Global Environmental and Occupational Health (GEOHealth)

Process Evaluation Report
2014-2019

Fogarty International Center
National Institutes of Health
August 2020

www.fic.nih.gov

Photo by Bangladesh Center for Global Environmental and Occupational Health

GEOHealth
Process Evaluation Report

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Executive Summary

The Fogarty Division of International Science Policy, Planning and Evaluation (DISPPE) conducted the process evaluation in early 2019. The review looks at the seven GEOHealth hubs, which are each supported by two linked cooperative agreement awards with a research award (U01) to the LMIC institution and a research training award (U2R) to a US institution, during the first five years of the GEOHealth program. At the time of the evaluation, the program had trained 118 people from 12 countries around the world. Cohorts included clinicians and public health professionals, medical students and undergraduates from academia, government and NGOs. Together, the hubs addressed seven research areas: outdoor air pollution, household air pollution, agricultural health, environmental contamination, electronic waste, climate change and industrialization. Hubs used their collaborations to launch new graduate programs thereby building institutional capacity.

Executive Summary

Introduction

The John E. Fogarty International Center (FIC) at the National Institutes of Health (NIH) supports international collaborative research and training programs that advance the NIH mission through international partnership. FIC often conducts process reviews of its extramural award programs after the first five years. The purpose of this process review is to analyze program implementation, identify near-term outputs, and make recommendations for future improvements to the program.

The Global Environmental and Occupational Health (GEOHealth) program, launched in 2012, supports the development of institutions in low- or middle-income countries (LMICs) serving as regional hubs for collaborative research, data management, training, curriculum and outreach material development, and policy support around high-priority local, national and regional environmental and occupational health threats. GEOHealth Hubs are supported by two coordinated linked awards to 1) a LMIC institution for research and 2) a US institution to coordinate research training. Together the hubs form the GEOHealth Network, a platform for coordinated environmental and occupational health research and research training activities.

Two funding announcements were released in 2014: a U01[1] for a research project cooperative agreement open to LMIC institutions, and a U2R[2], an international research training cooperative agreement open to US institutions. A total of 14 awards were made to US and LMIC institutions that comprise seven hubs during the first five years of the program. This report describes the results of the GEOHealth process review: a description of the program history, an overview of the hubs, partners' feedback, and findings and recommendations.

Evaluation Methods

The FIC Division of International Science Policy, Planning and Evaluation (DISPPE) conducted the process evaluation starting in late 2017. DISPPE staff worked with the GEOHealth program officer and Division of International Training and Research to develop key evaluation questions (Table 1), and the results of this evaluation will inform the future implementation of the GEOHealth program.

Table 1. Key Evaluation Questions
What models for capacity building have been implemented through the program thus far? What are the outputs of these efforts thus far?
Do the research and other capacity-building efforts that have taken place so far appear to have been appropriately focused?
What have been the research outputs from the program thus far?

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[1] RFA-TW-14-001
[2] RFA-TW-14-002

Data collection for the GEOHealth review included the following:

- *Administrative sources* (e.g., applications, progress reports) were collected and reviewed to identify the universe of grants, investigators, publications, and trainees associated with the programs.
- A *trainee roster* of all trainees trained through the GEOHealth program was developed based on the FIC CareerTrac database, which included trainee data from all of the hubs. All of the hubs entered trainee data in CareerTrac.
- *Publication* information was collected through PubMed to assess collaboration between LMIC and US researchers, early research outputs, and capacity building among trainees.
- *Interviews and discussions* with FIC staff and GEOHealth partners were used throughout the evaluation to provide qualitative insights into program design, management, and results.

Background
Program Origin and History
Nearly a quarter of all deaths worldwide—roughly 12.6 million deaths a year—are attributed to living or working in an unhealthy environment, including pollution, chemical exposures, climate change and other risk factors.[3] In fact, more than two million workers around the world die each year due to occupational injury or illness, and 317 million people suffer from work-related injuries, costing the global economy billions of dollars.[4] The burden is highest in LMICs, particularly in Africa, Southeast Asia and the Western Pacific.[5]

Addressing these challenges requires a critical mass of scientific experts in large-scale environmental and occupational health analysis, complementary skills such as data management, and appropriate understanding of the local and regional socioeconomic and policy context that influences the effectiveness of interventions. Although LMICs suffer more from environmental and occupational hazards, in many cases, inadequate capacity exists to study and mitigate these problems. Currently, few institutions outside of the United States and other high-income countries have sufficient research capacity to study toxic, carcinogenic, or occupational exposures or interactions with genetic, immune systems or population-based factors.[6]

For almost 25 years, FIC has been one of the few organizations funding grant programs for environmental and occupational health research training in LMICs (see *Niche Relative to Other Funders* below). The current GEOHealth Hub program originated from a reengineering of the FIC's long-standing International Training and Research in Environmental and Occupational Health (ITREOH) program. The ITREOH program, a research training program (D43 funding mechanism) which ran from 1995 to 2011, provided long-term research training to nearly 200 scientists at 34 institutions in 43 countries and

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[3] 2012 WHO Report

[4] International Labour Organization report

[5] Prüss-Ustün A, Wolf J, Corvalán C, Bos R and Neira M. (2016) Preventing disease through healthy environments: A global assessment of the burden of disease from environmental risks. World Health Organization. ISBN 978 92 4 156519 6. https://www.who.int/quantifying_ehimpacts/publications/preventing-disease/en/

[6] Rosenthal, J., Jessup, C., Felknor, S., Humble, M., Bader, F., & Bridbord, K. (2012). International environmental and occupational health: From individual scientists to networked science Hubs. *American journal of industrial medicine*, *55*(12), 1069–1077. doi:10.1002/ajim.22130

supported several thousand scientists from 75 institutions around the world to participate in short-term workshops. [7] Because of this breadth, there was less investment in any one program or LMIC institution. The shift to the GEOHealth model began in 2012 with two-year paired planning grants (R24 mechanism) to facilitate partnership building, needs assessments, and planning. The planning grant program was followed by a competition for full GEOHealth Hub awards in FY2015.

The goal of the new GEOHealth program, as outlined in the funding announcements, was to develop a handful of regional science hubs, based in LMICs, that would become internationally-recognized centers for environmental and occupational health research, ideally serving the multinational regions in which they reside.[8,9] To that end, the program endeavors to develop the individual and institutional capacity needed to support a critical mass of first-class EOH scientists whose research is recognized and supported by national governments and attracts multiple international collaborations and funding streams.

In addition, the GEOHealth program aims to strengthen environmental and occupational health-related research collaborations, accelerate scientific infrastructure development, enhance research training, create relevant advanced educational curricula and outreach material, and support research needed to identify and design mitigation strategies for the adverse consequences of environmental and occupational exposures and to inform nationally-relevant policy development in LMICs.

