# Geoscience and Human Health (GeoHealth): Impacts and Mitigation of Impacts on Human Health Due to a Changing Natural Environment

## Presented by the Geological Society of America

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The responses received to the Geological Society of America's (GSA) initiatives to crowdsource GeoHealth solutions illustrate the fundamental understanding that the health of Earth influences the health of humans. Human health intersects with all of Earth's spheres: the lithosphere, hydrosphere, atmosphere, and biosphere. It is therefore essential that geoscientists, who analyze all of Earth's spheres, partner with those in the health, epidemiological, and toxicological fields to maximize synergy in identifying, monitoring, communicating, and mitigating impacts on human health that occur through geologic processes.

Our approach to collecting information was crowdsourcing through a series of targeted brainstorming sessions, online questionnaires, section meeting events, and soliciting comments by directed outreach to leaders in the geoscience community. GSA is grateful to its members and the broader community for their thoughtful input. Results are given below as well as a brief description of our methodology. We also include the full complement of responses in an appendix to this document.

**What are the highest priority challenges in GeoHealth that can be addressed with actionable solutions in a two- to three-year timeframe?**

This document proposes five areas for short-term research: (1) identification of geologic processes that may be affected by climate change, with resulting impacts on human health: (2) development of geologic materials into products that benefit human health: (3) development of clear and communicable linkages between existing environmental contamination and impacts on human health through enhanced use of GIS tools; (4) pathogen research; and (5) human uptake of minerals and metals.

**How would you reach those GeoHealth goals? What stakeholders, technology, and/or partnerships are needed?**

Transdisciplinary collaboration, particularly with health scientists, will be a key requirement for many of the research initiatives described here, in part to gain access to fine-scale health data that are subject to confidentiality provisions outside of the researchers collecting the data. New funding sources and funding models are needed to incentivize and support these collaborations between geoscientists and medical/biomedical researchers at the state, federal, and international levels. In addition, it will be useful to develop technology partners such as Google Earth and the U.S. Geological Survey to better connect high-resolution geospatial data with health data.

**How do we effectively communicate the critical role of geoscience in addressing environmental impacts on human health to the public and decision makers?**

Communication and outreach are crucial to GeoHealth, both for identifying areas of needed research and sharing results. To be effective and drive participation, communication and outreach efforts must be funded, supported, and valued and involve professionals at all career stages and stakeholders in the community. A range of communication strategies, including developing visualization tools, are needed. Partnerships with not-for-profit organizations allow geoscientists to build upon their proficiencies in this area, while connections with high-visibility organizations such as National Public Radio (NPR) and Earth Day organizers allow for enhanced visibility of geosciences and outreach to the general public.

**What changes and resources are needed to embed a culture of innovation, entrepreneurialism, and translational research in GeoHealth?**

Develop new funding mechanisms (e.g., with National Institutes of Health (NIH) and education) and reward structures to incentivize partnerships and transdisciplinary research and prioritize better geoscience and geohealth education at all levels by enhancing opportunities to develop course content in geosciences to be embedded into traditional biological/medical sciences.

**Q1. What are the highest priority challenges in GeoHealth that can be addressed with actionable solutions in a two- to three-year timeframe?**

The research priorities described below were highlighted in the surveys undertaken by GSA and developed through discussion with senior GSA leaders. Relatively few suggestions were made in regard to toxicology or health effects, or how health effects could be studied. We recommend that geologists continue to do what they do best; that is, study Earth's spheres and partner with health professionals rather than attempting to learn these fields themselves. Education and outreach activities provide an opportunity to expand the portion of the geoscience community actively involved in GeoHealth research.

1. Impact of climate change on geologic processes that can in turn impact human health.

   Geologists have unique insights into how climate change will continue to transform the geologic environment and where these environmental changes have the potential to impact human health. Earth scientists can inform and partner with health researchers to identify health impacts brought about by climate change as mediated through geologic processes. In particular, climate change will exacerbate existing stresses on water resources, affecting the access of communities to clean and safe drinking water. Select examples of geologic processes induced by climate change that impact health, and could be acted on to predict and mitigate proactively, include:

