015). As an example, the *GeoHealth* workshop highlighted the significance of Flint, Michigan's historic, lead-based water delivery systems and fixtures as primary sources responsible for the lead poisoning phenomenon.

Considering drinking water policy and public health in a global context, there are current inadequacies of formal and informal institutions to ensure safe drinking water and sanitation. For example, World Health Organization (2014) found that less than one-third of 94 countries have policies, plans, and coverage targets set for educational institutions and health care facilities to meet and monitor safe drinking water standards. This pattern is pervasive in developing communities and correlated to a lack of funding, access to tools for monitoring, and a general infrastructure deficiency (Li & Wu, 2019; Montgomery & Elimelech, 2007).

A holistic approach to policy governance, involving government officials, professionals and the public, needs to be implemented to safeguard public health and ensure safe drinking water. These policies should include water supply and distribution regulations and measures to guarantee safe drinking water quality (Li & Wu, 2019). Examples where this has been effective include studies such as Javed et al. (2020) and Dey et al. (2019), who reported people's perception of poor water quality and health in the coastal areas of Bangladesh and identified that most of the households were willing to pay for safe drinking water. As evidenced by these studies, large datasets involving multiple stakeholders are essential for understanding the mechanisms of drinking water quality and public health outcomes (Li et al., 2017).

Acquiring the requisite large databases can be augmented through the use of citizen scientists. Furthermore, citizen science can help to play a significant role in these studies for helping with data accumulation and analysis (Farnham et al., 2017; McKinley et al., 2017). For example, citizen science can contribute to filling water quality data gaps by collecting information in remote or geographically challenging areas, and providing the necessary data to inform or influence regulatory decisions (Hadj-Hammou et al., 2017). For citizen science to achieve its greatest utility, regulatory agencies must develop quality assurance standards that allow crowdsourced data to be vetted and considered during policy development. Further, community-generated data can stimulate research driven questions by providing long-term monitoring information that would otherwise not be available to advisory committees or policy-developing entities. By providing correct tools in the hand of citizens, communities can make independent health conscientious decisions rather than unknowingly consume contaminated drinking water. In doing so, we see progress in bridging the gap between public health and environmental health from the ground up.

5. Fate, Transport, and Human Impact of Aqueous Contaminants in the Context of Climate Change

Human-induced alteration in climate is significantly associated with deteriorating physical and mental health (Meierrieks, 2021; Mullins & White, 2019). The climate features which affect health directly include extreme heat events (Lorenz et al., 2019; Oldenborgh et al., 2018), air pollution (Kinney, 2018; Orru et al., 2017; Silva et al., 2017), and extreme weather conditions (Ebi et al., 2006; Stott, 2016). However, the indirect impacts, though less obvious, also cause complex health outcomes, among which are: the spread of disease through insects, ticks, and rodents (Mosello et al., 2020; Paz et al., 2007; Short et al., 2017), contaminated water affecting food security (Gregory et al., 2005; Lake et al., 2012; Ruttan et al., 1994; Wlokas, 2008), and disruption of overall

well-being through loss of housing and/or access to clean food and water resources (Cianconi et al., 2020; Hrabok et al., 2020; Ingle & Mikulewicz, 2020; Palinkas & Wong, 2020).

Human-induced climate change also impacts water quality, as climate change leads to water depletion and scarcity, increasing geogenic contaminant concentrations in global drinking water sources (Coyte et al., 2019; Leveque et al., 2021). Notably, climate change attributed to rising temperature, increased precipitation intensity, and prolonged droughts are found to alter the environmental fate and behavior of chemical toxicants resulting in water quality deterioration (Kundzewicz et al., 2007; Murdoch et al., 2000; Noyes et al., 2009; Zwolsman & Van Bokhoven, 2007). As an example, for the 2012–2013 field season, Lombard et al. (2021) identified that drought in the conterminous United States increased the number of individuals exposed to elevated arsenic from 2.7 million to 4.1 million people (Lombard et al., 2021). Supporting this, Aribam et al. (2021) found a strong correlation between climate change and groundwater arsenic seasonal variation.