Hub Model

The Hubs are supported by two linked cooperative agreement awards with a research award (U01 funding mechanism) to the LMIC institution and a research training award (U2R funding mechanism) to a US institution. Hubs are expected to have multiple partnerships with other US and LMIC research institutions as well as connections with government agencies and ministries and non-governmental organizations. Each hub can receive up to a total of $600,000 per year through these two linked awards with at least half awarded directly to the LMIC institution. As a cooperative agreement, NIH or other USG staff have substantial scientific or programmatic involvement in the project activities. In this case, the hubs benefit from having NIH and CDC scientific officers involved as project collaborators who provide advisory input and serve as a point of contact for scientific and technical issues.

The program reflects a robust partnership with the NIH, CDC, and Canada's International Development Research Centre (IDRC). The program benefits from co-funding with the National Cancer Institute (NCI), the National Institute of Environmental Health Sciences (NIEHS), the National Institute for Occupational Safety and Health (NIOSH), and IDRC. The Global Alliance for Clean Cookstoves also participates in the program by offering supplemental funding. This co-funding represents nearly two-thirds of the $4.2M annual budget with FIC providing the remainder.

FIC envisions that the GEOHealth Hubs will become internationally recognized centers for the collection, management, synthesis and interpretation of data on environmental and occupational health, ideally serving the multinational regions in which they reside. Each Hub will provide training and curricular resources to academic institutions in the region. Hubs are also expected to have collaborative

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[7] Rosenthal et al. 2012
[8] RFA TW-14-001
[9] RFA TW-14-002

relationships with ministries of health and other key planning and operating agencies that oversee health-affecting activities, such as agriculture, labor and public works, to serve as a source of scientific evidence for policy formulation related to environmental and occupational health. Research partnerships can enhance access to expertise and resources that improve research capacity for environmental and occupational health in LMICs.

Together these regional hubs form the GEOHealth Network, which can serve as a platform for coordinated environmental and occupational health research and research training activities. It is anticipated that the GEOHealth Hubs will not only leverage the current investments of national governments and international research agencies and donors, but also become attractive for further investments in these institutions in the future. In doing so, the hubs can also become magnets that attract, develop and retain the best environmental and occupational health scientists in LMICs, key collaborators for scientists from the US and international partners, and among the most credible sources in the world for state-of-the-art knowledge on environmental and occupational health.

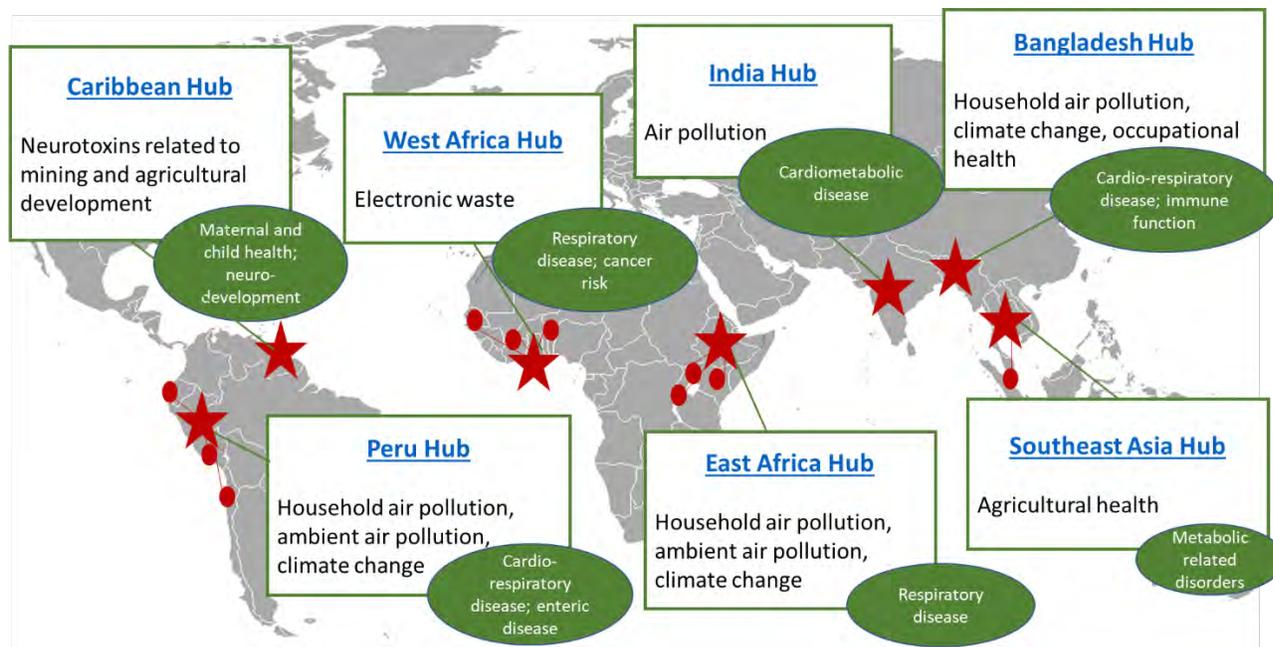## Descriptive Information on GEOHealth Hubs

The seven hubs reflect a broad geographic and research topic distribution (list of linked awards and key personnel can be found in Appendix A):

- The Caribbean GEOHealth Hub focuses on the impacts of neurotoxins from mining and agricultural development on maternal and child health. The Hub is based in Suriname and is connected regionally via the Caribbean Public Health Agency.
- The Peru GEOHealth Hub, with partners in Ecuador, Bolivia and Chile, is focusing on household air pollution as well as ambient air pollution and climate change impacts on diarrheal disease.
- The West Africa GEOHealth Hub, based in Ghana, is focusing on electronic waste (e-waste) recycling and the informal worker sector and has partnerships throughout West Africa including Benin, Cote d'Ivoire and Senegal.
- The East Africa GEOHealth Hub, based in Ethiopia with research and training activities in Ethiopia, Uganda, Rwanda and Kenya, is focusing on air pollution and children's health, household air pollution and climate change impacts on occupational health.
- The Southeast Asia GEOHealth Hub, based in Thailand and recently expanded to include Indonesia, is focusing on agricultural health, specifically the health impacts of exposure to widely-used pesticides in Southeast Asia.
- The Bangladesh GEOHealth Hub is focusing on household air pollution with a liquefied petroleum gas intervention and also addressing health risk in the garment worker sector.
- The India GEOHealth Hub is focusing on cardiometabolic impacts of ambient air pollution in urban India, including consideration of the modifying effects of social, behavioral and environmental factors on vulnerability and susceptibility.

It is worth noting that five of the hubs (Caribbean, Peru, West Africa, East Africa, and Southeast Asia) involve regional collaborations with other countries (Figure 1). Investigators at the University of Ghana, for example, created an inclusive regional network representative of West Africa, which includes French- and English-speaking countries. Similarly, the East Africa hub investigators, housed in Ethiopia, engage institutional partners in nearby Kenya, Rwanda, and Uganda. In Thailand, investigators draw trainees

from several research institutions within Thailand and from regional partners, such as the University of Indonesia Faculty of Public Health and the YARSI University Faculty of Medicine in Jakarta, Indonesia.

