A Section 508–conformant HTML version of this article
is available at https://doi.org/10.1289/EHP4752.

Let the "A" in WASH Stand for Air: Integrating Research and Interventions to Improve Household Air Pollution (HAP) and Water, Sanitation and Hygiene (WaSH) in Low-Income Settings

Thomas Clasen[1] *and Kirk R. Smith*[2,3]

[1]Department of Environmental Health, Rollins School of Public Health, Emory University, Atlanta, Georgia, USA
[2]Division of Environmental Health Sciences, School of Public Health, University of California, Berkeley, Berkeley, California, USA
[3]Collaborative Clean Air Policy Centre, New Delhi, India

Background: Research often suffers from overspecialization, a practice nurtured in academia and reinforced by funders. Indeed, investigators in household air pollution (HAP) and water, sanitation and hygiene (WaSH), working in poor parts of the world, rarely interact despite having similar training and using similar methods to evaluate interventions in the same vulnerable populations. Disappointing results from recent trials of improved cookstoves and traditional approaches to WaSH suggest the need for alternative approaches.

Objectives: We argue that bringing these two areas together would improve the effectiveness and efficiency of interventions to reduce the massive disease burden associated with HAP and poor WaSH, including pneumonia and diarrhea, the leading killers of young children in low-income countries.

Results: HAP and WaSH face similar challenges in designing, implementing, and securing the sustained and exclusive use of scalable interventions such as clean fuel and water.

Discussion: Research can advance greater coordination of these areas by demonstrating their interactions and wider impacts on well-being as well as the potential for programmatic synergies. Integrated solutions to clean households and communities can benefit from the contribution in multiple disciplines, including economics and policy analysis; business and finance; engineering and technology; lab sciences, environmental health, and biomedical sciences; and behavioral and implementation sciences.

Conclusion: There are compelling reasons to overcome the artificial and unproductive segregation of HAP and WaSH. Researchers should encourage integration by expanding the scope of their collaborations and projects. Policy makers, funders, and implementers can help by supporting comprehensive solutions, encouraging innovation, and requiring rigorous evaluations of their effects. https://doi.org/10.1289/EHP4752

The Segregation of Household Air Pollution and Water, Sanitation and Hygiene

Over the last decades, we have had the privilege of being invited into the homes of thousands of generous study participants in more than two dozen countries in Africa, Asia, and Latin America. Our research groups bring expertise across the board in environmental health, including epidemiology, exposure assessment, atmospheric modeling, microbiology, biostatistics, and the social sciences. We conduct surveys, record observations, use sensors to assess intervention uptake and other behaviors, collect clinical and environmental samples, directly evaluate health outcomes, and obtain detailed information from caretakers and health records about health conditions. We then analyze the data and samples, report the results, and do our best to have them influence policy.

But we are not there for exactly the same reasons. And despite the similarities in our expertise and methods, we mainly do not even talk to each other. We often do not work with the same colleagues, go to the same conferences, or sometimes even read each other's most important papers. We do not work with the same government officials or for the same units within United Nations institutions or funding organizations. And the people we talk with do not seem to talk with each other much either.

One of us investigates interventions to reduce household air pollutions (HAP) from solid fuel use; the other, mainly interventions to reduce exposures associated with poor water, sanitation, and hygiene (WaSH). We are each keenly aware of the health risks that are the foci of the other's research: HAP researchers step over open sewers and around animal feces to reach the homes of study participants, and WaSH researchers sometimes need to move outside to avoid heavy smoke from cooking fires. And yet, we largely ignore the central exposure of the other's research or the obvious threat it poses to health, probably to the puzzlement of our study participants.

Curious as it is for research, this lack of integration is even more inexplicable at the policy-relevant intervention level. According to the World Health Organization and the Institute for Health Metrics and Evaluation burden of disease estimates, which are always in flux, household air pollution causes 1.6–3.8 million premature deaths annually; deficiencies in WaSH cause another 0.8–1.8 million from diarrheal disease (GBD 2017 Risk Factor Collaborators 2018; Landrigan et al. 2018; WHO 2018). The vast majority of these deaths are among precisely the same population: poor people in sub-Saharan Africa and Asia, with limited formal education, many living in poor quality housing in rural settings or urban slums, with little access to clean fuels or clean water, often undernourished, and with poor access to health care. And the nature of effective interventions is fundamentally the same, usually a combination of hardware (clean fuels and clean water/improved sanitation) plus behavior change to encourage its adoption and exclusive use. HAP is a leading cause of pneumonia in young children as included in the burden of disease, but it is also a major risk factor for adverse pregnancy outcomes and probably for stunting and lower cognitive development in children (Gordon et al. 2014). In adults, it is a major risk factor for pulmonary and cardiovascular diseases in adults and potentially for

Address correspondence to Thomas Clasen, Department of Environmental Health, Rollins School of Public Health, Emory University, 1518 Clifton Rd. NE, Atlanta, GA 30322 USA. Telephone: (404) 727-3480. Email: tclasen@emory.edu

The authors declare they have no actual or potential competing financial interests.

