AMS Community Synthesis on Geohealth

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"Summer thunderstorm" by Manievannan Shreenivasan, NOAA Weather in Focus Photo Contest 2015

"NASA astronaut Photograph S09-41-2792"

Table of Contents

Executive Summary

The Earth system and human health are inextricably linked. In this period of widespread and rapid global change, understanding the challenges and opportunities at the intersection of health, geoscience, and the Earth system (broadly termed "geohealth") has taken on a new level of importance. Scientific discovery and innovation can play a key role in helping humanity understand and respond to environmental, technological, and societal drivers of global changes so as to enable security, prosperity, and positive health outcomes for all.

This American Meteorological Society Policy Program study synthesizes input from the AMS community on the various connections, gaps, and opportunities that currently exist at the geohealth interface. It was carried out in an accelerated time frame in response to a request from the National Science Foundation for rapid community input. Through these community discussions this study identifies: 1) a set of critical throughlines for effective convergence in geohealth research, 2) overarching challenges that currently impede progress, and 3) potential solution areas where significant progress might be made quickly.

Throughlines

- Issues of geohealth are often intricately connected to issues of environmental justice. As such, inclusion, equity, and justice are central to the advancement of and benefit from geohealth science.
- Advances in geohealth science require truly convergent research approaches to provide maximum benefit to society.
- Progress in geohealth requires participation from multiple sectors within disciplines, with important and complementary roles for those in the academic, government, private, and NGO sectors.
- Issues related to climate change are both hugely important and constitute a relatively small fraction of the overall geohealth landscape. In many instances, climate change will amplify and exacerbate existing issues in geohealth.
- Interoperability of data, research, understanding, and applications of knowledge is critically important and currently represents multiple challenges that are limiting progress within geohealth.

Challenges to progress

In gathering input from the geohealth community, several key challenges arose as common themes:

1. Funding agencies are not structured to adequately support progress in geohealth science or applications.
2. Datasets in both the geosciences and health professions are often incompatible or inadequate to address geohealth research needs.
3. The necessary interdisciplinary and transdisciplinary workforce is insufficient.

Each of these challenges is expanded upon in the report and recommendations for addressing components of each, suggested by the experts contributing to this effort, are provided.

Areas for rapid progress

The geohealth professionals contributing to this report covered a wide range of geohealth topics. In addition to identifying overarching challenges that impact most of all areas of the field, the contributors suggested more narrowly focused areas where rapid progress might be possible. The report includes these as examples that might foster productive new avenues for research funding, while recognizing that the rapid nature of this study meant that it could not be exhaustive in its coverage of the field and that a different set of contributors might have provided a much different set of examples.

Spotlight on mental health

From the call for community input and subsequent follow-up, there was an emerging recognition that the connection between the geosciences and mental health is frequently omitted from discussions of geohealth. A special effort was made to provide a spotlight on this facet of geohealth, which shares components of the throughlines and challenges with the broader geohealth community, but has its own special considerations that lead to some additional recommendations specific to the intersection of geosciences and mental health.

1. Introduction

1.1. Background and Context

The Earth system and human health are inextricably linked. Understanding and accounting for this linkage is even more critical now as the scale of human activities have grown to be large relative to the planet and the life-support services the Earth system provides. In this period of widespread and rapid global change, scientific discovery and innovation has a key role in helping humanity respond to these changes so as to enable security, prosperity, and positive health outcomes for all.

This project solicited and synthesized input from the AMS community on opportunities and challenges at the interface of health, geoscience, and the Earth system (broadly termed "geohealth"). We particularly focused on developing new ideas from the community on convergent, transformative, and applications-oriented (i.e., use-inspired) geohealth research that might be implemented immediately and show progress quickly (e.g., in a 2–3-year time frame), while having positive impacts on both scientific advancement and societal applications of science over a much longer period. This AMS Policy Program study was made possible by a grant from the National Science Foundation (NSF).