Since the climate-related stressors mentioned above are diverse, a multidisciplinary approach to identifying causation factors is required, as is research focusing on the identification of climate metrics that predict adverse human health outcomes (Kinney, 2018). There is also a need to prepare public health agencies through education, monitoring, and research. While some policymakers are beginning to accept climate change and its implications on human health, current policy approaches are still underdeveloped. One way to move forward is to begin integrating mitigation policies for climate change (e.g., reducing greenhouse gases) and adaptation policies for climate change (e.g., preparing the community for climate impacts), as evidenced by recent studies (e.g., Ganesh and Smith (2018)).

Supporting this, recent studies have pointed out four major principles for addressing health implications of climate change, which include mainstreaming, linked approach, population perspective, and coordination (Ganesh & Smith, 2018; Gould & Rudolph, 2015; Marinucci et al., 2014; Parker-Flynn, 2014). Mainstreaming corresponds to integrating climate change into all planning and policy processes throughout various sectors, while a linked approach emphasizes adaptation and mitigation policies as a part of climate change. A population perspective examines the health status of populations rather than the aggregation of individuals, while overall coordination can bring together public health law and policy to mediate the health impacts of climate change (Ganesh et al., 2020; Ganesh & Smith, 2018).

6. Future Recommendations

Researchers need to shift toward an integrated *GeoHealth* approach with sustained inclusion of and communication with the community. As the environmental problems being faced are complex, and research teams need to tackle these issues from a multidisciplinary approach, it is critical that communication is part of the process. Since these problems do not occur in isolation but in communities of varying socio-economic status and across broad geographies, active work is required to build *GeoHealth* capacity to understand challenges at the earth-health interface to ensure equity (Barnard et al., 2022; Hayhow et al., 2021). It is also the mission of *GeoHealth* professionals to be allies and advocates for environmental justice by collaborating with individuals to safeguard their communities from exposure to contaminants, particularly in the era of climate change. This could be achieved by adopting open science throughout the *GeoHealth* research using tools such as ICON (Fortner et al., 2022; Goldman et al., 2022).

As academic professionals, our moral obligation is to provide the necessary training and collaborative funding for the next generation of scientists to address global issues through a transdisciplinary lens. Additionally, to address the challenge of releasing data that the public needs, we need data tools and experts who can help the public use these tools. For instance, issues like the Flint water crisis need to be addressed from an environmental and public health perspective. However, ongoing data collection efforts are not designed in a way that maximizes their utility relative to environmental preservation or the safeguarding of community public health. A poignant example of this is the field of wastewater-based epidemiology, which has been successfully used to inform health care professionals about the spread of infectious agents, such as SARS-CoV-2 (Mao et al., 2020). These data are critical to protecting community health, yet the data are either not publicly released, or if they are, the implications are not made clear. Consequently, there is both a need and an opportunity to train not only the transdisciplinary scientists but also the community organizations using a convergent approach, such as *GeoHealth*, to address

water-related challenges in a manner that will benefit the environment while also addressing critical information needs in public health.

Although targeting a specific portion of the population or the “majority” can influence policy, it can also have negative consequences at the local level that lead to environmental injustices. From the *GeoHealth* perspective, it is the duty of engineers and scientists to inform communities about threats to their public health while still protecting their individual values. Together, we can change existing academic practices by integrating the *GeoHealth* perspective into the curriculum, fostering holistic multidisciplinary research, and including community-engaged participatory research approaches. In summary, to protect our environmental resources as our climate changes, we need community-engaged research and action along with training and funding so that the next generation can address the holistic issues that were the focus of this editorial and last year's workshop.

6.1. Summary of Calls for Action

The major calls for action put forward by the workshop corresponding to each of the sections are listed as follows:

1. Drinking water and chronic chemical exposure
 - Help propagate water quality methods, including methods for emerging or understudied contaminants, into places where water quality monitoring is scarce.
 - Make sure that water quality analyses continue to focus on cumulative impacts across a suite of water quality parameters.
2. Environmental injustice
 - Adopt open science strategies throughout the *GeoHealth* research using tools such as ICON science.
 - Partnerships between community members and scientists should focus on a long-term sustainable relationship to mitigate environmental injustices.
3. Public health and drinking water policy
 - A holistic approach to policy governance, including different stakeholders, should be implemented to ensure safe drinking water quality.
 - Citizen science can be used to address the issue of big data requirement to understand the mechanism of drinking water quality and public health outcome, providing that agencies can develop suitable quality assurance protocols.
4. Climate change
 - There is a need to prepare public health agencies regarding climate change and its impact on public health through education, monitoring, research, and contribution to public dialog.
 - Four major principles to mitigate the potential implications of climate change on human health are mainstreaming, linked approach, population perspective, and coordination.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data Availability Statement

Data were not used, nor created for this research.