Received 19 November 2018; Revised 4 February 2019; Accepted 7 February 2019; Published 25 February 2019.

Note to readers with disabilities: *EHP* strives to ensure that all journal content is accessible to all readers. However, some figures and Supplemental Material published in *EHP* articles may not conform to 508 standards due to the complexity of the information being presented. If you need assistance accessing journal content, please contact ehponline@niehs.nih.gov. Our staff will work with you to assess and meet your accessibility needs within 3 working days.

diabetes. Poor WaSH is the leading cause of diarrheal disease in children, but it is also a major contributor to trachoma, schistosomiasis, soil-transmitted helminth infection, and nutritional deficiencies, including stunting (Freeman et al. 2017).

There have been regular calls for integration of interventions that address childhood diseases and some success in doing so. However, these mainly focus on vaccines, nutritional supplementation, and improved case management. For example, the Integrated Management of Newborn and Childhood Illness (IMNCI), which first emerged as a strategy in 1995, aims to combine interventions against the major causes of childhood disease. However, the three foci of the strategy—improving case management skills of health-care staff, improving overall health systems, and improving family and community health practices—are all essentially clinical and do not include environmental measures. A more recent reflection of the strategy, dubbed a "Grand convergence for child survival and health," acknowledges the failure to link with other sectors, including WaSH, but does not mention HAP or specific ways for integration with environmental interventions (WHO 2016).

Environmental measures have been included in more specific strategies to address pneumonia and diarrhea. The WHO and UNICEF's *Integrated Global Action Plan for the Prevention and Control of Pneumonia and Diarrhoea (GAAPD)*, for example, lists "handwashing with soap, safe drinking water and sanitation and reduced household air pollution" among its target strategies (WHO/UNICEF 2013). The *Lancet* Diarrhoea and Pneumonia Interventions Study Group also identified improved WaSH and reduced household air pollution among its recommended interventions (along with nutrition, vaccines, and treatment) (Bhutta et al. 2013). The recent review by the *Lancet* Commission on Pollution and Health provides perhaps the most compelling case for addressing deficiencies in HAP and WaSH (Landrigan et al. 2018). Although these reports provide a strong case for the effectiveness and cost effectiveness of environmental measures to deal with these big risk factors, they suggest no strategies for the integration of WaSH and HAP. This is in contrast to specific calls in the report for other more holistic initiatives, for example, "for integrated community case management."

One example of a program aimed at both the reduction of HAP and the improvement of WaSH was WASHplus, the U.S. Agency for International Development's flagship global Environmental Health project, between 2010 and 2016. Led by FHI 360 in partnership with CARE and Winrock International, the program sought "to promote healthy households and communities by creating and delivering interventions that lead to significant improvements in access, practices, and health outcomes related to HAP and WaSH." However, while integration was a specific focus of the initiative, a special briefing on "the power of integration" emphasized only the integration of WaSH into nutrition, HIV, neglected tropical diseases, and education. The end-of-year report described various initiatives around improved cookstoves (WASHPlus 2016). However, neither the briefing nor the end-of-year report provided any account of integrating interventions aimed at WaSH and HAP over the life of the program. In 2018, the Indian government implemented an innovative integrated program across seven "pro-poor" village interventions, including liquefied petroleum gas (LPG), electricity, vaccination, health insurance, and LED lights. It has been implemented in about 50,000 villages to date but does not include WaSH interventions (Gram Swaraj Abhiyan 2018).

Why They Are Similar

At the most fundamental level, both of us try to persuade people to take up practices we believe to be more healthful and to give up ones that are increasingly understood to be substantially less healthful. The problem is that the practices they need to give up, besides being ancient and traditional, are essentially free. Defecating in the open or burning gathered wood may be reasonable practices in settings with low population densities that characterized much of human history. Today, however, with more than 7 billion people, and nearly all, even in villages, living close to each other, these practices are no longer appropriate.