1.2. The AMS Process

Our goal was to enable and encourage ideas as broadly as possible. The process solicited input from many members of the AMS community and synthesized insights from a wide range of individuals from the weather, water, and climate enterprise. The AMS community already includes some health care professionals and others working at the intersection of health and the environment. Since 2010, the volunteer Board on Environmental Health has organized an annual symposium on environment and health as part of the AMS Annual Meeting. AMS is also an affiliated society with the Medical Society Consortium on Climate and Health.

AMS Policy Program staff reached out directly to the existing network of scientists and practitioners within the AMS community—including current and past members of the Board on Environmental Health, those who have presented at AMS conferences and published in AMS journals on related topics, and others who have worked in related areas. Through this network, program staff engaged in one-on-one or small group discussions on the issues they see facing research in the intersections of geosciences and

health. In each case, program staff asked for the names of other researchers who might provide additional useful input for the study. This resulted in an expanding list of contacts over the brief study period that allowed for a spectrum of input. In addition, AMS created a dedicated web portal to allow written input from individuals and requested and encouraged input from the full membership through a variety of media channels. The project team then synthesized the inputs. Despite the tight time frame for this project, the investigators feel that they were able to organize an adequate number of individual and group sessions, along with written input, to achieve a sufficient diversity of participants and perspectives.

2. Findings and Recommendations

Through conversations with members of the community working at the intersection of geosciences and health, a number of areas of emphasis were identified where critical progress can be made. In particular, three key challenges emerged as common themes in many independent conversations with geohealth researchers and practitioners.

2.1. Key Challenges

2.1.1. Funding agencies are not structured to adequately support progress in geohealth science or applications

At present, researchers and other practitioners looking to make progress in geohealth may struggle to navigate the landscape of funding options, particularly at the federal level. NSF and NIH are two agencies commonly looked to for geohealth funding; however, researchers report encountering mismatches between their work and applicable grant opportunities. In particular, research which aims to combine health and geoscience data may not fit neatly into the categories of fundamental or applied research typically used to determine which agency to go through. Researchers can also feel pressure to shed interdisciplinary aspects of planned proposals in order to better fit available grants. For some early career faculty, the NSF CAREER grant has provided a source of funding that could bridge the interdisciplinary divide, but all agreed that this was an inadequate solution to the challenge.

Moreover, current funding structures do not support the effective assembly of interdisciplinary teams. An ideal team for a geohealth project may include geoscientists, epidemiologists, social scientists, and public health officials, each of whose research interests would normally be funded by a different agency. However, investigators may be challenged in putting together a team that fits the needs of their desired interdisciplinary project because funding for large groups can be limited. Additionally, the proposal review process may be difficult for investigators to navigate after leaving their field of expertise.

It was also stressed that calls for proposals that prescribed specific team member disciplines could be problematic. Researchers said that a better approach was to identify the interdisciplinary problem to be addressed, provide mechanisms for funding a diverse interdisciplinary team, and allow the proposal review process to ensure that the proposal brought together the right kinds of expertise to address the proposed research effort.

Recommendations:

- Create funding mechanisms that bridge the divide between traditional NSF and NIH domains intended to support geohealth research.
- Put out calls for research that are problem-focused and support the assembly of interdisciplinary teams as needed.
- Establish clear guidelines in calls for proposals about what forms of data are acceptable and what is considered fundamental research.

2.1.2. Datasets in both the geosciences and health professions are often incompatible or inadequate to address geohealth research needs

Geohealth encompasses a broad range of disciplines, topics, and jurisdictions. As a result, data collection and use varies widely, often in ways that hamper research convergence. Public health information and systems in particular are highly fragmented across federal, state, and local governments. An additional complication is that health and geoscience datasets differ greatly at spatial or temporal scales. Public health data is typically local in nature, although datasets are necessarily limited in granularity by privacy concerns. Consequently, health data are often aggregated by census tract, ZIP code, or county. Geospatial data, on the other hand, are often collected via satellite programs from agencies such as NASA, NOAA, and USGS, are typically gridded and unlikely to be at the resolution needed for health applications. Ground-level sensors may be used to help fill in some of the gaps in environmental data, although such sensors are sparse in less densely populated areas. However, these limitations in geohealth-relevant datasets may represent an opportunity for the private sector. There are multiple examples of this, with the following being merely representative:

- The WeatherBug network of low-cost weather sensor packages located at homes, businesses, and schools, provides higher resolution surface data than the official weather stations. (The NWS currently ingests into its dataset some fraction of Weatherbug data.)
- The Purple Air network provides data from a commercially-run network of home air quality sensors, and can provide high resolution particulate data within neighborhoods.
- Commercial satellites may be able to provide views of outdoor swimming pools throughout neighborhoods at centimeter-scale resolution, with color analysis being able to identify which are well-maintained and which represent stagnant pools likely to breed mosquitoes.

Efforts to use or collate health and geoscience datasets may be unsuccessful due to a

number of accessibility issues. Community members noted struggles to locate relevant datasets in a sea of available information. Although datasets may be limited in certain areas, as noted above, as a whole the amount of available data is constantly increasing, resulting in a need for researchers to sort through vast amounts of data in order to determine what information is useful. Converting data into a usable format may require specific technical knowledge, further complicated by the fact that geohealth-relevant datasets utilize various formats and nomenclature that can differ between fields or even individual projects. In general, health data does not conform to rigorous structured formats that support effective merging with geoscience datasets or that allows successful data mining. NIH's Data and Technology Advancement (DATA) Program is one promising approach to expand the data sets available to health researchers.

An additional complication noted by several researchers is that health data may need epidemiological interpretation before data entries can be correlated with weather or other environmental conditions. For example, the variability in coding hospital intake data may mask heat or air-quality stresses that were contributory factors in respiratory illness hospitalizations. Similarly, health researchers may need to have climate data interpreted by climate scientists before the data can be used in some health projections of factors influenced by climate (e.g., vector-borne diseases or pollen) in order to properly incorporate the associated uncertainties of climate forecasts.

Large long-lasting cohort studies are often the best way to establish robust causal relationships between environmental conditions and health effects. However, these studies are expensive and therefore relatively rare. Thus, it will be important to improve methods and technologies that facilitate the collection and exploration of health data that is collected routinely such as through Medicare and Medicaid. These datasets are not designed for research purposes and often require significant bureaucratic and scientific work to be useful in a geohealth context.

Researchers noted that new types of data, including health data from wearables, vehicle sensor data, and data produced by the Internet of Things (IoT), offered opportunities for hyper-local datasets that could be of value in geohealth studies. Health data from wearable sensors, in particular, could have real value since the health information received from the wearable device has the potential to also provide detailed time and location data that can be merged with environmental data. It was noted, however, that such devices are likely to be most available (for now) among wealthier individuals and that can bias the resulting datasets in ways that make them hard to address environmental justice issues. Further, while such community-produced data has the potential to fill in some of the noted data gaps, there is a need to establish standards for their collection and use in order to ensure that they are both reliable and ethical for

researchers to use.

Recommendations:

- Provide funding support for research on data standards and data translation approaches that allow health data to be used more readily in geohealth studies.
- Provide support for webtools and data toolkits that help translate data into common formats, and for visualization tools supporting the unique nature of geohealth data.
- Provide support for the creation of datasets linking health impacts to reanalysis datasets of weather and climate data, and create a clearinghouse for datasets that can serve as trusted resources.
- Provide training programs for researchers in data management practices: data collection, storage, use of metadata, etc., aligned with appropriate data format standards.
- Provide support for the establishment of new sensors/networks where needed, including opportunities for hyperlocal data through internet of things, with guidelines for data formats that ensure interoperability and that privacy and other issues are adequately addressed.
- Provide support for the development of methodologies to translate and incorporate uncertainty into health projections or predictions for a variety of weather and climate health factors.