References

- Acharya, B. S., Ahmed, B., Chen, Y., Davison, J. H., Haygood, L., Hensley, R. T., et al. (2022). Hydrological perspectives on integrated, coordinated, open, networked (ICON) science. *Earth and Space Science*, 9(4), e2022EA002320. <https://doi.org/10.1029/2022ea002320>
- Al-Emadi, A., Sellami, A. L., & Fadlalla, A. M. (2022). The perceived impacts of staging the 2022 FIFA world cup in Qatar. *Journal of Sport & Tourism*, 26(1), 1–20. <https://doi.org/10.1080/14775085.2021.2017327>
- Almberg, K. S., Turyk, M. E., Jones, R. M., Rankin, K., Freels, S., & Stayner, L. T. (2018). Atrazine contamination of drinking water and adverse birth outcomes in community water systems with elevated atrazine in Ohio, 2006–2008. *International Journal of Environmental Research and Public Health*, 15(9), 1889. <https://doi.org/10.3390/ijerph15091889>
- Altman, R. G., Morello-Frosch, R., Brody, J. G., Rudel, R., Brown, P., & Averick, M. (2008). Pollution comes home and gets personal: Women's experience of household chemical exposure. *Journal of Health and Social Behavior*, 49(4), 417–435. <https://doi.org/10.1177/002214650804900404>