Directly related to density is that both practices have strong community effects. If only a few households shift to clean practices in the midst of dozens who do not, the health benefits may be low or not even measurable (Eisenberg et al. 2012). This is because enteric pathogens and air pollution travel away from the households that produce them to affect others nearby. Gut infections provide perhaps the most extreme example of the need for community-level improvements: A healthy person is not really at risk from environmentally mediated reinfection with his/her own enteric pathogens (Pomp 2013) and, thus in this sense, the health impacts related to WaSH are solely due to the community effect. However, even in moderately dense communities, individual households that adopt clean cooking technologies may not have sufficient impacts on their exposure to achieve health gains. Although the interventions are often at the household level, it takes a village to achieve meaningful and enduring effects on HAP and WaSH (Eisenberg et al. 2012; Zhou et al. 2011). This has profound implications for policy measures to reduce health risks, not only in terms of the need to achieve high levels of coverage and adoption of effective interventions, but also in terms of their financing, delivery, and allocation of costs.

One reason why HAP and poor WaSH affects the same populations is that they both fundamentally arise from poverty (Landrigan et al. 2018). Or, rather, they suffer from the same failure of policy measures to invest in clean reliable energy, water, and sanitary sewerage at the household level because of unwillingness to see these costs as social investments in the same way as schools and primary health care (Ravindra and Smith 2018). Women and children (mainly) do not prefer to spend hours collecting wood, dung, or making charcoal for fuel; they lack access to clean fuels such as gas or adequate levels of electricity for cooking. They step over open sewers on their way to often-contaminated wells and springs to collect water for drinking, steal away before first light to practice open defecation, and empty latrine pits and septic tanks with a shovel and bucket. They face these conditions not always because they are poor; they often pay dearly for the services they have. Perhaps more fundamentally, they are often ignored politically or offered cheap, quick-fix solutions that may count toward national or international targets; reliable services that could provide them with clean cooking fuels or safe water never reach them at all. Indeed, the common prioritization of urban over rural populations is one of the major obstacles to change.

Another factor that HAP and WaSH share is that they are not focused on one objective; they each address several health and non-health aspects of poverty. They save time, bring dignity, affect several diseases among several family members, and may even help reduce climate change and local environmental degeneration. They may not be as effective as a pneumonia or rotavirus vaccine in dealing with specific diseases, but what do these disease-specific approaches do about the daily time spent in the unpleasant household chores of hauling fuel and water? However, because decisions by donors and government agencies are often driven by siloed criteria around specific diseases, the upstream determinants of health, such as air quality and WaSH, and the collateral benefits on overall well-being are often overlooked.

Why They Are Different

A striking difference between WaSH and HAP risk factors is seen in their history. Feces in the water seems today about as obvious a risk factor as one can imagine, although it was only recognized in the mid- to late-1800s. Thus, for nearly 150 years, few have doubted this hazard. This is not so for HAP, which was essentially entirely ignored by the health establishment until the turn of the (recent) century and is still not widely understood by large parts of the medical and public health communities. It is rather sobering to think how poorly low-cost WaSH interventions have succeeded in 150 years with no doubts about causality to hold it back. What does this mean for HAP, which still struggles to verify causality for some of its important effects? Will we be no further along 100 years from now than WaSH is today?

Another big difference between the risk factors is in their scale. Fecal matter travels some distance in the environment, but several physical, chemical, and biological mechanisms limit its impact downstream and downhill. Air pollution, however, travels thousands of kilometers and exposes populations far away who may use clean cookfuels themselves. Estimates vary, but in India for example, some 20–40% of the total exposure to ambient fine particulate matter in the country seems to be due to household solid fuels, and households are almost certainly the largest ambient air pollution source category in the country (GBD MAPS Working Group 2018). This understanding is why the field moved away from the term "indoor" air pollution about a decade back—the pollution may be generated indoors in the kitchen, but it soon goes outdoors, into the neighbors' houses, and out into the general ambient environment. Ironically, given that ambient air pollution has a big impact in cities where the political and economic elite suffers and from where journalists file their stories, doing something about HAP may in the end derive more from concern about fixing these downwind effects than for the exposures to the villagers themselves. In China, the accumulation of research results has led to the control of household sources as part of the new agenda on ambient air pollution control (Liu et al. 2016). Indeed, the need to control household sources of air pollution for health reasons is leading to concerns in some quarters over the "cross benefits" that may be involved in promoting clean fossil fuels, such as gas, to households now using biomass, that is, it is good for health but perhaps slightly negative for climate (Qin et al. 2017; Goldemberg et al. 2018).