2.1.3. The necessary interdisciplinary and transdisciplinary workforce is insufficient

A common sentiment held by surveyed community members was that, as a whole, the current workforce is not well-prepared with the interdisciplinary (i.e., integrating multiple disciplines) or transdisciplinary (i.e., holistically fusing disciplines and expertises in ways that extend beyond academic boundaries) skill sets necessary to effectively conduct geohealth research. Researchers told us that this concern is just as relevant for midcareer and senior researchers as it is for graduate students and early career researchers. The traditional pathways of academic preparation often encourage specialization in a single or small number of methodologies, with limited opportunities to gain perspectives from other disciplines unless specifically sought out by the student. Moreover, opportunities and time for training on new topics or methodologies may be limited once an individual is established in their career. As researchers in either health or geoscience try to move into more interdisciplinary *geohealth* areas of research, progress may be impeded by relatively basic skill set mismatches. For example, health researchers employ some statistical techniques that are not commonly used in the geosciences (and vice versa). Workshops or short courses on some of these basic

techniques could quickly remove these impediments and help support the creation of effective interdisciplinary geohealth teams.

An additional challenge is that current incentives and reward structures in academia do not promote interdisciplinary and transdisciplinary efforts in geohealth. University structures that may readily support interdisciplinary connections between more closely aligned disciplines (such as geoscience and chemistry or engineering) may not yet have the structural elements needed to support connections between a geoscience department and a medical school. And further, the university structure may not adequately value geoscientists working with public health officials.

Achieving a truly transdisciplinary workforce to address geohealth issues will require new curriculum development and the establishment of new programs at universities, as well as expanded opportunities to do interdisciplinary or transdisciplinary work. Creating centers of excellence and cooperative institutes at selected universities to lead the way toward broader curriculum adoption at other universities may provide a path forward. Current efforts in creating interdisciplinary and transdisciplinary programs for research on natural disasters offer examples that might be followed for geohealth.

It is also critical that opportunities to shape and contribute to the field of geohealth expand beyond the traditional norms of academia. Including members of all communities in geohealth research is likely to lead to better outcomes and potentially discover new issues and solutions. This may involve incentivizing collaboration with boundary organizations and promoting co-authorship with community members, as well as making research findings and other products accessible to those who have contributed to the research. Traditionally, geohealth research has often focused on establishing (causal) relationships between environmental conditions and health outcomes without explicitly addressing or testing solutions. As a result, the efficacy of many approaches to improve health outcomes is largely unknown or unproven. Partnerships with local organizations and experts can inform research questions and ensure that results translate to improved quality of life more readily.

Recommendations:

- Provide support for transdisciplinary graduate programs, fellowships, summer training programs, short courses, workshops for current researchers, etc.
- Provide support for meaningful codesign between the groups that are producing and consuming data, including the creation of pathways for community engagement and participation that extend beyond the traditional norms for research and publication.

- Take lessons from other interdisciplinary geosciences successes and fund institutes like the CONVERGE facility at University of Colorado, but focused on geohealth instead of natural disasters.

2.2. Target Areas for Progress

The prior sections outline a number of opportunities to address structural challenges to progress in convergent research and applications in geohealth. Additionally, as part of the conversations with professionals working in the geohealth arena, several topics were raised as ones where significant progress could be made if the geosciences pushed into new areas or pushed to scale up or coordinate existing efforts, especially once those overarching challenges are addressed. These topics include:

2.2.1. Air quality

Issues relating to air quality represent a powerful area of convergence within geohealth, as air moves regardless of political boundaries and therefore affects the health of all people. However, better coupling of pollution models to health data may aid in furthering understanding of which communities are at most risk and in what ways. Researchers stressed that understanding the interactions between and health impacts of various air pollutants is all the more critical as the climate changes, as the harmful impact of air pollutants are likely to compound as environmental events such as heatwaves or wildfires become more common or severe. Improved understanding of the linkages between climate change and respiratory conditions such as asthma are also important because previous studies may have controlled for elements such as temperature and consequently created an incomplete picture of risk factors.