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- American Public Health Association. (2001). Drinking water quality and public health (position paper). *American Journal of Public Health*, 91(3), 499. <https://doi.org/10.2105/ajph.91.3.499>
- Aribam, B., Alam, W., & Thokchom, B. (2021). Water, arsenic, and climate change. In *Water conservation in the era of global climate change* (pp. 167–190). Elsevier.
- Arora, B., Currin, A., Dwivedi, D., Fru, M. I., Kumar, N., McLeod, C. L., & Roman, D. C. (2022). Volcanology, geochemistry, and petrology perspectives on integrated, coordinated, open, networked (ICON) science. *Earth and Space Science*, 9(4), e2021EA002120. <https://doi.org/10.1029/2021ea002120>
- Barnard, M. A., Emani, S. R., Fortner, S., Haygood, L., Sun, Q., White-Newsome, J. L., & Zaitchik, B. F. (2022). *GeoHealth* perspectives on integrated, coordinated, open, networked (ICON) science. *Earth and Space Science Open Archive*, 9, e2021EA002157. <https://doi.org/10.1002/essoar.10509342.1>
- Bashir, S. A. (2002). Home is where the harm is: Inadequate housing as a public health crisis. *American Journal of Public Health*, 92(5), 733–738. <https://doi.org/10.2105/ajph.92.5.733>
- Bennett, N. J., & Dearden, P. (2014). Why local people do not support conservation: Community perceptions of marine protected area livelihood impacts, governance and management in Thailand. *Marine Policy*, 44, 107–116. <https://doi.org/10.1016/j.marpol.2013.08.017>
- Butler, L. J., Scammell, M. K., & Benson, E. B. (2016). The Flint, Michigan, water crisis: A case study in regulatory failure and environmental injustice. *Environmental Justice*, 9(4), 93–97. <https://doi.org/10.1089/env.2016.0014>
- Cianconi, P., Betrò, S., & Janiri, L. (2020). The impact of climate change on mental health: A systematic descriptive review. *Frontiers in Psychiatry*, 11, 74. <https://doi.org/10.3389/fpsy.2020.00074>
- Cook, Q., Argenio, K., & Lovinsky-Desir, S. (2021). The impact of environmental injustice and social determinants of health on the role of air pollution in asthma and allergic disease in the United States. *The Journal of Allergy and Clinical Immunology*, 148(5), 1089–1101. e1085. <https://doi.org/10.1016/j.jaci.2021.09.018>
- Coyte, R. M., Singh, A., Furst, K. E., Mitch, W. A., & Vengosh, A. (2019). Co-occurrence of geogenic and anthropogenic contaminants in groundwater from Rajasthan, India. *Science of the Total Environment*, 688, 1216–1227. <https://doi.org/10.1016/j.scitotenv.2019.06.334>
- Dey, N. C., Parvez, M., Saha, R., Islam, M. R., Akter, T., Rahman, M., et al. (2019). Water quality and willingness to pay for safe drinking water in Tala Upazila in a coastal district of Bangladesh. *Exposure and Health*, 11(4), 297–310. <https://doi.org/10.1007/s12403-018-0272-3>
- Diaz, R. S. (2016). Getting to the root of environmental injustice: Evaluating claims, causes, and solutions. *Georgetown Environmental Law Review*, 29, 767.
- Dwivedi, D., Santos, A., Barnard, M. A., Crimmins, T. M., Malhotra, A., Rod, K. A., et al. (2022). Biogeosciences perspectives on integrated, coordinated, open, networked (ICON) science. *Earth and Space Science*, 9(3), e2021EA002119. <https://doi.org/10.1029/2021ea002119>
- Ebi, K. L., Kovats, R. S., & Menne, B. (2006). An approach for assessing human health vulnerability and public health interventions to adapt to climate change. *Environmental Health Perspectives*, 114(12), 1930–1934. <https://doi.org/10.1289/ehp.8430>
- Edwards, M., Triantafyllidou, S., & Best, D. (2009). Elevated blood lead in young children due to lead-contaminated drinking water: Washington, DC, 2001–2004. *Environmental science & technology*, 43(5), 1618–1623. <https://doi.org/10.1021/es802789w>
- Evans, G. W. (2004). The environment of childhood poverty. *American Psychologist*, 59(2), 77–92. <https://doi.org/10.1037/0003-066x.59.2.77>
- Fanini, L., Plaiti, W., & Papageorgiou, N. (2019). Environmental education: Constraints and potential as seen by sandy beach researchers. *Estuarine, Coastal and Shelf Science*, 218, 173–178. <https://doi.org/10.1016/j.ecss.2018.12.014>