   - Sea-level rise—Salt water intrusion into coastal drinking water aquifers will reduce available sources of drinking water and place subsequent pressure on other water resources to serve the impacted populations. Opportunities exist to identify areas where water quality and quantity are likely to degrade and begin to proactively mitigate.
   - Over-use of groundwater—Decrease in water tables in populated areas have potential impacts on the quality of drinking water; e.g., from higher gas levels in aquifers, or from redox-induced changes in solubility or transport of specific chemical elements such as As, Cr, and U, which will now impact drinking water where they did not before. (For example, U is immobile in the +3 oxidation state but highly mobile and toxic in the +6 state.)
   - Increased aridity and desertification—induces modern dust-bowl conditions that impact air particulate matter loads and affect wider populations than are currently affected. Analysis of the chemical, mineralogical, and microbiological characteristics of dusts and other atmospheric particulates to help understand their sources, transport, fate, and disposition in the body if inhaled is needed. Critically important is the identification of mineral dusts that are and are not hazardous; mineral composition is a key factor to determine health impacts, as is lung burden. Additionally, increased solid materials increase lung burden on a wide swath of populations and have deleterious effects on human and animal health. Commensurate with this are the long-range transport of dusts world-wide as the deserts increase in size, as does their impact on human and animal respiration and soil degradation.
   - Severity and impact of wildfires—degrades soil quality and impacts subsequent crop survival. Crops may increase their uptake of contaminants from the soil and thus the food supplies across the globe will be affected. High-quality modeling studies are available and could be combined with surficial geologic data, which can be used to assess the extent of damage and propose approaches for short-term and long-term mitigation. In addition, work is needed to identify and develop emergency-response plans for areas where post-wildfire landslides are likely to occur.
   - Increased mining activities for mineral resource extraction to fuel the low-carbon transition can cause environmental degradation. As more and different resources are required for electrical generation and transportation (e.g., rare earth elements, lithium, nickel), Earth's surface will be disturbed, potentially enhancing erosion and dust generation. Enhanced monitoring and mitigation measures should be employed. Rare earth mining also has the potential to release metals into the environment that are not typically observed today, with unknown potential health impacts at this time. Studies should commence/continue to understand human-mineral/element interactions.

2. Development of geologic materials into products that benefit human health.

   Additional areas at the intersection of geology and health include developing geologic materials into products that benefit human health. One example is the use of antibacterial clays to defeat antibiotic resistant pathogens. Trial studies have produced interesting results, but more funding is needed. Typically, NIH does not fund geoscientists on the scale needed for advancements in this field. Opportunities exist for NSF to provide funding in this arena, perhaps in concert with the NIH.

3. Developing clear and communicable linkages between existing environmental contamination and impacts on health through enhanced use of GIS tools.

Massive datasets for geological parameters, as well as various health parameters, are available. These datasets can be mined, analyzed, and mapped using geospatial tools to create new insights and high-impact visuals for communication among scientists and non-scientists. Application of geospatial tools is a vastly underutilized method to determine correlations between geological data (e.g., soil and groundwater contaminant concentrations) and health and demographic parameters. Such studies can be performed within a two- to three-year time-frame, provided that demographic and health data are available on the granular scale needed to make correlations. Geoscientists will need to engage directly with health researchers as much health data is subject to confidentiality requirements. Such studies can help pinpoint areas or neighborhoods with greatest risks of exposure to various contaminants, such as PFAS, microplastics, and pharmaceuticals, as well as mine waste and agricultural runoff.

4. Pathogen research.

   Use geological, soil, geochemical, ecological, and climate parameters to examine the distribution of pathogens globally. Research is needed to understand geochemical and mineralogical controls on the occurrence and viability of natural soil- and water-borne pathogens (Cocci, B. Anthracis, Vibrio, etc.), and on the persistence, viability, and transmissivity of pathogens shed from animal hosts into the environment (Avian influenza virus, SARS-CoV-2, prions, etc.).

5. Human uptake of minerals and metals.

   Progress can be made in characterizing the sources and disposition of minerals and metals in humans. For example, recent USGS research examined the etiology of rapidly progressing coal workers' pneumoconiosis by using SEM and other analytical methods to characterize mineral matter in lung tissue samples. The application of chemical analyses and stable and radiogenic isotopes can be used to track sources and disposition of toxic metals in the body and physiological processes.

**Q2. How would you reach those GeoHealth goals? What stakeholders, technology, and/or partnerships are needed?**

Geoscientists have a unique set of tools and study broad topics related to all of Earth's spheres, which places health aspects into a geoscience context. Connections among health scientists and geoscientists must be established to maximize acquisition and interpretation of both geological and health data.