While anthropogenic aerosols receive a lot of focus, there is also a need to better understand the impact of “natural” aerosols such as dust which may have a relatively low daily impact but severe long-term effects. Attributing aerosol concentrations to specific sources remains difficult. Scientists also mentioned that there is no widely accepted methodology to calculate uncertainties related to air quality. This can be caused by the different standards in different fields or the difficult problem of combining uncertainties that were derived from different data sets or research approaches.

It is well-documented that certain communities, such as low-income and Black communities, face increased exposure to air pollution. Additional research and investment in air quality therefore not only have the potential to improve health outcomes for millions but to address legacies of environmental injustices.

2.2.2. Heat and humidity health impacts (including in athletics and outdoor work)

As the climate changes, understanding and mitigating the health impacts of heatwaves and other instances of extreme heat is critical. Higher temperatures can serve as a compounding factor for a number of other environmental health issues, including air pollution, while also placing stress on the body. The burden of excessive heat is disproportionately felt by certain groups, including those with existing health issues or those who are socially isolated, and is one of several health impacts that need to be viewed through the lense of environmental justice. The heat island effect, where urbanized areas experience higher temperatures than outlying areas, is a notable example of how heat risks are often exacerbated by local disparities, as even within a city certain areas may be hotter than others due to the distribution of urban surfaces and green spaces. While planting trees is a common method used by communities to help mitigate risks from extreme heat, when deployed without appropriate consideration of the surroundings it may have deleterious effects, such as trapping air pollutants at ground level. AI and other tools may aid in developing strategies to plant trees in locations where they can bring the greatest benefit to groups with the greatest risk factors for heat impacts.

Additionally, there has been a lot of research on the impact of weather on athletes, especially in terms of the stresses caused by heat and humidity. Wet bulb globe temperature (WBGT) is a measure of the heat stress in direct sunlight. It takes into account temperature, humidity, wind speed, sun angle, and cloud cover (to assess solar radiation). WBGT differs from the heat index, which takes into consideration temperature and humidity, but is calculated based on shady areas. While WBGT can be useful in gauging the expected stress on athletes (and in fact, anyone who is doing physical activity outdoors), routine forecasts of WBGT are not produced by the National Weather Service. And while routine WBGT forecasts would be useful, research has begun toward more sophisticated indices that would better align with health risks. It was noted that monitoring of body heat by wearable technology would be ideal, but in the absence of that, having a reliable predictive index that can guide planning for acceptable levels of exertion by athletes and workers is needed. There was also input from those in the field who felt that more social science research is needed on the decision process of trainers and others charged with protecting the safety of athletes (and other workers), with the potential goal of better guidance for those in the position of making heat and humidity health safety decisions.

2.2.3. Predictive warning systems

The operational meteorological community includes a number of health-related

predictions as part of their routine forecasts (including dangerous heat or cold events, air-quality issues, etc.). Researchers indicated that verifying those predictions against documented health impacts can be difficult because of the data-relevant challenges outlined in this report. As such, efforts to develop early warning systems for environmental conditions that promote disease, would be of high impact, especially when including the cascading risks associated with compounding extreme events.

Beyond those routine health-related forecasts, there is a need for more research on high-impact events whose probability of occurrence is either low or unknown. As just one example, consider outbreaks of asthma attacks triggered by thunderstorm outflow. Though rare, there are well-documented cases in which thunderstorm outflow winds have spread pollen and allergens through populated areas and triggered outbreaks of asthma attacks that reached epidemic proportions (including fatalities). Understanding the precursor conditions and contributing factors well enough to allow effective prediction of these events has been difficult, and early efforts toward an operational warning system have not been very successful.

