 © IWA Publishing 2019 Journal of Water, Sanitation and Hygiene for Development | 09.4 | 2019

Short Communication

Underrepresented groups in WaSH – the overlooked role of chemical toxicants in water and health

Joshua P. Kearns, Matthew J. Bentley, Poorva Mokashi, Jennifer H. Redmon and Keith Levine

ABSTRACT

The anthropogenic release of chemicals from industry, agriculture and the breakdown of consumer wastes constitute a major threat to water resources and public health. Pollution is severe and increasing in the developing world where chemical substances are produced, used, and disposed of in an unregulated manner. The global public health consequences of chemical pollution are comparable to or greater than those of widespread infectious diseases such as HIV/AIDS, tuberculosis, and malaria. However, chemicals have so far been neglected by the WaSH sector. Here, we report the results of a systematic review of the *Journal of Water, Sanitation, and Hygiene for Development* (2011–2018) and oral/poster presentations given at the UNC Water & Health Conference (2010–2018). The review enumerated studies that focused on water quality and treatment from a chemical perspective, highlighting in particular organic contaminants of emerging concern. Organic chemicals were addressed in only 2% of journal articles and fewer than 0.7% of conference presentations. Geogenic contaminants arsenic and fluoride were only addressed in 2–3% of articles and presentations. The review concludes that a rapid, major effort to address toxic chemicals in WaSH is necessary to meet UN Sustainable Development Goals for universal access to safe and affordable drinking water by 2030.

Key words | chemicals, drinking water, health, inorganic, organic, toxicants

Joshua P. Kearns (corresponding author)
Poorva Mokashi
Department of Civil, Construction, and Environmental Engineering,
North Carolina State University,
2501 Stinson Dr, 208 Mann Hall, Raleigh, North Carolina 27695,
USA
E-mail: *jpkearns@ncsu.edu*

Matthew J. Bentley
Department of Civil, Environmental, and Architectural Engineering,
University of Colorado-Boulder,
4001 Discovery Drive, Boulder, Colorado 80309,
USA

Jennifer H. Redmon
Keith Levine
RTI International,
3040 E. Cornwallis Road, Research Triangle, North Carolina 27709,
USA

INTRODUCTION

In May 2019, the Chemical Abstracts Service registered its 150 millionth unique chemical substance (Wang 2019). Around 100,000 chemical compounds are produced in significant volumes annually (Burton *et al.* 2017). The rates of chemical production and diversification, particularly within low- and middle-income countries (LMICs), have outpaced the other major drivers of global environmental change such as CO_2 emissions, nutrient pollution, habitat destruction, and biodiversity loss (Bernhardt *et al.* 2017). The biosphere has a finite capacity for chemical assimilation and many compounds persist and accumulate, thereby threatening ecosystems, water sources, and, ultimately, human health. Chemical pollution is often severe and is increasing in LMICs where the production, use, and the disposal of chemical substances is highly unregulated. Driven by low labor costs, lax environmental and public health protections, and lack of regulatory enforcement, the manufacture and use of chemicals have increasingly shifted to LMICs over recent decades (Landrigan & Fuller 2016; Suk & Mishamandani 2016; Weiss *et al.* 2016) (Figure 1).

Surveying chemical production trends over recent decades, a 2016 report (Weiss *et al.* 2016) revealed an

doi: 10.2166/washdev.2019.059

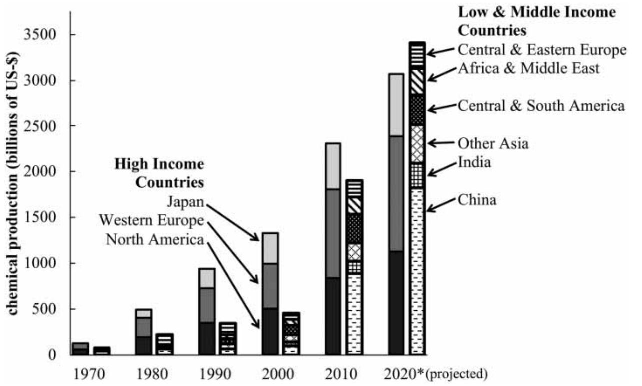

Figure 1 | Chemical production trends measured in billions of US$ 1970–2020 for HICs compared with LMICs.