Figure 1. Hub Networks and Research and Disease Areas

NB: Boxes indicate exposure; green circles represent health outcomes

The hubs address a wide range of disease areas that the WHO and NIEHS have identified as priority environmental and occupational areas,[10,11,12] including respiratory diseases, immune function, maternal and child health, metabolic disorders, cardio-vascular diseases, and diabetes. While all the GEOHealth hubs address priority disease areas, there are some areas from the WHO and NIEHS, such as aging, autism, obesity, and Parkinson's disease, that are not currently covered in the GEOHealth program. These missing areas could provide areas for development in the next round of the GEOHealth program.

The program addresses a diverse and complementary range of research disciplines and methods as encouraged in the RFAs. Grants include conventional disciplines like surveillance and environmental exposure assessment (four hubs each) and less common ones, such as workplace risk assessment, implementation science, and industrial hygiene unique to specific hubs. Not all the disciplines and methods in the RFAs were addressed.

GEOHealth Hub Research Areas

Together, the hubs address seven research areas: outdoor air pollution, household air pollution (HAP), agricultural health, environmental contamination, electronic waste, climate change, and

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[10] WHO (2020). Ambient air pollution: Health impacts. Retrieved from: https://www.who.int/airpollution/ambient/health-impacts/en/

[11] National Institute for Environmental Health Sciences (2019). Overview. Retrieved from: https://www.niehs.nih.gov/health/materials/niehs_overview_508.pdf

[12] National Institute for Environmental Health Sciences (2020). Conditions & Diseases. Retrieved from: https://www.niehs.nih.gov/health/topics/conditions/index.cfm

industrialization. As noted in Figure 1 (map above), most hubs addressed more than one research topic. Along with the research outlined below, investigators across the hubs are building research capacity (see Training Models below).

Outdoor and household air pollution

Nearly 7 million people die prematurely each year from diseases linked to air pollution—both household and outdoor. Given the magnitude of the problem in LMICs, four of the seven hubs have made air pollution research their main project.

Because of rapid urbanization, India has some of the world's worst air pollution. This hub team is developing prediction models to estimate daily exposure to air pollution in two large cities: Chennai and New Delhi. The team is also studying the effects on cardiometabolic health outcomes and characterizing the populations most susceptible to exposure given their socioeconomic status, built environment and occupation. The hub, based at the Centre for Chronic Disease Control in New Delhi, partners with the Harvard T. H. Chan School of Public Health to bring together experts from fields that include atmospheric modeling, data science, epidemiology and policy translation to both conduct research and provide short term and masters level trainings as well as mentored research opportunities.

Investigators from the hub in East Africa are studying both outdoor and indoor air pollution. Researchers from the core institutions, Addis Ababa University in Ethiopia and University of Southern California in the US, and partner institutions in Kenya, Rwanda and Uganda, are conducting continuous air quality monitoring in the four capital cities and analyzing hospital records to study the effect of particulate matter on morbidity and mortality. The hub is also investigating the effects of air quality on lung function in school children.

In Peru, hub investigators from Universidad Peruana Cayetano Heredia, Emory University, Johns Hopkins University, and the University of Georgia are conducting an intervention trial to determine if liquefied petroleum gas (LPG) stoves are a feasible and effective way to reduce HAP. Researchers recruited women who cook with biomass fuels daily and supplied them with LPG stoves. Investigators are studying the effects on pollution and health, as well as what motivates participants to use the new stoves exclusively.

Investigators from the hub in Bangladesh are studying the association between exposure to particulate matter, carbon monoxide and black carbon in HAP and preclinical markers of cardiopulmonary disease. Along with assessing the effectiveness of LPG stoves, the team from International Centre for Diarrhoeal Disease Research, Bangladesh (icddr,b) and University of Chicago are investigating whether the pollutants are associated with stable biomarkers of immune dysfunction and inflammation.

Agricultural health

With agricultural health as its focus, the Southeast Asia hub pairs Mahidol University and the University of Massachusetts Lowell to investigate whether some widely used pesticides act as endocrine disrupters, which can increase the risk of metabolic syndrome associated with diabetes, stroke, heart disease and other health concerns. The project has expanded to other areas, including the effect of agricultural work on hearing. The hub is based at Thailand's Mahidol University and has expanded to the University of Indonesia Depok and YARSI University in Indonesia.

Environmental contamination

Investigators from the Caribbean hub, comprised of Academisch Ziekenhuis Paramaribo, Anton de Kom University of Suriname, and Tulane University, are researching neurotoxicant exposures and their impact on maternal and child health. The team has initiated a maternal and child cohort study, following 1,000 pregnant mothers from various regions of Suriname. Researchers are studying the effects of environmental contamination related to gold mining and agricultural development. Analysis includes mercury levels in fish and the amount of pesticides found in produce and rice. Scientists are also exploring whether certain minerals and chemicals in nutriceuticals have a neuroprotective effect.

Electronic waste

The number of discarded computers and other electronic waste (e-waste) is growing immensely. Primitive recycling techniques, largely in the informal sector, expose workers and their families to hazardous substances. Investigators from the University of Ghana, the University of Michigan, and McGill University, which make up the West African hub, are studying e-waste workers and evaluating associations between exposures and the risk of cancer and respiratory problems. An e-waste processing center in Accra, Ghana, believed to be one of the world's largest, is the main research site and is providing learning opportunities bridging fields from epidemiology to chemistry.

Climate change

In addition to their main research projects, three hubs are studying the health impacts of climate change. The Bangladesh hub investigators are exploring the effects of temperature change on chronic health outcomes; the investigators from the Peru hub are examining the effects of temperature on childhood diarrhea rates; and researchers in East Africa are starting to examine occupational heat stress on workers in key industries, including the flower-growing industry.

Industrialization

In another pilot study, the Bangladesh hub investigators plan to explore the occupational health hazards of industrialization. Through analyzing injury and illness reports, researchers will concentrate on health and safety in the readymade garment industry, which has grown so much over the past few decades that Bangladesh has become the world's second-largest garments exporter.

Niche Relative to Other Funders

GEOHealth's focus on linking environmental and occupational health research and research capacity building in LMICs is unique among funders. At the NIH, the National Institute of Environmental Health Sciences includes global environmental health as a part of its strategic themes and has developed funding announcements that address "research, education, training, and research translation directed at health problems that are related to environmental exposures and transcend national boundaries."[13] A number of the US government agencies, including the Environmental Protection Agency (EPA) and the US Agency for International Development, provide funding for environmental health through research

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[13] National Institute of Environmental Health Sciences. (2020). Global Environmental Health. Retrieved from: https://www.niehs.nih.gov/research/programs/geh/index.cfm

grants and program support, though the EPA does not focus on international efforts.[14,15] Wellcome Trust's Our Planet, Our Health supports research on climate change, global food systems, and urban environments.[16] Like GEOHealth, Our Planet, Our Health is investigating the links between the environment and human health; unlike the FIC program, Wellcome is geared specifically to collaborations across different academic disciplines and funds research in both LMIC and high income countries.[17] FIC's GEOHealth program is the only program that provides a platform for coordinated environmental and occupational health research and research training activities with linked funding to both US and LMIC institutions. These research partnerships both improve research capacity and address high-priority local, national and regional environmental and occupational health threats.