In its 2018 Public Sector Report, the United Nations specifically addressed the need to promote integration of its sustainable development goals by finding ways to foster cooperation and common approaches among institutions dealing with closely interrelated issues (UN 2018). National WaSH-related efforts, although usually run by a different agency, commonly have strong inputs from health ministries, as well as support from the WHO, UNICEF, the World Bank, and dozens of bilateral agencies. This is not so for HAP, which is to date nearly orphaned by the structure commonly found in most countries, that is, air pollution is handled by the environment ministry, which sees itself as having a mandate to protect only the ambient environment. No health ministry in low- and middle-income countries, to our knowledge, has added air pollution, of any sort, to its portfolio. This is so despite the strong push by the WHO as seen in a formal resolution in 2015 and a global meeting in 2018 to promote household and ambient air pollution into national health ministry thinking (WHO 2015). Nevertheless, the major multilateral and bilateral donors in health have only relatively recently started to pay attention to the health side of household energy, and even the WHO itself still has not brought air pollution professionals onto its staff. Even in its section on "interlinkages," the United Nations report on its Sustainable Development Goals provides no guidance as to how such integration might optimally occur across WaSH and HAP and little in the way of concrete examples (Sustainable Development Goals 2018).

What Might Be Achieved Together: Clean Household Environments

Policy makers usually blame inadequate resources for the failure to provide safe energy, water, and sanitation to those in low-income settings. However, they almost certainly leave considerable money on the table by ignoring the potential synergies of combining initiatives that address both HAP and WaSH. Costs for providing, managing, and collecting payments—much of which consists of facilitation costs at the implementer level—could be minimized by spreading them among energy, water, and sanitation service providers (Crocker et al. 2017). There are similar potential savings for establishing and maintaining supply chains. As the private sector has shown, much of the cost in sales is in actually reaching and converting the potential customer. Once the salesperson has established the householder as a customer, the marginal costs of selling additional goods and services is comparatively low; compare, for example, the packaging of TV cable, internet, and phone services in wealthy countries.

There are also potential synergies in financing combinations of HAP and WaSH. Microfinance, for example, has been used to provide credit for both stoves and water filters, for solar panels and rainwater harvesting systems. Economists could contribute to the integration of these sectors by documenting these potential synergies and exploring further opportunities. They can also help identify optimal pricing strategies for targeted subsidies as well as potential inequalities and other adverse impacts of shifting from public to private utilities or directly to householders. A recent large-scale distribution of water filters and stoves in Rwanda financed by carbon credits also suggests the possible synergies in financing and delivery of programs designed address both clean air and clean water (Barstow et al. 2016).

In addition to the policy and economic barriers that are sometimes common between HAP and WaSH interventions, there are important engineering and technological challenges to achieving sustained impacts (Anadon et al. 2016). Hundreds of millions of improved biomass cookstoves have been distributed throughout Asia, Latin America, and sub-Saharan Africa over the decades (Smith et al. 1993). Although the best of these stoves reduce fuel consumption, and thus offer economic benefits, recent research has found that most of these improved wood and charcoal stoves are incapable of reducing HAP to the levels necessary to avoid health risks, even if they are used regularly (Pope et al. 2017). Household water treatment and safe storage can improve drinking-water quality and high numbers of household latrines can reduce the risks of fecal exposure (Clasen et al. 2015). However, low-cost solutions, such as point-of-use chlorination are not effective against the full range of fecal pathogens and boiling is effective but is done inconsistently in many cases. Latrines are often of poor quality, leading to low levels of adoption or sustained use. There is a clear need for improvements in these household technologies and better understanding of the factors that affect usage. Some improvements could once again be synergistic between HAP and WaSH: Higher-efficiency stoves that include reservoirs for pasteurizing water could provide both cleaner air and safe drinking water.

Social scientists also have an important role in advancing the potential gains from interventions to improve HAP and WaSH. Providing reliable supplies of sustainable energy, safe water, and sanitary sewerage at the household level are necessary goals, offering optimal returns in health, poverty reduction, and well-being. When these services are available on a 24-7 basis, there is often little need for behavior-change strategies to optimize their uptake. In many cases, however, these services are not available or they are not reliable. In that case, householders are required to implement solutions themselves. Technologies, affordability and accessibility are improving, and some approaches—such as clean-fuel stoves and advanced water filters—could achieve acceptable indoor air and drinking-water quality. The challenge then, however, is to ensure that these technologies are used correctly and consistently over the long term. This is likely more of a challenge than developing the technology.