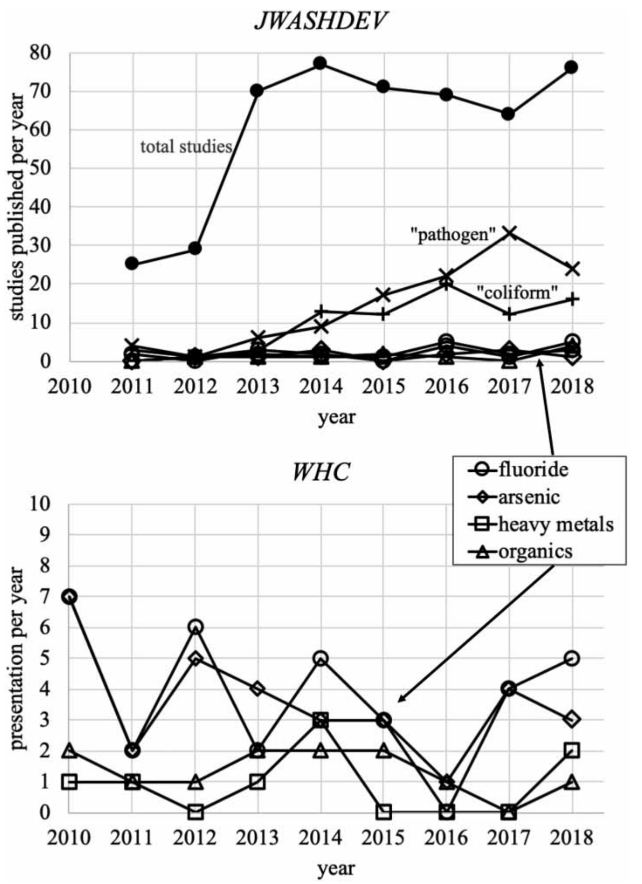

Figure 2 | Upper panel: Number of studies published in *JWASHDEV* 2011–2018 on inorganic and organic chemical contaminants by year. Total studies published per year and the number of studies identified using search terms 'pathogen' and 'coliform' are shown for comparison. Lower panel: Number of combined O and P presentations at *WHC* 2010–2018 on inorganic and organic chemical contaminants by year.

exponential rate of growth in LMICs, compared with approximately linear growth in high-income countries (HICs) (Figure 1, data from Weiss *et al.* 2016). This has in turn led to the increased environmental occurrence and negative impacts on human and environmental health in LMICs (Suk & Mishamandani 2016). Compared with HICs, LMICs lack infrastructure to protect public health and the environment, and face greater difficulties in responding with appropriate policy, technology, management, and enforcement measures (Suk & Mishamandani 2016). Consequently, global public health consequences of chemical pollution are now comparable to or greater than those of widespread infectious diseases such as HIV/AIDS, tuberculosis, and malaria (Landrigan & Fuller 2016; Landrigan *et al.* 2018; Broadfoot 2019). The UN Sustainable Development Goals (UN-SDP 2015) explicitly aim to 'reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination' (3.9), 'improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials' (6.3), and 'achieve the environmentally sound management of chemicals and all wastes throughout their life cycle … and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment' (12.4). However, chemical pollutants have so far been overlooked in the international development agenda, and pollution control currently receives <0.5% of global development spending (Landrigan & Fuller 2016).

Chemical pollution and non-communicable diseases

Patterns of pollution and pollution-related diseases change as communities advance through stages of development. In addition to traditional hazards such as infectious disease, indoor air pollution, drinking water contaminated by fecal pathogens, poor sanitation, and inadequate nutrition, people in LMICs are at increasingly high risk of non-communicable diseases (NCDs) driven by exposure to proliferating chemical pollutants (Laborde *et al.* 2015; Landrigan & Fuller 2016; Suk & Mishamandani 2016). In this way, LMIC communities are thus simultaneously exposed to both old and new forms of pollution and suffer a 'double burden' of disease (Landrigan & Fuller 2016). NCDs resulting from chronic and acute exposure to environmental chemicals include neurobehavioral disorders, pediatric and adult cancers, birth defects, obesity, diabetes, hypertension, asthma, reproductive disorders, endocrine disruption, neurodevelopmental disorders, cardiovascular disease, chronic kidney disease of unknown etiology, organ damage, and other health problems (CDC 2009; Laborde *et al.* 2015; Redmon *et al.* 2016; Suk & Mishamandani 2016). NCDs have emerged as a leading cause of death and disability in LMICs – for example, 55% of new cancer cases are arising in LMICs and could reach 60% by 2020 (Suk & Mishamandani 2016). Major recent global public health studies have underscored that NCDs are significant and growing factors in the overall burden of disease, including reports by *The Lancet* (Landrigan *et al.* 2018), the *Journal of Clinical Endocrinology and Metabolism* (Woodruff 2015), the Council on Foreign Relations (Daniels *et al.* 2014), and the World Health Organization (WHO) (Prüss-Ustün *et al.* 2016).