Partnerships
Partnership among funding entities is demonstrated in terms of both co-funding and substantial scientific and programmatic involvement in the hub activities.

Program Partners including Co-funding
The GEOHealth Program is a partnership between FIC and NIEHS, NCI, NIOSH, and IDRC. The program receives co-funding from these four funding partners. Contributions were relatively stable over the four fiscal years (FY15-18) apart from NIOSH's reduced funding starting in the third year. Partners have historically contributed to all the hubs with the exception of NCI, which funds both components of the India and Peru hubs, and IDRC, which funds two LMIC institutions (East Africa and West Africa hubs) working in their priority areas (Figure 2). While FIC is the single largest funder, there is substantial co-funding. Overall, FIC contributes about a third of the GEOHealth program funding. NIEHS and NCI make up almost half (46%) with the remaining approximately 20% divided between NIOSH and IDRC. Additionally, the Global Alliance for Clean Cookstoves provided supplemental funding for research and training focused on household air pollution in East Africa and Bangladesh.
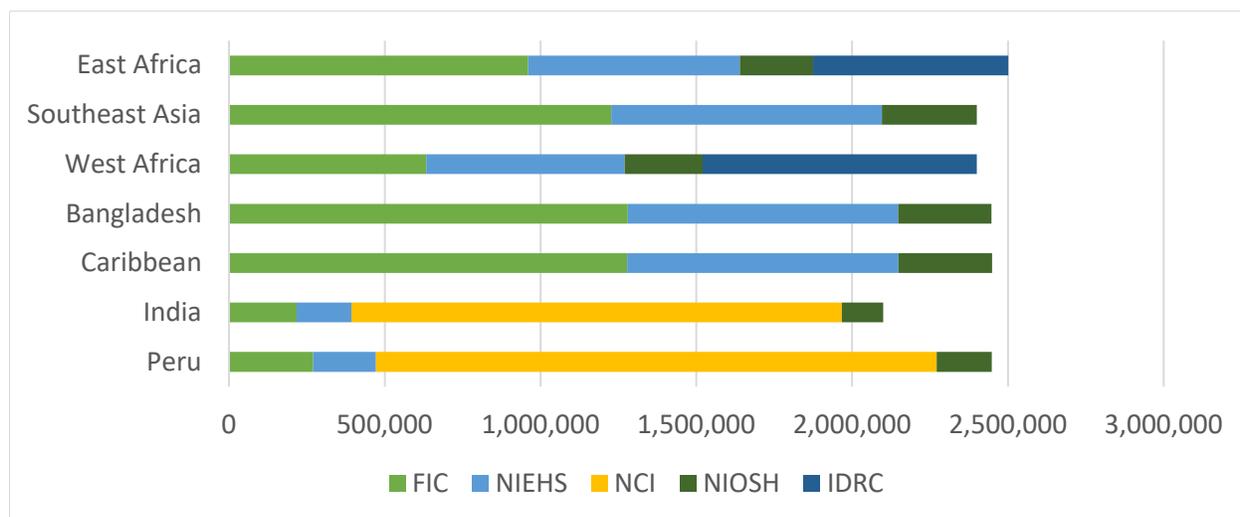
[14] Environmental Health Agency. (2019). Health Research Grants. Retrieved from: https://www.epa.gov/research-grants/health-research-grants

[15] US Agency for International Development. (2018). Environmental Health. Retrieved from: https://www.usaid.gov/what-we-do/global-health/maternal-and-child-health/technical-areas/water-sanitation-hygiene-wash

[16] Wellcome Trust. (2020). Our Planet, Our Health: responding to a changing world. Retrieved from: https://wellcome.ac.uk/what-we-do/our-work/our-planet-our-health

[17] Devi S. Wellcome Trust launches Our Planet, Our Health initiative. Lancet. 2015;386(10000):1227.

Figure 2. Source of funding contributing to the GEOHealth Hubs

In addition to the financial contributions, the program partners also provide considerable programmatic support. As a cooperative agreement, USG scientific officers from NCI, NIEHS, FIC, and NIOSH contribute substantial staff involvement by helping the hubs articulate and meet their goals, monitoring progress, connecting the hubs to potential partners, and providing feedback on their proposed activities.

Interviews were conducted with representatives of each partner organization: FIC and NIEHS, NCI, NIOSH, and IDRC. These partner interviews provided valuable comments that will inform the scope, management, and implementation of the program moving forward with the goal of developing a robust global network for environmental and occupational health research in LMICs.

Management of GEOHealth Hubs

Training Models and Strategies for Recruiting Trainees
Each hub designed a research training program relevant to their current capacity and research goals. Some hubs offer a mixture of short-term training for pre-docs and long-term support for more established researchers; others also included development of graduate-level degree programs. Some aspects of their training models cut across all the hubs. For instance, all of the hubs provide mentored training by both US and LMIC investigators, support graduate-level training and degree programs, and provided short-term courses trailered to a specific audience.

Bangladesh Hub
Hub investigators are training year-long, post-doctoral and three-month-long, pre-doctoral trainees through a combination of targeted course work and hands-on laboratory/research rotations in Chicago and two-week, in-country mini-courses and one-to-two days workshops in Bangladesh. They conducted two training tracks: 1) an eight-week training program for exposure to introductory concepts of quantitative research methods in environmental health and 2) a year-long training for more in-depth exposure to environmental and molecular epidemiology research.

Caribbean Hub

Investigators at the Anton de Kom University of Suriname (AdeKUS), Academisch Ziekenhuis Paramaribo, and Tulane University are building capacity through three unique opportunities. First, a new PhD program at AdeKUS recruits individuals with a graduate degree in health sciences and existing research or clinical expertise in the key areas of the hub's U01 research award. Students create their research projects in the second year of the program in alignment with the GEOHealth hub goals. In addition, the two-year joint Suriname/US MSPH program has a 200-hour field practicum and a research thesis based at AdeKUS with select courses delivered online in conjunction with Tulane University. All students have developed an individualized practicum plan with their practicum advisor and practicum coordinator, a Tulane postdoc based in Suriname. Finally, a short-term training at Tulane University on biological assays for laboratory technicians from the Department of Pharmacology at AdeKUS provides training in new laboratory techniques and assessments to examine the public health benefits of nutriceuticals.

East Africa Hub

Investigators from University of Southern California and Addis Ababa University provide a progressive and tiered training program that trains key researchers and their associated research teams from partner institutions in the participating LMICs to carry out the hub's research agenda. The training is conducted during the first, third, and fifth years of funding for three separate cohorts and developed curricular materials for academic and stakeholder institutions fostering evidence translation and implementation with the goal of establishing a sustainable Hub for the region. It targets both multidisciplinary research teams and twelve lead scientists—three from each of the four participating LMICs—who will become national leaders in environmental and occupational health research. The training consists of a series of in-person, didactic and hands-on workshops followed by distance education, training portals, virtual communication methods, and tailored mentored research support.