Research has consistently shown that householders who are provided access to these products will often revert to traditional practices. Community-led total sanitation, a major initiative in rural low-income settings, suffers from backsliding ("slippage") to open defecation due in part to poor quality facilities (Venkataramanan et al. 2018). Continued reliance on conventional cooking ("stacking") is a major challenge for improving HAP, although there is now clear evidence of increasing usage of clean fuel over time (Smith and Jain 2019). These, together with the continued consumption of untreated water, unsafe disposal of child feces, and inconsistent handwashing, can all leave household exposure to high levels of fine particulate and fecal pathogens that will vitiate the potential health effects that these technologies can accord. Although these practices can sometimes be overcome with intensive behavior change strategies, these "software" aspects of the intervention are often given inadequate attention or funding. These problems are not unique to HAP and WaSH interventions, and the emerging field of implementation science, which has been largely confined to clinical contexts, has much to offer to improve the delivery, adoption, and uptake of environmental health interventions (Sesan et al. 2018; Rosenthal et al. 2017). We know that the clean household solutions woudl be scalable and sustainable; the challenge is to quicken uptake among vulnerable populations in order to accelerate health gains.

Researchers in environmental health and biomedical sciences may also play a vital role. First, however, they need to learn from each other. Exposure scientists in air quality, for example, have sophisticated devices for directly assessing the actual exposure of the toxicant (such as fine particulates) that householders actually inhale. Based on this, epidemiologists and toxicologists can make well-informed exposure–response models to inform health guidelines. These are also facilitated by being able to incorporate risks from air pollution exposures of entirely different sorts: ambient, secondhand tobacco smoke, and active smoking, for example. By comparison, the WaSH sector, if it measures exposure at all, typically assesses fecal loads in the environment indirectly along possible transmission pathways, uses fecal indicators rather than pathogens, and constructs models based on estimated contact with the environment. This, we are realizing now, constitutes a major downside to consolidating effects. Biochemists have developed sophisticated markers of HAP exposure and nascent diseases that could also benefit WaSH research; there is promising work in using serological responses to enteric pathogens. Remote sensing and spatial modeling also has much to offer both fields. Perhaps most intriguing are the potential interactions between the effects of HAP and fecal exposure due to poor WaSH conditions. There is some evidence that enteric insults could make one more susceptible to respiratory infections and vice versa, either by way of stress on the immune system or other mechanisms (Ashraf et al. 2013). In this way, a protective intervention against pneumonia could also reduce diarrhea.

While these are some of the areas in which WaSH and HAP might be integrated, we acknowledge the challenges. Each of the areas already encompasses multiple foci that struggle to combine synergistically. WaSH practitioners debate the relative merits of water, sanitation, and hygiene interventions, often ignoring other sources of fecal contamination such as food and animals. HAP interventions focus mainly on clean cooking but acknowledge the risks associated with lighting and heating. Integration for its own sake can also be counterproductive when goals become diffused, skills honed by long disciplinary attention to detail become lost, and even common terminologies become confused (Klenk and Meehan 2015). Tellingly for HAP and WaSH, the locus of action and responsibility could become less clear and farther from current reality on the ground. Effective integration of environmental interventions requires more than simply combining initiatives that may seem well aligned; it requires the realization of improved outcomes or reduced costs that are rigorously documented in context.

Poor People, Poor Solutions

Improvements in HAP and WaSH share a decidedly mixed blessing: the attraction they hold for non-government organizations (NGOs), governments, donors, and even some health scientists to believe that technical solutions *a*) are easy—all we need is a simple modified stove or latrine—and *b*) are all that is needed—when behavioral change is at least half of the requirement for effective change. Hundreds of millions of "improved" latrines and "improved" stoves lie unused across the world because some well-meaning NGO or government, sometimes supported by donors and scientists, has marched off to promote some technology or other. Indeed, we have been in communities where the households are like stove museums, each with dead stoves lying covered by cobwebs or used for storage, due to a dozen years of ill-thought-through programs that have passed through. Broken water pumps and dry wells are ubiquitous in sub-Saharan Africa. Concrete slabs from unfinished latrines look like gravestones in parts of rural India, and superstructures are used to keep grain and fuel dry, the result of sanitation campaigns with misaligned incentives. No NGO or government thinks it can develop a simple vaccine that will save the world, but many have fallen into the trap of thinking their simple stove or latrine will fix things.