New funding sources and funding models are needed to support these collaborations between geoscientists and medical/biomedical researchers at the state and federal level. Successful programs exist that can be used as a model. For example, the Superfund Research Program of the National Institute of Environmental Health Sciences (NIEHS) funds a portfolio of proposals from a collaborative group that is required to include both health-based and environmental science-based individual proposals. Partnerships between the NIH and NSF may be another avenue. Developing databases of experts in each area would allow easier networking and provide identifiable linkages to those scientists seeking collaborations.

More partnerships should be developed on an international scale so as to elevate the status and image of GeoHealth within the geoscience and broader science communities, some of which may be underfunded. Health is a priority of all governments worldwide, and therefore, generating interest for such collaborations (e.g., specific GeoHealth conferences) would be possible.

Develop technology partners, for example—partner with Google Earth to provide high-resolution data for geohealth and surface geologic coverage; partner with USGS to utilize their geologic geospatial maps to connect to health data; develop methods to aggregate health data on a finer scale, to combine with geodata, while not infringing on privacy of individual health records.

**Q3. How do we effectively communicate the critical role of geoscience in addressing environmental impacts on human health to the public and decision makers?**

Communication and outreach are crucial in GeoHealth, both for identifying areas of needed research and sharing results. To be effective and drive participation, communication and outreach efforts must be funded, supported, and valued. Communication of research results is essential, because the results have societal relevance. Communication must not be restricted to other scientists, policy makers, local, state, or federal governments, but must also involve public engagement and outreach to affected communities. Some geohealth issues are non-discriminatory, such as smog in the Los Angeles basin, while other health and environmental impacts are highly localized and intersect with environmental justice issues. Different communication styles and materials may be needed depending on the audience or affected community.

Early career professionals as well as students should be involved in the communication strategy. Geoscience researchers can partner with not-for-profit societies to further the scientific goals (e.g. Union of Concerned Scientists, Nature Conservancy, Sierra Club and local chapters). Opportunities for input by stakeholders in the community must be provided to empower them to have a voice in developing and communicating the science that affects them.

Visuals, such as those that can be developed through the enhanced use of GIS tools as described in Question 1 responses, and other visualization tools, can be a more widely accessible form of communication than publications and can be disseminated more easily than research papers. These products also provide powerful support when reaching out to policy makers and local communities. For example, geologic maps that include assessments of modifications of the near-surface can be an important educational tool to educate the public about the character of the materials below our feet, and the impact of those materials on the built environment.

To reach the broader public, connect GeoHealth in targeted geosciences events that are already high visibility to the public such as Earth Day (e.g., work with non-governmental agencies at EarthDay.org), embed information on the weather channel (e.g., beware of high dust days, have segments that educate the public about geology and health [similar to those for volcanic eruptions or high pollen days]). Use social media when appropriate.

Public engagement and community outreach are essential to creating visibility of the role geosciences play in addressing GeoHealth challenges. Effective communication will help build partnerships, trust in science, and risk awareness, all of which are essential for developing inclusive and innovative solutions that address the most pressing GeoHealth challenges. Possible avenues for public engagement and community outreach include:

- Social media, when used effectively, can be a powerful and broad-reaching tool for disseminating information and bringing awareness to issues, and is something the GeoHealth community has not yet taken advantage of.
- Translating information about GeoHealth into other languages will broaden outreach efforts.
- Community or place-based outreach and citizen science around GeoHealth issues will significantly increase the awareness about GeoHealth risks, build trust in science, and stimulate inclusive solutions.
- Providing funding for outreach events, from international meetings to local events.

**Q4. What changes and resources are needed to embed a culture of innovation, entrepreneurialism, and translational research in GeoHealth?**

Many of the suggested ideas for ways to embed a culture of innovation, entrepreneurialism, and translational research in GeoHealth are similar to those submitted addressing how to effectively communicate the critical role of geoscience in addressing environmental impacts on human health to the public and decision makers. Partnerships, transdisciplinary research, communication, and education are common themes, with changes in the rewards structure needed to incentivize these activities. These efforts need to be well funded and centrally coordinated.