- Farnham, D. J., Gibson, R. A., Hsueh, D. Y., McGillis, W. R., Culligan, P. J., Zain, N., & Buchanan, R. (2017). Citizen science-based water quality monitoring: Constructing a large database to characterize the impacts of combined sewer overflow in New York City. *Science of the Total Environment*, 580, 168–177. <https://doi.org/10.1016/j.scitotenv.2016.11.116>
- Fortner, S. K., Manduca, C. A., Ali, H. N., Saup, C. M., Nyarko, S. C., Othus-Gault, S., et al. (2022). Geoscience education perspectives on integrated, coordinated, open, networked (ICON) science. *Earth and Space Science*, 9(5), e2022EA002298. <https://doi.org/10.1029/2022ea002298>
- Ganesh, C., Schmeltz, M., & Smith, J. (2020). Introduction climate change and the legal, ethical, and health issues facing healthcare and public health systems. *Journal of Law Medicine & Ethics*, 48(4), 636–642. <https://doi.org/10.1177/1073110520979370>
- Ganesh, C., & Smith, J. A. (2018). Climate change, public health, and policy: A California case study. *American Journal of Public Health*, 108(S2), S114–S119. <https://doi.org/10.2105/ajph.2017.304047>
- Gehrig, S., Schlüter, A., & Jiddawi, N. S. (2018). Overlapping identities: The role of village and occupational group for small-scale Fishers' perceptions on environment and governance. *Marine Policy*, 96, 100–110. <https://doi.org/10.1016/j.marpol.2018.06.017>
- Goldman, A. E., Emani, S. R., Pérez-Angel, L. C., Rodríguez-Ramos, J. A., & Stegen, J. C. (2022). Integrated, coordinated, open, and networked (ICON) science to advance the geosciences: Introduction and synthesis of a special collection of commentary articles. *Earth and Space Science*, 9(4), e2021EA002099. Wiley Online Library. <https://doi.org/10.1029/2021ea002099>
- Gould, S., & Rudolph, L. (2015). Challenges and opportunities for advancing work on climate change and public health. *International Journal of Environmental Research and Public Health*, 12(12), 15649–15672. <https://doi.org/10.3390/ijerph121215010>
- Gralton, A., Sinclair, M., & Purnell, K. (2004). Changes in attitudes, beliefs and behaviour: A critical review of research into the impacts of environmental education initiatives. *Australian Journal of Environmental Education*, 20(2), 41–52. <https://doi.org/10.1017/s0814062600002196>
- Gray, K. M. (2018). From content knowledge to community change: A review of representations of environmental health literacy. *International Journal of Environmental Research and Public Health*, 15(3), 466. <https://doi.org/10.3390/ijerph15030466>
- Gregory, P. J., Ingram, J. S., & Brklacich, M. (2005). Climate change and food security. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 360(1463), 2139–2148. <https://doi.org/10.1098/rstb.2005.1745>
- Grigg, N. S. (2015). Infrastructure report card: Purpose and results. *Journal of Infrastructure Systems*, 21(4), 02514001. [https://doi.org/10.1061/\(asce\)is.1943-555x.0000186](https://doi.org/10.1061/(asce)is.1943-555x.0000186)
- Hadj-Hammou, J., Loïsele, S., Ophof, D., & Thornhill, I. (2017). Getting the full picture: Assessing the complementarity of citizen science and agency monitoring data. *PLoS One*, 12(12), e0188507. <https://doi.org/10.1371/journal.pone.0188507>
- Hayhow, C. M., Brabander, D. J., Jim, R., Lively, M., & Filippelli, G. M. (2021). Addressing the need for just *GeoHealth* engagement: Evolving models for actionable research that transform communities. *GeoHealth*, 5(12), e2021GH000496. <https://doi.org/10.1029/2021gh000496>
- Holmes, R. T. (2011). Avian population and community processes in forest ecosystems: Long-term research in the Hubbard Brook Experimental Forest. *Forest Ecology and Management*, 262(1), 20–32. <https://doi.org/10.1016/j.foreco.2010.06.021>
- Hrabok, M., Delorme, A., & Agyapong, V. I. (2020). Threats to mental health and well-being associated with climate change. *Journal of Anxiety Disorders*, 76, 102295. <https://doi.org/10.1016/j.janxdis.2020.102295>
- Ingle, H. E., & Mikulewicz, M. (2020). Mental health and climate change: Tackling invisible injustice. *The Lancet Planetary Health*, 4(4), e128–e130. [https://doi.org/10.1016/s2542-5196\(20\)30081-4](https://doi.org/10.1016/s2542-5196(20)30081-4)
- Jabed, A., Paul, A., & Nath, T. K. (2020). Peoples' perception of the water salinity impacts on human health: A case study in south-eastern coastal region of Bangladesh. *Exposure and Health*, 12(1), 41–50. <https://doi.org/10.1007/s12403-018-0283-0>