Recent research by others and us has raised important questions about the hypothesis that the standard development paths for improvements in HAP and WaSH can be circumvented by a small set of magic levers that can make people healthy before they are wealthy (Mortimer et al. 2017; Null et al. 2018; Luby et al. 2018). Science has helped develop solutions such as vaccines, essential antibiotics, nutrition, and effective primary care that are low cost and scalable, and there may eventually be some such solutions to improve HAP and WaSH. At present, however, we would be hard pressed to pick any but variations of what has already been proven in populations with good water, sanitation, and fuel: reliably treated piped water delivered to the home; sanitation facilities that ensure privacy, security and safe management of excreta; and clean fossil fuels/electricity in single-family kitchens. Although these solutions have comparatively high upfront costs compared with an improved stove or latrine, spread over their useful life, the costs are manageable, especially after considering the cost saving to health systems (Hutton 2013). These environmental interventions also add "intrinsic value" to personal dignity and human rights that are difficult to monetize and are thus often ignored in such economic analyses (Jain and Subramanian 2018). Long-term financing, both public and private, can actually reduce current household expenditures for clean energy and water while making the allocation of costs more equitable. These high-quality, community-wide approaches to ensuing safe environments are the only ones considered in higher-income settings. Is there any reason to believe that poor solutions will work for the poor?

After nearly 40 years of working on "improved" stoves, which try to make the "available (biomass) clean," one of us has now mostly shifted to work to make the "clean available," that is, to find ways to push known clean fuels such as LPG and electricity down deeper among the poor and accelerate the natural transition that has occurred already in most of the world (Smith and Sagar 2014). This is not easy either, given the costs and infrastructure requirements, but advances in information technology are providing innovative ways to finance and manage the transition. Moreover, importantly, the institutions involved have the capability, at least in many countries, of operating at the scale required, that is, of hundreds of millions of households and their communities. One wonders whether there may be something equivalent on the WaSH side to make the known clean options used by most of the world more affordable and usable by the poor.

Conclusion

There is much to be done in order to secure the promise of a fully integrated initiative that addresses HAP and WaSH. Researchers have much to contribute to this integration, expanding their expertise and collaborations and working across the disciplines of political science and public policy, economics and business/finance, engineering and technology, social and behavioral science, and environmental health and biomedical sciences. Researchers must also ensure that their results are actionable and communicated in a manner that reflects the complex dynamics of the policy environment. Ultimately, however, it is up to policy makers, funders, and implementers to take the initiative, to explore the opportunities for synergies, to encourage experimentation and innovation, to rigorously evaluate and transparently report the results, and then to do it again. Let us start by thinking about the "A" in WaSH as standing for "Air," so that by pursuing a comprehensive WASH strategy, we are challenging and dedicating ourselves, both in research and in implementation, to a complete and clean household and community solution to environmental health for the people that need it most.

Acknowledgments

The authors are grateful to A. Pillarisetti, M. Kirby, and A. Jain for their helpful comments on this manuscript.

References

Anadon LD, Chan G, Harley AG, Matus K, Moon S, Murthy SL, et al. 2016. Making technological innovation work for sustainable development. Proc Natl Acad Sci USA 113(35):9682–9690, PMID: 27519800, https://doi.org/10.1073/pnas.1525004113.

Ashraf S, Huque MH, Kenah E, Agboatwalla M, Luby SP. 2013. Effect of recent diarrhoeal episodes on risk of pneumonia in children under the age of 5 years in Karachi, Pakistan. Int J Epidemiol 42(1):194–200, PMID: 23378152, https://doi.org/10.1093/ije/dys233.

Barstow CK, Nagel CL, Clasen TF, Thomas EA. 2016. Process evaluation and assessment of use of a large scale water filter and cookstove program in Rwanda. BMC Public Health 16:584, PMID: 27421646, https://doi.org/10.1186/s12889-016-3237-0.

Bhutta ZA, Das JK, Walker N, Rizvi A, Campbell H, Rudan I, et al. 2013. Interventions to address deaths from childhood pneumonia and diarrhoea equitably: what works and at what cost? Lancet 381(9875):1417–1429, PMID: 23582723, https://doi.org/10.1016/S0140-6736(13)60648-0.

Clasen TF, Alexander KT, Sinclair D, Boisson S, Peletz R, Chang HH, et al. 2015. Interventions to improve water quality for preventing diarrhoea. Cochrane Database Syst Rev 10:CD004794, PMID: 26488938, https://doi.org/10.1002/14651858.CD004794.pub3.