Chemical pollution, immunotoxicity, and infectious diseases

Exposure to many synthetic chemicals can dysregulate immune function in ways that lead not only to increased vulnerability to NCDs such as cancer but also to greater susceptibility to pathogens and reduced effectiveness of vaccinations against infectious diseases (Winans *et al.* 2011; Erickson 2019). Maternal and early life exposures to chemicals that impair immune function have been demonstrated to critically increase susceptibility to infections and disease later in life (Winans *et al.* 2011). Low-dose exposures occurring during developmental windows of heightened susceptibility, for example, periods in embryonic, fetal, and early postnatal life, can have far greater effects than high-dose exposure in adults (Suk & Mishamandani 2016). Immunotoxicity has been demonstrated for compounds within several classes of synthetic chemicals, including organohalogen compounds, such as polychlorinated biphenyls (Heilmann *et al.* 2006; Winans *et al.* 2011; Hodges & Tomcej 2016), dioxins (Burleson *et al.* 1996; Winans *et al.* 2011), and solvents such as trichloroethylene and toluene (Winans *et al.* 2011); organophosphate flame retardants (Canbaz *et al.* 2017) and plasticizers such as phthalates and bisphenol-A (Winans *et al.* 2011); numerous pesticides, including atrazine and chlordane (Winans *et al.* 2011; Hodges & Tomcej 2016); and per-/poly-fluoroalkyl substances (PFASs) (Granum *et al.* 2013; Pennings *et al.* 2016; Grandjean *et al.* 2017).

Recent research has correlated maternal levels of PFAS perfluorooctanoate and perfluorohexane sulfonate and gastroenteritis in children (Granum *et al.* 2013). A study in Bangladesh found that arsenic exposure during pregnancy increased the risk of diarrhea during infancy (Rahman *et al.* 2011). It is therefore possible that exposure to chemical immunotoxins is partly responsible for the failure of WaSH interventions that target only pathogens to achieve reductions in diarrheal disease and knock-on effects such as stunting.

To-date, the WaSH sector has yet to recognize and grapple with the challenge of mitigating threats to health from chemical toxicants in water. For example, the recently published *World Health Organization Household Water Treatment Evaluation Scheme* did not take into account chemical safety of drinking water (WHO 2019). Likewise, in interpreting the disappointing results of the WaSH Benefits trials in Bangladesh and Kenya (Luby *et al.* 2018; Null *et al.* 2018) and the SHINE trial in Zimbabwe (Humphrey *et al.* 2019) and identifying next steps for the WaSH sector, Pickering *et al.* (2019) neglected to consider the role of chemical toxicants. It is our intent to demonstrate a critical need for WaSH to move beyond the current limited focus on microbial pathogens toward a holistic approach to water and health in LMICs that takes chemicals into account. The aim of this Short Communication is to summarize the results of a systematic review identifying studies that focused on chemical water quality and treatment in (1) the *Journal of Water, Sanitation, and Hygiene for Development* (*JWASHDEV*) and (2) oral and poster presentations given at the annual University of North Carolina *Water & Health Conference* (WHC). *JWASHDEV* and *WHC* are arguably two of the most important touchstones for assessing the breadth and depth of research and intervention activities in the WaSH sector.

METHODS

Abstracts of all Research Papers, Practical Papers, Short Communications, Review Papers, Discussions, and Editorials published in *JWASHDEV*, Volumes 1–8, years 2011–2018, were systematically reviewed ($n = 481$). Abstract and Conference Program booklets from *WHC* years 2010–2018 were also reviewed. Abstracts from *WHC* Poster (P) and Oral (O) presentations were available for years 2012–2015 and 2017–2018. During this timeframe, there were approximately 100 P and 100 O presentations per year. Based on these figures, it was estimated that 1,800 combined P and O presentations took place at *WHC* from 2010 to 2018. Abstracts from presentations in years 2010–2011 and 2016 were not available. For those years, program booklets listing presentation titles were used for this review.

The terms listed in Table 1 were used to search the *JWASHDEV* website and the *WHC* program and abstract booklets for studies that included terms for organic and inorganic chemical contaminants. Organic chemicals were

Table 1 | Search terms used to identify the studies published in *JWASHDEV* (2011–2018) and presented at UNC Water Institute's annual *Water and Health Conference* (2010–2018) applicable in LMICs and concerning chemicals in water