India Hub

Investigators in the India hub support research training for Indian trainees with a masters-level training at the Harvard School of Public Health and curriculum that supports the development of an environmental health concentration as part of the Public Health Foundation of India's (PHFI) existing masters-level training. There is also support for PHFI faculty to complete mentored research activities at Harvard, and an intensive summer training and mentored research program.

Peru Hub

The newly developed graduate degree program in Environmental Health at the School of Public Health and Administration at Universidad Peruana Cayetano Heredia provides critical one-on-one training for Peruvian researchers. The hub training program also recruits and trains students from Peru, Ecuador, and Bolivia each year to participate in the hub's research projects. Trainees are provided opportunities to participate in short courses and one-on-one training in Peru and Chile with US and Latin American investigators. Hub investigators continue to follow alumni every six months to maintain engagement in hub activities and create a network that facilitates project collaborations.

The Southeast Asia GEOHealth hub training program is designed to establish an international, interdisciplinary collaborative research group that will continue to work together at the end of the training period. It provides mentored research training experience for junior faculty and medical staff in the US and in the LMIC at partnering institutions. For LMIC trainees, it includes: 1) an introduction to GEOHealth program, agricultural health and the role of various Ministries, conducted at Mahidol University and 2) data collection, analysis and manuscript(s) development from trainee research proposals under the mentorship of Thai and US mentors. US trainees get up to six months of research specific training and mentorship in the US, resulting in a funded interdisciplinary research proposal. LMIC trainees receive mentorship by a US or home university senior faculty mentor, resulting in a funded interdisciplinary research proposal.

West Africa Hub

The West African hub has developed two cohorts of cross-disciplinary, West African post-docs and doctoral students—one cohort trained at the University of Michigan and the other at McGill University—for four months of training with both North American and West African senior scientist mentors who accompany the trainees for part of their stay. Trainee activities include 1) intensive mentoring focused on detailed planning of research projects and/or laboratory methods for analysis of toxic metals and organic pollutants, as well as on career development, by integrated, interdisciplinary teams of US Ghanaian, and Canadian senior scientists; 2) presentations on planned research projects near the beginning and end of the four-month program; and 3) seminars/discussion groups jointly attended by US post-docs participating in similarly designed programs. In addition, there are core courses tailored to the needs of the trainees with areas of particular emphasis on responsible conduct of research, designing interdisciplinary research encouraging innovations, advanced statistical methods for analysis of data, scientific writing for grant proposals and for journal articles, and optimized use of technology and information resources. Trainees can audit regularly scheduled courses on campus fitting with their unique research development needs.

Given the diversity of training models, it is not surprising that there is a variety of trainees in terms of career level, background, and professional officialization. Even within one hub, there is often a diverse group of trainees. For example, the Bangladesh hub is training clinicians, medical students, public health professionals and undergraduate students while the East Africa Hub trained participants from academia, government and NGOs with knowledge of the fundamental tools of public health research and policy on new environmental and occupational health areas. Trainees were identified from a variety of science-based disciplines (e.g., biology, toxicology), medical specialties, and public health disciplines and often cut across institutions, languages, and academic backgrounds.

Recruitment strategies vary according to the type of trainee the hub is looking to attract and ultimately the goal of their capacity building efforts. Strategies range from solicitations limited to the home academic department or university to broader outreach to existing networks, scientists and clinicians in associated fields, and affiliated academic institutions. In some cases, hubs hold an open competition advertising in regional trade journals and peer-reviewed journals and developing marketing materials and program websites for broad distribution. With the exception of some cross-network training

described below, recruitment has been limited to the region in which the hub operates and was tailored to the specific training being offered.

Mentoring Models

Hubs are required to provide mentored research between LMIC and US mentors and their trainees as part of their capacity building efforts. DISPPE identified a few types of mentorship that some of the hubs are providing, including journal clubs, one-on-one mentoring, and distance mentoring. Hubs also provided hands-on mentoring in the form of co-authorship of journal articles, research proposal development, and research and data collection.

Training linked to Research

A cornerstone of the GEOHealth hub model is the linkage of awards for research and for research training. As outlined in the training models above, hubs tend achieve this linkage in three different ways: 1) targeted training in preparation to lead the research projects supported by the linked U01; 2) trainees selected to be part of the research; and 3) shared learning.

Targeted training in preparation to lead the research projects supported by the linked U01
In East Africa, the hub provided training to LMIC U01 investigators and their teams in exposure assessment, respiratory disease research methods, and health assessment.
Trainees selected to be part of the research
In Peru, two Environmental Health Scholars collaborated with researchers investigating air pollution and health outcomes in Lima at the time of this evaluation.
In Bangladesh, at the time of this evaluation, five trainees were selected to participate in and contribute to the research project.
In West Africa, postdoctoral fellows and doctoral students organized into interdisciplinary, inter-country project teams spent four months training on the UM or McGill campus, followed by six months in their home countries executing research projects.
Shared learning
In Bangladesh, the investigators invited hub partner organizations, universities, and government agencies to a short-term, three-day trainings and workshops to develop the capacity of young local environmental health researchers across the country and help translate research results into policies that would mitigate the health effects of environmental health problems.

Results

Training and Career Development Outputs

At the time of this evaluation, the GEOHealth Program has trained 118 people from 12 countries around the world (Figure 3). Several hubs have included trainees from other countries in regions. The Peru hub included trainees from both Peru and Colombia; the West Africa hub trained individuals from Benin,

Cote d'Ivoire, Ghana, and Senegal; and the Southeast Asia hub included trainees from both Thailand and Indonesia.
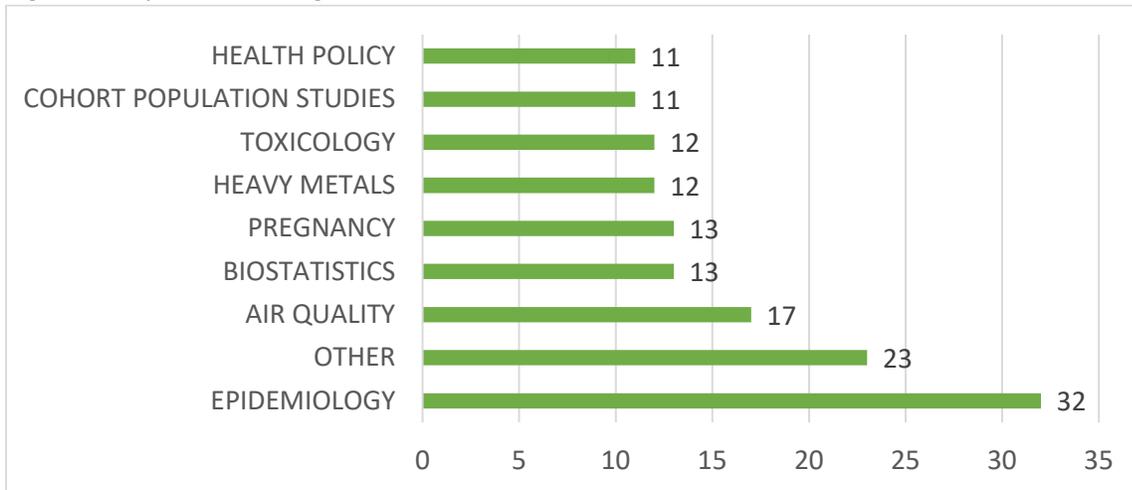
Figure 3. Trainees Distribution