Crocker J, Saywell D, Shields KF, Kolsky P, Bartram J. 2017. The true costs of participatory sanitation: evidence from community-led total sanitation studies in Ghana and Ethiopia. Sci Total Environ 601–602:1075–1083, PMID: 28599364, https://doi.org/10.1016/j.scitotenv.2017.05.279.

Eisenberg JN, Trostle J, Sorensen RJ, Shields KF. 2012. Toward a systems approach to enteric pathogen transmission: from individual independence to community interdependence. Annu Rev Public Health 33:239–257, PMID: 22224881, https://doi.org/10.1146/annurev-publhealth-031811-124530.

Freeman MC, Garn JV, Sclar GD, Boisson S, Medlicott K, Alexander KT, et al. 2017. The impact of sanitation on infectious disease and nutritional status: a systematic review and meta-analysis. Int J Hyg Environ Health 220(6):928–949, PMID: 28602619, https://doi.org/10.1016/j.ijheh.2017.05.007.

GBD MAPS (Global Burden of Disease Major Air Pollution Sources) Working Group. 2018. *Burden of Disease Attributable to Major Air Pollution Sources in India*. Special Report 21. Boston, MA:Health Effects Institute.

GBD 2017 Risk Factor Collaborators. 2018. Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. Lancet 392 (10159):1923–1994, PMID: 30496105, https://doi.org/10.1016/S0140-6736(18)32225-6.

Goldemberg J, Martinez-Gomez J, Sagar A, Smith KR. 2018. Household air pollution, health, and climate change: clearing the air. Environ Res Lett 13(3):030201, https://doi.org/10.1088/1748-9326/aaa49d/meta.

Gordon SB, Bruce NG, Grigg J, Hibberd PL, Kurmi OP, Lam KB, et al. 2014. Respiratory risks from household air pollution in low and middle income countries. Lancet Respir Med 2(10):823–860 2nd. Oct, PMID: 25193349, https://doi.org/10.1016/S2213-2600(14)70168-7.

Gram Swaraj Abhiyan. 2018. Government of India. http://gsa.nic.in/Rural_GSA/main.html [accessed 30 January 2019].

Hutton G. 2013. Global costs and benefits of reaching universal coverage of sanitation and drinking-water supply. J Water Health 11(1):1–12, PMID: 23428544, https://doi.org/10.2166/wh.2012.105.

Jain A, Subramanian SV. 2018. Intrinsic and instrumental perspectives to sanitation. SSM Popul Health 5:267–269, PMID: 30094322, https://doi.org/10.1016/j.ssmph.2018.07.005.

Klenk N, Meehan K. 2015. Climate change and transdisciplinary science: Problematizing the integration imperative. Environ Sci Policy 54:160–167, https://doi.org/10.1016/j.envsci.2015.05.017.

Landrigan PJ, Fuller R, Acosta NJR, Adeyi O, Arnold R, Basu NN, et al. 2018. The *Lancet* Commission on pollution and health. Lancet 391(10119):462–512, PMID: 29056410, https://doi.org/10.1016/S0140-6736(17)32345-0.

Liu J, Mauzerall DL, Chen Q, Zhang Q, Song Y, Peng W, et al. 2016. Air pollutant emissions from Chinese households: a major and underappreciated ambient pollution source. Proc Natl Acad Sci USA 113(28):7756–7761, PMID: 27354524, https://doi.org/10.1073/pnas.1604537113.

Luby SP, Rahman M, Arnold BF, Unicomb L, Ashraf S, Winch PJ, et al. 2018. Effects of water quality, sanitation, handwashing, and nutritional interventions on diarrhoea and child growth in rural Bangladesh: a cluster randomised controlled trial. Lancet Glob Health 6(3):e302–e315, PMID: 29396217, https://doi.org/10.1016/S2214-109X(17)30490-4.

Mortimer K, Ndamala CB, Naunje AW, Malava J, Katundu C, Weston W, et al. 2017. A cleaner burning biomass-fuelled cookstove intervention to prevent pneumonia in children under 5 years old in rural Malawi (the Cooking and Pneumonia Study): a cluster randomised controlled trial. Lancet 389(10065):167–175, PMID: 27939058, https://doi.org/10.1016/S0140-6736(16)32507-7.