- Jones, L., Credo, J., Parnell, R., & Ingram, J. C. (2020). Dissolved uranium and arsenic in unregulated groundwater sources—Western Navajo Nation. *Journal of Contemporary Water Research & Education*, 169(1), 27–43. <https://doi.org/10.1111/j.1936-704x.2020.03330.x>
- Jordan, S. J., & Benson, W. H. (2015). Sustainable watersheds: Integrating ecosystem services and public health. *Environmental Health Insights*, 9, EHI.S19586. <https://doi.org/10.4137/ehi.s19586>
- Joseph, N., Propper, C. R., Goebel, M., Henry, S., Roy, I., & Kolok, A. S. (2022). Investigation of relationships between the geospatial distribution of cancer incidence and estimated pesticide use in the US West. *GeoHealth*, 6(5), e2021GH000544. <https://doi.org/10.1029/2021gh000544>
- Kinney, P. L. (2018). Interactions of climate change, air pollution, and human health. *Current environmental health reports*, 5(1), 179–186. <https://doi.org/10.1007/s40572-018-0188-x>
- Kundzewicz, Z. W., Mata, L. J., Arnell, N., Doll, P., Kabat, P., Jimenez, B., et al. (2007). Freshwater resources and their management.
- Lagunas-Rangel, F. A., Linnea-Niemi, J. V., Kudlak, B., Williams, M. J., Jönsson, J., & Schiöth, H. B. (2022). Role of the synergistic interactions of environmental pollutants in the development of cancer. *GeoHealth*, 6(4), e2021GH000552. <https://doi.org/10.1029/2021gh000552>
- Lake, I. R., Hooper, L., Abdelhamid, A., Bentham, G., Boxall, A. B., Draper, A., et al. (2012). Climate change and food security: Health impacts in developed countries. *Environmental Health Perspectives*, 120(11), 1520–1526. <https://doi.org/10.1289/ehp.1104424>
- Levallois, P., & Villanueva, C. M. (2019). Drinking water quality and human health: An editorial. *Multidisciplinary Digital Publishing Institute*, 16(4), 631. <https://doi.org/10.3390/ijerph16040631>
- Leveque, B., Burnet, J.-B., Dorner, S., & Bichai, F. (2021). Impact of climate change on the vulnerability of drinking water intakes in a northern region. *Sustainable Cities and Society*, 66, 102656. <https://doi.org/10.1016/j.scs.2020.102656>
- Li, P., Tian, R., Xue, C., & Wu, J. (2017). Progress, opportunities, and key fields for groundwater quality research under the impacts of human activities in China with a special focus on Western China. *Environmental Science and Pollution Research*, 24(15), 13224–13234. <https://doi.org/10.1007/s11356-017-8753-7>
- Li, P., & Wu, J. (2019). Drinking water quality and public health. *Exposure and Health*, 11(2), 73–79. <https://doi.org/10.1007/s12403-019-00299-8>
- Lindenmayer, D. B., Likens, G. E., Andersen, A., Bowman, D., Bull, C. M., Burns, E., et al. (2012). Value of long-term ecological studies. *Austral Ecology*, 37(7), 745–757. <https://doi.org/10.1111/j.1442-9993.2011.02351.x>
- Lombard, M. A., Daniel, J., Jeddy, Z., Hay, L. E., & Ayotte, J. D. (2021). Assessing the impact of drought on arsenic exposure from private domestic wells in the conterminous United States. *Environmental Science and Technology*, 55(3), 1822–1831. <https://doi.org/10.1021/acs.est.9b05835>
- Lorenz, R., Stalhandske, Z., & Fischer, E. M. (2019). Detection of a climate change signal in extreme heat, heat stress, and cold in Europe from observations. *Geophysical Research Letters*, 46(14), 8363–8374. <https://doi.org/10.1029/2019gl082062>
- Mao, K., Zhang, H., & Yang, Z. (2020). An integrated biosensor system with mobile health and wastewater-based epidemiology (iBMW) for COVID-19 pandemic. *Biosensors and Bioelectronics*, 169, 112617. <https://doi.org/10.1016/j.bios.2020.112617>
- Marinucci, G. D., Lubber, G., Uejio, C. K., Saha, S., & Hess, J. J. (2014). Building resilience against climate effects—A novel framework to facilitate climate readiness in public health agencies. *International Journal of Environmental Research and Public Health*, 11(6), 6433–6458. <https://doi.org/10.3390/ijerph110606433>
- Mathiarasan, S., & Hüls, A. (2021). Impact of environmental injustice on children's health—Interaction between air pollution and socioeconomic status. *International Journal of Environmental Research and Public Health*, 18(2), 795. <https://doi.org/10.3390/ijerph18020795>