2.2.4. Attribution and communication of environmental impacts

There is great need for rigorous attribution, characterization of scientific understanding, and effective communication of information to diverse audiences and stakeholders. As such, there is a need for robust studies that examine how environmental changes might affect particular health outcomes, including intersections with various vulnerabilities or risk factors. Rigorous and systematic attribution could also serve to enable efforts to establish the health benefits of climate action, an area in which respondents felt there was little available synthesis.

There are also opportunities to develop new strategies for effectively communicating geohealth risks to decision makers and the general public. This includes the development of effective communicators of accurate information. One option may be to tap into the existing network of broadcast meteorologists, who are often highly recognized and respected figures within their communities.

2.3. Mental Health

Beyond the impacts of the Earth system and sciences on physical human health, our mental health and wellbeing is also affected by weather and climate, especially in times of crises. Earth systems can impact mental health indirectly, exemplified by the burden placed on those experiencing displacement due to weather hazards (e.g., hurricanes, tornadoes, blizzards) and climate disruptions (e.g., wildfires, flooding), or those

experiencing food insecurity as a result of droughts or novel weather patterns. Changes to the earth system and climate can also impact people's mental health directly: the stress and awareness of an existential danger presented by climate change and the lack of agency over solutions can pose a negative impact on mental wellbeing. The mental burden of these experiences and knowledge weigh on both the public at large as well as members of the Weather, Water, Climate (WWC) workforce whose job it is to understand, organize, and communicate weather and climate information daily. This section will explore some of the current concerns and challenges surrounding declining mental health in the face of climate change and weather disasters, as well as overarching principles for progress and actions that can be taken to improve the situation. Fortunately, not all interactions with our earth system prove detrimental and many solutions to declining mental wellbeing involve increasing access to nature and natural areas.

Members of the WWC workforce, specifically meteorologists, report a feeling of helplessness when forecasting and witnessing repeat climate and weather disasters. Specifically, the experience of forecasting continually worsening scenarios (more frequently or more damaging) is detrimental to their mental health when coupled with the feeling and knowledge of not being able to lessen or stop the disasters from occurring. In addition to this, having climate science be publicly denied, deemed unimportant, or mocked on the political stage or in public discourse when the threats and hazards are abundantly clear and continually communicated takes a toll on the mental health of those working in this field.

As mentioned previously, individuals that do not work in the WWC enterprise still experience declining mental health due to the concerns of consequences or ramifications from climate change and dangerous weather events. Terms such as 'climate anxiety', 'climate nihilism', and 'climate doomism' are increasingly included in public discourse surrounding society's feelings about our earth system's health. Continually being informed of record-breaking events attributed to climate change and the ramifications these events have on communities can be overwhelming, especially when acknowledging the fact that these consequences are not equitably dispersed. Populations that have contributed the least to carbon emissions are experiencing the first and worst consequences of a changing climate. As climate change is continually described as an 'existential threat', it is increasingly clear that people, especially youths and young adults, are coping with the reality that their lives will likely be impacted by such hazards in dangerous or dramatic ways. This feeling, coupled with the perception that action against climate change is too little, too late, or solely in the discretion of large companies or the wealthiest 1%, is disheartening. How can we support the mental health of the public when the despair surrounding climate change hinges on the fact that the problem

is 1) global, 2) existential, and 3) out of control of the individual?

Principles:

- Community health (both physical and mental) is inextricably linked with Environmental Justice (EJ). Throughout efforts to secure better mental health, concepts and principles of EJ will need to be addressed.
- Access to nature is important to a sense of self and environmental identity—how one views themselves in relation to, or as part of, the natural world. Access to nature provides space to reflect; be independent; feel like one is part of a greater whole: all things that are positive thoughts of one's self.