Cohorts have included clinicians and public health professionals, medical students and undergraduates. They come from academia, government and NGOs. Of the 118 trainees, over 70% (84) have participated in long-term training of six months or more, which includes both degree and non-degree programs. Master's degree programs make up most of those long-term trainings. The other non-degree trainings were three- to six-months. Short-term training—under three months—accounted for less than 15% of all the trainings. Based on the progress reports, we suspect that there are more short-term trainees that have not been included in CareerTrac. [18] At the time of this evaluation, about half of the trainings are still in progress, which given the amount of long-term training and cycle of the program, is expected.

In the CareerTrac database, for each trainee, the PIs identify the primary research area and up to six scientific or technical fields addressed during the training. Most of the trainings (70%) have been focused on environmental health as the broad area of research. For the technical areas, there were 66 unique fields with a total of 307 entries. Epidemiology, air quality, and biostatistics were the top areas (Figure 4), which is in keeping with the research, disciplines and methods areas identified in their applications.

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[18] It is worth noting that this data is reported by the PIs into CareerTrac and does not include data from the progress reports. For instance, in its progress report, India referred to "over 150 participants" in the short courses offered by the hub representing over 50 institutions and 12 States; however, this information was not uploaded to CareerTrac and was therefore not included in the summary presented here.

Figure 4. Top Nine Training Technical Fields

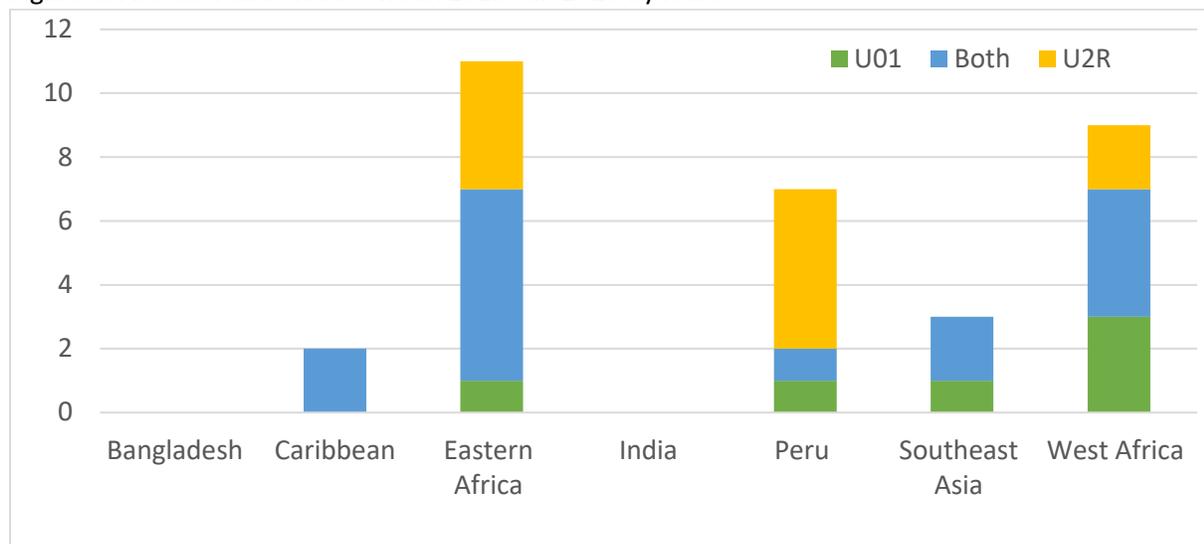NB: "Other" is undefined in CareerTrac.

Hubs have used the collaborations to launch new graduate programs thereby building institutional capacity. The Peru hub launched a Master of Environmental Health at UPCH in Fall 2018 and interest has been high, with 261 applicants for 15 available spots. In the inaugural class, five students received full scholarships for two years. The hub also supported three LMIC students pursuing their PhD degrees at Johns Hopkins University and the Universidad de Chile.

Some, like the Caribbean hub, are documenting the success of their programs on students' employment. Three of the nine people enrolled in their new PhD program at AdeKUS, which began in July 2016, are graduates of the cross Tulane/University of Suriname MPSH program. A survey of the first three cohorts (2014, 2015, 2016) of the MSPH program found that almost all are employed in public health (97%). Half of the third cohort received a job promotion after completing their degree. The fourth cohort of the MSPH program in 2017, the most recent reported in their progress report, enrolled 23 students.

Publications and Other Research Outputs

Thirty-two publications, published between 2015 and Jan 2019, cite a GEOHealth award (Appendix B). Most of the publications are research (18) and review (11) articles and cite both awards comprising the GEOHealth hub (Figure 5). As it is still early in the GEOHealth program, we expect to see more publications over the next few years—especially from the U01 research awards.

Figure 5. Articles Published between 2015-Jan 2019 by Hubs

Authorship on the publications generally reflects the US/LMIC partnership. Almost three-quarters of the articles have at least one author from an LMIC institution, and more than a third of articles include trainees as authors. The publications illustrate a diversity of topics, trainee involvement, and journals.

Strengthening and Expanding Collaborations

Over the past few years, the hubs have been developing their country and regional networks and expanding their reach in a variety of ways. The Suriname, Peru, West Africa, and Southeast Asia hubs have connected and, in some instances, formalized partnerships with ministries of health and other government agencies, including the Ministry of Youth and Department of Agriculture. Some, like the West Africa Hub, met with local communities, including local Chiefs, Imams, and key government representatives. Many hubs, including the East Africa Hub, developed collaborations with deans and faculty of related departments and conducted outreach to other universities and NGOs. This outreach has resulted in a number of new collaborations (below).

New Collaborations from GEOHealth Hubs

In Peru, investigators are developing a partnership with National Meteorology and Hydrology Service of Peru to estimate daily PM2.5 air pollution to help conduct their study of hospital emergency room visits in Lima in relation to daily air pollution.

In Suriname, investigators were invited to collaborate with colleagues from French Guyana in the Aymara project investigating exposure of pregnant women to neurotoxicants in the border region of Suriname and French Guyana. Dr. Maureen Lichtveld, lead PI, has also been Invited to join Caribbean Consortium for Research in Environmental and Occupational Health.

In Bangladesh, investigators report adding a small cadre of local partner institutions who have the potential to be future players in GEOHealth research.