- McDonald, Y. J., & Jones, N. E. (2018). Drinking water violations and environmental justice in the United States, 2011–2015. *American Journal of Public Health*, 108(10), 1401–1407. <https://doi.org/10.2105/ajph.2018.304621>
- McEntee, C. (2016). GeoHealth: A transdisciplinary science comes of age. In *Paper presented at the AGU fall meeting abstracts*.
- McKinley, D. C., Miller-Rushing, A. J., Ballard, H. L., Bonney, R., Brown, H., Cook-Patton, S. C., et al. (2017). Citizen science can improve conservation science, natural resource management, and environmental protection. *Biological Conservation*, 208, 15–28. <https://doi.org/10.1016/j.biocon.2016.05.015>
- Meierrieks, D. (2021). Weather shocks, climate change and human health. *World Development*, 138, 105228. <https://doi.org/10.1016/j.worlddev.2020.105228>
- Mercer, N., & Littleton, K. (2007). *Dialogue and the development of children's thinking: A sociocultural approach*. Routledge.
- Montgomery, M. A., & Elimelech, M. (2007). Water and sanitation in developing countries: Including health in the equation. *Environmental Science and Technology*, 41(1), 17–24. <https://doi.org/10.1021/es072435t>
- Mosello, B., Foong, A., König, C., Wolfmaier, S., & Wright, E. (2020). *Spreading disease, spreading conflict? COVID-19, climate change and security risks*. Adelphi.
- Mullins, J. T., & White, C. (2019). Temperature and mental health: Evidence from the spectrum of mental health outcomes. *Journal of Health Economics*, 68, 102240. <https://doi.org/10.1016/j.jhealeco.2019.102240>
- Murdoch, P. S., Baron, J. S., & Miller, T. L. (2000). Potential effects of climate change on surface-water quality in North America I. *JAWRA Journal of the American Water Resources Association*, 36(2), 347–366. <https://doi.org/10.1111/j.1752-1688.2000.tb04273.x>
- Noyes, P. D., McElwee, M. K., Miller, H. D., Clark, B. W., Van Tiem, L. A., Walcott, K. C., et al. (2009). The toxicology of climate change: Environmental contaminants in a warming world. *Environment International*, 35(6), 971–986. <https://doi.org/10.1016/j.envint.2009.02.006>
- Nyström, M. E., Karlun, J., Keller, C., & Andersson Gäre, B. (2018). Collaborative and partnership research for improvement of health and social services: Researcher's experiences from 20 projects. *Health Research Policy and Systems*, 16(1), 1–17. <https://doi.org/10.1186/s12961-018-0322-0>
- Oldendorgh, G. J. V., Philip, S., Kew, S., Weele, M. V., Uhe, P., Otto, F., et al. (2018). Extreme heat in India and anthropogenic climate change. *Natural Hazards and Earth System Sciences*, 18(1), 365–381. <https://doi.org/10.5194/nhess-18-365-2018>
- Orru, H., Ebi, K., & Forsberg, B. (2017). The interplay of climate change and air pollution on health. *Current environmental health reports*, 4(4), 504–513. <https://doi.org/10.1007/s40572-017-0168-6>
- Palinkas, L. A., & Wong, M. (2020). Global climate change and mental health. *Current opinion in psychology*, 32, 12–16. <https://doi.org/10.1016/j.copsyc.2019.06.023>
- Parker-Flynn, J. E. (2014). The intersection of mitigation and adaptation in climate law and policy. *Environ: Envtl. L. & Pol'y J.*, 38, 1.
- Paz, S., Bisharat, N., Paz, E., Kidar, O., & Cohen, D. (2007). Climate change and the emergence of *Vibrio vulnificus* disease in Israel. *Environmental Research*, 103(3), 390–396. <https://doi.org/10.1016/j.envres.2006.07.002>
- Prayag, G., Chowdhury, M., Prajogo, D., Mariani, M., & Guizzardi, A. (2021). Residents' perceptions of environmental certification, environmental impacts and support for the world expo 2015: The moderating effect of place attachment. *International Journal of Contemporary Hospitality Management*, 34(3), 1204–1224. <https://doi.org/10.1108/ijchm-06-2021-0824>
- Richard, A. M., Diaz, J. H., & Kaye, A. D. (2014). Reexamining the risks of drinking-water nitrates on public health. *The Ochsner Journal*, 14(3), 392–398.