Recommendations:

- Encourage and support community building through storytelling and sharing of experiences in community or social groups.
    - For example: Create or join unofficial social media groups centered on mental health, share resources, express that one is not alone in their struggles.
- De-stigmatize mental health issues and concerns by increasing awareness at all scales.
    - For example: An organization could speak on mental health and wellbeing or provide resources to staff and members; an individual could share their experiences.
- Institutions and organizations should be part of these conversations and solutions. Public and official involvement indicates that mental health and wellbeing is a topic that is taken seriously.
    - For example: NOAA line offices have hired or are in the process of hiring a behavioral and mental health wellness officer, trained in clinical psychology (NOAA 2021).
- For members of the WWC workforce, employers can provide support.
    - For example: Provide training on topics such as PTSD, suicide prevention, how to cope with grief/loss, how to help those who are coping with grief/loss. This may be especially helpful for those who work in natural disasters, forecasting, or hazard mitigation; Provide resources to connect with climate-aware therapists.
- Increase access to nature and natural areas.
    - For example: The increase of trees and exposure to tree canopy in urban areas is correlated with less psychological distress (Astell-Burt & Feng 2019); Similarly, increasing access to and availability of parks is beneficial for mental wellbeing.

- Invest in green infrastructure and green adaptation measures.
    - For example: Instead of implementing hard shorelines to prevent coastal erosion, employ a living shoreline technique that includes elements such as native plants, oyster reefs, and aquatic vegetation (EPA n.d.). This is beneficial not only for the expansion of natural areas and wellbeing, but also as a long-term climate adaptation solution.
- Support and enable the teaching of environmental sciences in early education.
    - For example: Environmental and food education, especially from an early age, can help children develop both an environmental identity and the tools and knowledge to create effective change as they grow.
- Support and enable the following areas of study:
    - 1) Collection of baseline information and criteria to understand when the stress of climate change impairs mental health and normal function;
    - 2) Understand anxiety as a motivator or paralyzer: what factors lead to one outcome or the other? Current ideas for determining factors include degrees of a) social support (are fears validated or mocked and politicized as opposed to being seriously considered) and b) sense of efficiency in actions.

3. Conclusion

The interface of health, geoscience, and the Earth system encompasses numerous pressing challenges, including: global change, environmental variability and degradation, and the disruption of key life-support services. The input received from community members throughout the course of this study also highlights the myriad ways in which geohealth issues are linked to broader societal concerns relating to community engagement, decision making, and research design, among others.

From across this range of perspectives, certain critical throughlines emerged:

- Issues of geohealth are often intricately connected to issues of environmental justice. As such, inclusion, equity, and justice are central to the advancement of and benefit from geohealth science.
- Advances in geohealth science require truly convergent research approaches to provide maximum benefit to society.
- Progress in geohealth requires participation from multiple sectors within disciplines, with important and complementary roles for those in the academic, government, private, and NGO sectors.
- Issues related to climate change are both hugely important and constitute a relatively small fraction of the overall geohealth landscape. In many instances, climate change will amplify and exacerbate existing issues in geohealth.
- Interoperability of data, research, understanding, and applications of knowledge is critically important and currently represents multiple challenges that are limiting progress within geohealth.

The breadth of subject areas within the field of geohealth result in a variety of high-impact opportunities. These solution areas include issues of air quality, heat, and humidity, as well as predictive warning systems and the attribution and communication of environmental impacts. Efforts to understand and mitigate the mental health impacts of repeat weather and climate crises are also considered to be of utmost importance by the community. Enabling the effective pursuit of these opportunities will require a shift in the way that interdisciplinary and transdisciplinary research is carried out, including establishing dedicated mechanisms for funding and community partnership, as well as training in relevant skill sets.

References

Astell-Burt, T. and X. Feng, 2019: Association of urban green space with mental health and general health among adults in Australia. *JAMA Netw Open, 2(7), https://doi.org/10.1001/jamanetworkopen.2019.8209*.

EPA. Coastal resiliency. https://www.epa.gov/green-infrastructure/coastal-resiliency.

NOAA, 2021: Mental health awareness flyer. https://www.corpscpc.noaa.gov/cyberflash/cyberflash2021/mha_month_flyer_cyb20210521.pdf.

Appendix: Study Contributors

List of experts who contributed to this study in alphabetical order. The listed organizations represent primary employers at the time of the interview/comment.

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