***New Funding Mechanisms to Incentivize Partnerships***
Increased investment and new funding models would stimulate vital partnerships to help effectively communicate the critical role of geoscience in addressing GeoHealth issues as well as help embed a culture of innovation, entrepreneurialism, and translational research in GeoHealth. Examples of models include:

- Working groups with a directed charge to solve GeoHealth issues.
- University cross-disciplinary GeoHealth institutes/research centers drawing from different departments, including biological, medical, geoscientists, physical, and social sciences, that include generalists and specialists.
- Provide medical professionals with accessible geoscientists partners they can easily turn to facilitate their work.
- Partnerships between academia (geosciences, medical sciences, and social sciences), governmental organizations (including federal, state, and local), non-governmental and industry.
- Public/private partnerships, including venture capitalists.
- GeoHealth planning grants to fund time needed to build connection and collaboration across disciplines.
- Transdisciplinary funding programs (geoscientists and health scientists).
- NSF Geoscience divisions should partner with NSF Education and Human Resources to fund proposals related to course content development at all educational levels. All students take biology classes, integrating geological effects into health and biological discussions provides an entrée for more students to learn about the earth sciences.

***Values and Reward Structure***
Changing reward structures could incentivize scientists to increase communication and participation in transdisciplinary research projects. Until these activities are valued as part of a reward structure, it will be difficult to make substantive changes including developing transdisciplinary partnerships. NSF can directly affect this system by expanding its Broader Impacts program. From its crowdsourcing responses and position statement, "Rewarding Professional Contributions in the Public Spheres," GSA recommends that geoscientists receive formal recognition and reward for interdisciplinary and outreach efforts through positive performance evaluations, reappointments, promotions, and tenure reviews. GSA also encourages support, by means of appropriate reassigned time or travel assistance to conferences, workshops, and other appropriate endeavors, to those individual geoscientists engaged in this arena.

***Education, Communication, and Outreach***
Survey and brainstorming session responses revealed there is a general lack of knowledge around the definition of GeoHealth. Education can play a large role in addressing this knowledge gap. Opportunities and tools to make progress exist in formal and informal education, including public education. Public education and understanding requires a holistic approach, utilizing people skilled in science education as well as content specific instructors. Improving K–12 geology/earth-science education is needed. Embedding the health aspects of geologic processes into the K–12 curriculum is one mechanism to introduce geoscience to more students. Additionally, GeoHealth connections should be introduced within science courses so that students gain an inherent understanding of the term throughout their education.

# Methodology

Our primary format for receiving feedback was a web-based submission platform. Information about the opportunity and an invitation to participate was sent to GSA members through email and posts in the Connected Community network that reaches the entire membership. Our combined efforts focus on broad outreach and ensuring broad disciplinary participation reaching students, early career professionals, and underrepresented groups, as well as experienced professionals in the geosciences.

GSA used multiple social media channels with a large reach to publicize this opportunity. Current numbers of GSA's followers on various social media channels include:

- Facebook: 275,140
- Twitter: 53,326
- Instagram: 7,150
- LinkedIn Group: 40,496
- LinkedIn Page: 14,046
- YouTube subscribers: 2,017

GSA also requested participation from the leadership of each of its 22 Divisions and 75 Associated Societies. Targeted outreach was conducted to Associated Societies and organizations with a focus on underrepresented groups, including the National Association of Black Geoscientists (NABG) and International Association for Geoscience Diversity (IAGD), along with the Mineralogical Society of America, the Association of American State Geologists, and International Association for Promoting Geoethics, allowing GSA to receive insights from local to international perspectives.

GSA held in-person opportunities for direct contributions at its joint North-Central and Southeastern Section Meeting, which has a large percentage of student participants. GSA staff and leadership also conducted direct outreach to attendees at the joint Rocky Mountain–Cordilleran Section Meeting and Northeastern Section Meeting.

GSA also held two online brainstorming sessions focused on attracting students, early career geoscientists, and geoscientists from underrepresented groups, including alumni of GSA's On To the Future (OTF) program for bringing in underrepresented students. The Geology and Health Division also hosted an online Town Hall on GeoHealth. Targeted expertise was provided by the Geology and Health Division leadership, including Dr. Reto Gieré, Dr. Ann Ojeda, Dr. Jeff Rubin, and Dr. Malcolm Siegel, and from disciplinary experts Dr. Terri Bowers, Dr. Geoffrey Plumlee and Dr. Lynda Williams.

Many GSA staff contributed valuable insight and leadership to these activities, including Justin Samuel, Emily Levine, Collin Rudkin, Jazzy Graham-Davis, Christa Stratton, Elizabeth Long, and Morgan Disbrow-Monz.



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