- Riesch, H., & Potter, C. (2014). Citizen science as seen by scientists: Methodological, epistemological and ethical dimensions. *Public Understanding of Science*, 23(1), 107–120. <https://doi.org/10.1177/0963662513497324>
- Roche, J., Bell, L., Galvão, C., Golumbic, Y. N., Kloetzer, L., Knobens, N., et al. (2020). Citizen science, education, and learning: Challenges and opportunities. *Frontiers in Sociology*, 5, 110. <https://doi.org/10.3389/fsoc.2020.613814>
- Rosen, L. D., & Imus, D. (2007). Environmental injustice: Children's health disparities and the role of the environment. *Explore*, 3(5), 524–528. <https://doi.org/10.1016/j.explore.2007.07.009>
- Ruttan, V. W., Bell, D. E., & Clark, W. C. (1994). Climate change and food security: Agriculture, health and environmental research. *Global Environmental Change*, 4(1), 63–77. [https://doi.org/10.1016/0959-3780\(94\)90022-1](https://doi.org/10.1016/0959-3780(94)90022-1)
- Salman, M., Slater, L., Briggs, M., & Li, L. (2022). Near-Surface geophysics perspectives on integrated, coordinated, open, networked (ICON) science. *Earth and Space Science*, 9(3), e2021EA002140. <https://doi.org/10.1029/2021ea002140>
- Sharma, S., Dahal, K., Nava, L., Gouli, M. R., Talchabhadel, R., Panthi, J., et al. (2022). Natural hazards perspectives on integrated, coordinated, open, networked (ICON) science. *Earth and Space Science*, 9(1), e2021EA002114. <https://doi.org/10.1029/2021ea002114>
- Short, E. E., Caminade, C., & Thomas, B. N. (2017). Climate change contribution to the emergence or re-emergence of parasitic diseases. *Infectious Diseases: Research and Treatment*, 10, 1178633617732296. <https://doi.org/10.1177/1178633617732296>
- Silva, R. A., West, J. J., Lamarque, J.-F., Shindell, D. T., Collins, W. J., Faluvegi, G., et al. (2017). Future global mortality from changes in air pollution attributable to climate change. *Nature Climate Change*, 7(9), 647–651. <https://doi.org/10.1038/nclimate3354>
- Stott, P. (2016). How climate change affects extreme weather events. *Science*, 352(6293), 1517–1518. <https://doi.org/10.1126/science.aaf7271>
- Switzer, D., & Teodoro, M. P. (2017). The color of drinking water: Class, race, ethnicity, and safe drinking water act compliance. *Journal-American Water Works Association*, 109(9), 40–45. <https://doi.org/10.5942/jawwa.2017.109.0128>
- Villanueva, C. M., Kogevinas, M., Cordier, S., Templeton, M. R., Vermeulen, R., Nuckols, J. R., et al. (2014). Assessing exposure and health consequences of chemicals in drinking water: Current state of knowledge and research needs. *Environmental Health Perspectives*, 122(3), 213–221. <https://doi.org/10.1289/ehp.1206229>
- Villanueva, C. M., & Levallois, P. (2015). Exposure assessment of water contaminants. *Exposure assessment in environmental epidemiology*, 329–348. <https://doi.org/10.1093/med/9780199378784.003.0016>
- Ward, M. H., Jones, R. R., Brender, J. D., De Kok, T. M., Weyer, P. J., Nolan, B. T., et al. (2018). Drinking water nitrate and human health: An updated review. *International Journal of Environmental Research and Public Health*, 15(7), 1557. <https://doi.org/10.3390/ijerph15071557>
- Wines, M., & Schwartz, J. (2016). *Unsafe lead levels in tap water not limited to Flint* (Vol. 8). The New York Times.
- Wlokas, H. (2008). The impacts of climate change on food security and health in Southern Africa. *Journal of Energy in Southern Africa*, 19(4), 12–20. <https://doi.org/10.17159/2413-3051/2008/v19i4a3334>
- World Health Organization. (2014). *UN-Water global analysis and assessment of sanitation and drinking-water (GLAAS) 2014: Investing in water and sanitation: Increasing access, reducing inequalities: Main findings*. World Health Organization.
- World Health Organization. (2015). *Progress on sanitation and drinking water: 2015 update and MDG assessment: Joint water supply sanitation monitoring program*. World Health Organization.
- Zwolsman, J., & Van Bokhoven, A. (2007). Impact of summer droughts on water quality of the Rhine River—a preview of climate change? *Water Science and Technology*, 56(4), 45–55. <https://doi.org/10.2166/wst.2007.535>