Null C, Stewart CP, Pickering AJ, Dentz HN, Arnold BF, Arnold CD, et al. 2018. Effects of water quality, sanitation, handwashing, and nutritional interventions on diarrhoea and child growth in rural Kenya: a cluster-randomised controlled trial. Lancet Glob Health 6(3):e316–e329, PMID: 29396219, https://doi.org/10.1016/S2214-109X(18)30005-6.

Pomp D. 2013. Can you eat your own poop? https://gawker.com/5985723/can-you-eat-your-own-poop [accessed 30 January 2019].

Pope D, Bruce N, Dherani M, Jagoe K, Rehfuess E. 2017. Real-life effectiveness of 'improved' stoves and clean fuels in reducing $PM_{2.5}$ and CO: systematic review and meta-analysis. Environ Int 101:7–18, PMID: 28285622, https://doi.org/10.1016/j.envint.2017.01.012.

Qin Y, Wagner F, Scovronick N, Peng W, Yang J, Zhu T, et al. 2017. Air quality, health, and climate implications of China's synthetic natural gas development. Proc Natl Acad Sci USA 114(19):4887–4892, PMID: 28438993, https://doi.org/10.1073/pnas.1703167114.

Ravindra K, Smith KR. 2018. Better kitchens and toilets: both needed for better health. Environ Sci Pollut Res Int, PMID: 29627958, https://doi.org/10.1007/s11356-018-1879-4.

Rosenthal J, Balakrishnan K, Bruce N, Chambers D, Graham J, Jack D, et al. 2017. Implementation science to accelerate clean cooking for public health. Environ Health Perspect 125(1):A3–A7, PMID: 28055947, https://doi.org/10.1289/EHP1018.

Sesan T, Jewitt S, Clifford M, Ray C. 2018. Toilet training: what can the cookstove sector learn from improved sanitation promotion? Int J Environ Health Res 28(6):667–682, PMID: 30068235, https://doi.org/10.1080/09603123.2018.1503235.

Smith KR, Jain A. 2019 (in press). Household energy transition in India and elsewhere: the role of LPG. In: *Energizing India: Fueling a Billion Lives*. Mitra S, ed. New Delhi:Rupa Publications.

Smith KR, Sagar A. 2014. Making the clean available: escaping India's chulha trap. Energy Policy 75:410–414, https://doi.org/10.1016/j.enpol.2014.09.024.

Smith KR, Shuhua G, Kun H, Daxiong Q. 1993. 100 million improved stoves in China: How was it done? World Dev 21(6):941–961, https://doi.org/10.1016/0305-750X(93)90053-C.

Sustainable Development Goals. 2018. Interlinked nature of the Sustainable Development Goals. https://unstats.un.org/sdgs/report/2018/interlinkages/ [accessed 30 January 2019].

United Nations. 2018. *Working Together: Integration, Institutions and the Sustainable Development Goals: World Public Sector Report 2018*. New York, New York:United Nations, Department of Economic and Social Affairs.

Venkataramanan V, Crocker J, Karon A, Bartram J. 2018. Community-led total sanitation: a mixed-methods systematic review of evidence and its quality. Environ Health Perspect 126(2):026001, PMID: 29398655, https://doi.org/10.1289/EHP1965.

WASHplus. 2016. WASHplus End of Project Report. http://www.washplus.org/sites/default/files/EOP%20report%20final%20508.pdf [accessed 11 February 2019].

WHO (World Health Organization). 2015. Resolution WHA68.8. Health and the environment: addressing the health impact of air pollution. In: *Sixty-Eighth World Health Assembly: Resolutions and Decisions; Annexes*. WHA68/2015/REC/1. Geneva, Switzerland:WHO.

WHO. 2016. *Towards a Grand Convergence for Child Survival and Health: A Strategic Review of Options for the Future Building on Lessons Learnt from IMNCI*. Geneva, Switzerland:WHO.

WHO. 2018. Burden of disease from household air pollution for 2016, Vol 3. https://www.who.int/airpollution/data/HAP_BoD_results_May2018_final.pdf [accessed 3 February 2019].

WHO, UNICEF (World Health Organization, United Nations International Children's Emergency Fund). 2013. Integrated global action plan for the prevention and control of pneumonia and diarrhoea. Geneva, Switzerland:World Health Organization/United Nations Children's Fund.

Zhou Z, Dionisio KL, Arku RE, Quaye A, Hughes AF, Vallarino J, et al. 2011. Household and community poverty, biomass use, and air pollution in Accra, Ghana. Proc Natl Acad Sci USA 108(27):11028–11033, PMID: 21690396, https://doi.org/10.1073/pnas.1019183108.