In India, investigators engaged with the Steering Committee on Air Pollution and Health Related Issues run by the Indian Ministry of Health and Family Welfare and are actively involved in collecting, disseminating and commenting on policies related to air pollution.

> **In Southeast Asia**, investigators are adding new partners to the hub within Thailand and across Southeast Asia—the University of Indonesia, YARSI University in Indonesia and possibly a university in Vietnam.

These strategic partnerships have also extended across the region. The hub at the University of Ghana, for example, aimed to create an inclusive regional network representative of West Africa, which includes French- and English-speaking countries such as Mali, Cameroon, and Nigeria. To expand their reach, they strategically linked with an IDRC-funded activity (Community of Practice in EcoHealth for West and Central Africa) that spans four Francophone countries: Benin, Burkina Faso, Côte d'Ivoire and Senegal.

Along with new external partners, hubs are also starting to collaborate across the GEOHealth network. In early 2018, two members of the West Africa hub and two of the Bangladesh hub participated in a workshop on "Air pollution, climate and health – methods and modelling" organized by the Indian hub. In July 2019 members of the India, Bangladesh, and Peru hubs were invited to participate in a hands-on workshop on indoor air pollution organized by the East Africa hub in collaboration with the Global Alliance for Clean Cookstoves. Leveraging GEOHealth activities, a lead PI of the Caribbean hub has successfully obtained NIEHS R13 grants to support environmental and occupational training workshops associated with the Caribbean Public Health Agency annual meeting.[19] A supplement from Fogarty to the GEOHealth award allowed them to invite trainees from other GEOHealth hubs to attend. In addition, the Peru and Suriname hubs collaborated on a pilot study of pregnant women in southern Peru to investigate the impact of arsenic in drinking water on adverse birth outcomes.[20]

Conclusion
The funding partners developed a program concept to continue the GEOHealth program that was presented to Fogarty's advisory board and posted online in February 2019. Notices of intent to publish the associated FOAs, were recently published in the NIH guide [GEOHealth Research (U01) (NOT-TW-20-002) and GEOHealth Research Training (U2R) (NOT-TW-20-003)].

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[19] R13 ES029016-01A1; R13 ES030618-01; R13 ES031834-01

[20] Fano, D., Vásquez-Velásquez, C., Aguilar, J. et al. Arsenic Concentrations in Household Drinking Water: A Cross-Sectional Survey of Pregnant Women in Tacna, Peru, 2019. Expo Health (2019). https://doi.org/10.1007/s12403-019-00337-5

Appendix A. List of linked awards and key personnel

Hub	Participating Countries	Principal Investigators	Lead Partner Institutions	Grant Number
Peru	Peru*, Bolivia, Chile, Ecuador	William N Checkley, Johns Hopkins University Gustavo F Gonzales, Universidad Peruana Cayetano Heredia Luke P Naeher, University of Georgia Nelson K Steenland, Emory University	U2R: Emory University U01: Universidad Peruana Cayetano Heredia	U2RTW010114 U01TW010107
India	India*	Richard A Cash, Harvard School of Public Health Dorairaj Prabhakaran, Centre For Chronic Disease Control Reddy, K Srinath, Public Health Foundation of India Joel D Schwartz, Harvard School of Public Health	U2R: Harvard School of Public Health U01: Centre For Chronic Disease Control	U2RTW010108 U01TW010097
Caribbean	Suriname*	Maureen Y Lichtveld, Tulane University of Louisiana Dennis R Mans, Anton de Kom University Wilco Zijlmans, Academisch Ziekenhuis Paramaribo	U2R: Tulane University of Louisiana U01: Academisch Ziekenhuis Paramaribo	U2RTW010104 U01TW010087
Bangladesh	Bangladesh*	Habibul Ahsan, University of Chicago Mohammad Yunus, International Centre for Diarrhoeal Disease Research	U2R: University of Chicago U01: International Centre for Diarrhoeal Disease Research	U2RTW010122 U01TW010120
West Africa	Ghana*, Benin, Cote d'Ivoire, Senegal	Julius Fobil, University of Ghana Thomas G Robins, University of Michigan	U2R: University of Michigan U01: University of Ghana	U2RTW010110 U01TW010103
Southeast Asia	Thailand*	Pornpimol Kongtip, Mahidol University Susan Woskie, University of Massachusetts Lowell	U2R: University of Massachusetts Lowell U01: Mahidol University	U2RTW010088 U01TW010091
East Africa	Ethiopia*, Kenya, Rwanda, Uganda	Kiros T Berhane, University of Southern California Abera Takele Kumie, Addis Ababa University Jonathan M Samet, University of Colorado	U2R: University of Southern California U01: Addis Ababa University	U2RTW010125 U01TW010094

*Primary site; Underline- Contact PIs

Appendix B. List of Publications Citing a GEOHealth Award between 2015 and Jan 2019

Abdoel Wahid F, Wickliffe J, Wilson M, Van Sauers A, Bond N, Hawkins W, Mans D, Lichtveld M. Presence of pesticide residues on produce cultivated in Suriname. Environ Monit Assess. 2017 Jun;189(6):303. doi: 10.1007/s10661-017-6009-0. Epub 2017 May 31.

Alcantara Zapata DE, Mazzei Pimental M. [Bioethics and environmental justice in the health of the Andean residents of Peru]. Rev Latinoam Bioet. 2018;18(34-1):36-50.

Alcantara-Zapata DE, Gonzales GF, Pino P. Prostatic-Specific Antigen Levels in Men from Two Andean Cities of Peru. High Alt Med Biol. 2018 Jun;19(2):213-214.

Asampong E, Dwuma-Badu K, Stephens J, Srigboh R, Neitzel R, Basu N, Fobil JN. Health seeking behaviours among electronic waste workers in Ghana. BMC Public Health. 2015 Oct 16;15:1065.

Basu N, Clarke E, Green A, Calys-Tagoe B, Chan L, Dzodzomenyo M, Fobil J, Long RN, Neitzel RL, Obiri S, Odei E, Ovadje L, Quansah R, Rajaee M, Wilson ML. Integrated assessment of artisanal and small-scale gold mining in Ghana--part 1: human health review. Int J Environ Res Public Health. 2015 May 13;12(5):5143-76.

Basu N, Renne EP, Long RN. An Integrated Assessment Approach to Address Artisanal and Small-Scale Gold Mining in Ghana. Int J Environ Res Public Health. 2015 Sep 17;12(9):11683-98.

Berhane K, Chang CC, McConnell R, Gauderman WJ, Avol E, Rapapport E, Urman R, Lurmann F, Gilliland F. Association of Changes in Air Quality With Bronchitic Symptoms in Children in California, 1993-2012. JAMA. 2016 Apr 12;315(14):1491-501.

Berhane K, Kumie A, Samet J. Health Effects of Environmental Exposures, Occupational Hazards and Climate Change in Ethiopia: Synthesis of Situational Analysis, Needs Assessment and the Way Forward. Ethiop J Health Dev. 2016;30(1 Spec Iss):50-56.

Burns KN, Sun K, Fobil JN, Neitzel RL. Heart Rate, Stress, and Occupational Noise Exposure among Electronic Waste Recycling Workers. Int J Environ Res Public Health. 2016 Jan 19;13(1). pii: E140.

Chen JC, Samet JM. Air pollution and suicide risk: another adverse effect of air pollution? Eur J Epidemiol. 2017 Nov;32(11):943-946.

Eibach D, Herrera-León S, Gil H, Hogan B, Ehlkes L, Adjabeng M, Kreuels B, Nagel M, Opare D, Fobil JN, May J. Molecular Epidemiology and Antibiotic Susceptibility of Vibrio cholerae Associated with a Large Cholera Outbreak in Ghana in 2014. PLoS Negl Trop Dis. 2016 May 27;10(5):e0004751.

Fandiño-Del-Rio M, Goodman D, Kephart JL, Miele CH, Williams KN, Moazzami M, Fung EC, Koehler K, Davila-Roman VG, Lee KA, Nangia S, Harvey SA, Steenland K, Gonzales GF, Checkley W; Cardiopulmonary outcomes and Household Air Pollution trial (CHAP) Trial Investigators. Effects of a liquefied petroleum

gas stove intervention on pollutant exposure and adult cardiopulmonary outcomes (CHAP): study protocol for a randomized controlled trial. Trials. 2017 Nov 3;18(1):518.

Gonzales GF, Rubín de Celis V, Begazo J, Del Rosario Hinojosa M, Yucra S, Zevallos-Concha A, Tapia V. Correcting the cut-off point of hemoglobin at high altitude favors misclassification of anemia, erythrocytosis and excessive erythrocytosis. Am J Hematol. 2018 Jan;93(1):E12-E16.

Gonzales GF, Tello J, Zevallos-Concha A, Baquerizo L, Caballero L. Nitrogen balance after a single oral consumption of sacha inchi (Plukenetia volúbilis L.) protein compared to soy protein: a randomized study in humans. Toxicol Mech Methods. 2018 Feb;28(2):140-147.

Hailemariam D. Strengthening the Link between Economic Development, Environment and Public Health. Ethiop J Health Dev. 2016;30(1 Spec Iss):1-4.

Kongtip P, Nankongnab N, Tipayamongkholgul M, Bunngamchairat A, Yimsabai J, Pataitiemthong A, Woskie S. A Cross-Sectional Investigation of Cardiovascular and Metabolic Biomarkers among Conventional and Organic Farmers in Thailand. Int J Environ Res Public Health. 2018 Nov 20;15(11). pii: E2590.

Konthonbut P, Kongtip P, Nankongnab N, Tipayamongkholgul M, Yoosook W, Woskie S. Paraquat Exposure of Pregnant Women and Neonates in Agricultural Areas in Thailand. Int J Environ Res Public Health. 2018 Jun 3;15(6). pii: E1163.

Kumie A, Amera T, Berhane K, Samet J, Hundal N, G/Michael F, Gilliland F. Occupational Health and Safety in Ethiopia: A review of Situational Analysis and Needs Assessment. Ethiop J Health Dev. 2016;30(1 Spec Iss):17-27.

Mahaboonpeeti R, Kongtip P, Nankongnab N, Tipayamongkholgul M, Bunngamchairat A, Yoosook W, Woskie S. Evaluation of Dermal Exposure to the Herbicide Alachlor Among Vegetable Farmers in Thailand. Ann Work Expo Health. 2018 Nov 12;62(9):1147-1158.

Mentz G, Robins TG, Batterman S, Naidoo RN. Acute respiratory symptoms associated with short term fluctuations in ambient pollutants among schoolchildren in Durban, South Africa. Environ Pollut. 2018 Feb;233:529-539.

Mitike G, Motbainor A, Kumie A, Samet J, Wipfli H. Review of Policy, Regulatory, and Organizational Frameworks of Environment and Health in Ethiopia. Ethiop J Health Dev. 2016;30(1 Spec Iss):42-49.

Ouboter PE, Landburg G, Satnarain GU, Starke SY, Nanden I, Simon-Friedt B, Hawkins WB, Taylor R, Lichtveld MY, Harville E, Wickliffe JK. Mercury Levels in Women and Children from Interior Villages in Suriname, South America. Int J Environ Res Public Health. 2018 May 17;15(5). pii: E1007.

Pollard SL, Williams KN, O'Brien CJ, Winiker A, Puzzolo E, Kephart JL, Fandiño-Del-Rio M, Tarazona-Meza C, Grigsby M, Chiang M, Checkley W. An evaluation of the Fondo de Inclusión Social Energético program to promote access to liquefied petroleum gas in Peru. Energy Sustain Dev. 2018 Oct;46:82-93.

Rajaee M, Obiri S, Green A, Long R, Cobbina SJ, Nartey V, Buck D, Antwi E, Basu N. Integrated Assessment of Artisanal and Small-Scale Gold Mining in Ghana-Part 2: Natural Sciences Review. Int J Environ Res Public Health. 2015 Jul 31;12(8):8971-9011.

Samet JM. The 60th Annual Thomas L. Petty Aspen Lung Conference Summary. Ann Am Thorac Soc. 2018 Apr;15(Suppl 2):S118-S121.

Samet JM, Bahrami H, Berhane K. Indoor Air Pollution and Cardiovascular Disease: New Evidence From Iran. Circulation. 2016 Jun 14;133(24):2342-4.

Siddharthan T, North CM, Attia EF, Christiani DC, Checkley W, West TE. Global Health Education in Pulmonary and Critical Care Medicine Fellowships. Ann Am Thorac Soc. 2016 Jun;13(6):779-83.

Simane B, Beyene H, Deressa W, Kumie A, Berhane K, Samet J. Review of Climate Change and Health in Ethiopia: Status and Gap Analysis. Ethiop J Health Dev. 2016;30(1 Spec Iss):28-41.

Srigboh RK, Basu N, Stephens J, Asampong E, Perkins M, Neitzel RL, Fobil J. Multiple elemental exposures amongst workers at the Agbogbloshie electronic waste (e-waste) site in Ghana. Chemosphere. 2016 Dec;164:68-74.

Tefera W, Asfaw A, Gilliland F, Worku A, Wondimagegn M, Kumie A, Samet J, Berhane K. Indoor and Outdoor Air Pollution- related Health Problem in Ethiopia: Review of Related Literature. Ethiop J Health Dev. 2016;30(1):5-16.

Wilson ML, Renne E, Roncoli C, Agyei-Baffour P, Tenkorang EY. Integrated Assessment of Artisanal and Small-Scale Gold Mining in Ghana - Part 3: Social Sciences and Economics. Int J Environ Res Public Health. 2015 Jul 15;12(7):8133-56.

Woodward AJ, Samet JM. Climate Change, Hurricanes, and Health. Am J Public Health. 2018 Jan;108(1):33-35.