Systematic review categories		Results			
Search terms		*JWASHDEV*		*WHC*	
General	toxin, toxic, synthetic, cancer, carcinogen, endocrine, disrupter, EDC, emerging contaminants, industrial, organic, inorganic, micropollutant, neurotoxin, immunotoxin, heavy, metal	**# of studies**	**% of total**	**# of studies**	**% of total**
Organic contaminants ***subcategory (abbrev.)***					
Pesticides/herbicides (P/Hs)	pesticide, herbicide, insecticide, fungicide, fumigant, agrichemical, agrochemical, biocide, atrazine, DDT, permethrin, glyphosate	2.	0.42%	6	0.33%
Per-/poly-fluoroalkyl substances (PFASs)	PFAS, fluorochemical, PFOA, PFOS, GenX, fluoroalkyl, AFFF, fire fighting foam	0	0.00%	0	0.00%
Disinfection byproducts (DBPs)	byproduct, byproduct, DBP, trihalomethane, THM, haloacetic acid, HAA, NDMA, chloroform, bromoform, bromate, chlorate	4	0.83%	3	0.17%
Legacy hydrocarbons (LHCs)	hydrocarbon, BTEX, PAH, PCB, dioxin, MTBE, solvent, fuel, PCE, TCE, vinyl, benzene, toluene, phenol, petroleum	3	0.62%	1	0.056%
Flame retardants, plasticizers (FR/Ps)	flame retardant, plasticizer, plastic, BPA, bisphenol-A, e-waste, electronic waste, WEEE	0	0.00%	1	0.056%
Pharmaceuticals and personal care products (PPCPs)	pharmaceutical, pharma, antibiotic, hormone, NSAID, estrogen, drug, sulfamethoxazole, fluoroquinolone, estradiol	1	0.21%	3	0.17%
Naturally occurring (NO)	MIB, isobomeol, geosmin, algal, algae, mierocystin, cyanotoxin, cyanobacteria	5	1.0%	1	0.056%
Dye compounds (DY)	dye, tannery, textile	1	0.21%	2	0.11%
Total studies, organic		**10**	**2.1%**	**12**	**0.67%**
Inorganic contaminants ***subcategory (abbrev.)***					
Geogenic (GEO)	Arsenic	11	2.3%	32	1.8%
	Fluoride	17	3.5%	34	**1.9%**
Heavy metals (HMs)	cadmium, chromium, mercury, nickel, lead, zinc	15	3.1%	8	0.44%
Total studies, inorganic		**36**	**7.5%**	**60**	**3.3%**
Total studies, organic and inorganic		**43**	**8.9%**	**70**	**3.9%**

grouped into subcategories: pesticides/herbicides (P/Hs); PFASs; disinfection byproducts (DBPs), including the inorganic DBPs chlorate and bromate; legacy hydrocarbons such as solvents and fuel compounds (LHCs); flame retardants and plasticizers (FR/Ps); pharmaceuticals and personal care products (PPCPs); naturally occurring cyanobacterial and algal toxins and taste and odor compounds (NO); and dye compounds, for example from textile manufacture (DY). Inorganic chemical toxins included in this review were geogenic (GEO) arsenic and fluoride, and the heavy metals (HMs) cadmium, chromium, mercury, nickel, lead, and zinc. All *JWASHDEV* articles and *WHC* poster and verbal presentation titles or abstracts that contained one or more search terms were compiled into a database in MS Excel. *WHC* studies were examined for their applicability in LMICs, as some presentations focused exclusively on the USA or other HICs – for example, a 2012 presentation titled, 'Evaluation of Public Water System Violations in the USA'. *WHC* presentations with only HIC applicability were excluded from further analysis. All *JWASHDEV* articles in the database were found to be applicable in LMICs. All studies were further classified as 'Class A' and 'Class B' with respect to how chemical contaminants were addressed in the study. 'Class A' signified that the study addressed one or more chemical contaminants in a substantive manner, for example, by identifying and/or quantifying in water and/or by evaluating a treatment intervention for the removal of one or more chemicals. 'Class B' studies made only passing mention of chemicals. For example, a *JWASHDEV* article (Alfa *et al.* 2016) mentions 'pesticides, insecticides, [and other] oestrogens-mimicking [*sic*] substances' as being potential water quality problems in South Africa; however, these compounds were not the subject of the study and were not mentioned again in the paper. The database was queried using the AutoFilter function in MS Excel to quantify the number of Class A studies addressing contaminants in each of the different chemical subcategories. The full Excel database is provided in the Supplementary Information.

RESULTS AND DISCUSSION

Results of the systematic review are presented in the right columns of Table 1. The absolute numbers of Class A studies appearing in *JWASHDEV* and as combined P and O presentations at *WHC* are shown. Percentages are also given out of the total of 481 *JWASHDEV* articles published between 2011 and 2018 and out of an estimated 1,800 combined P and O presentations at *WHC* from 2010 to 2018. Subcategories do not sum to totals because some studies addressed more than one chemical subcategory.

In total, 43 *JWASHDEV* studies (8.9%) and 70 *WHC* presentations (3.9%) were identified that addressed one or more chemical contaminants. Thirty-six *JWASHDEV* studies (7.5%) and 60 *WHC* presentations (3.3%) were identified that addressed one or more inorganic chemical contaminants. In *JWASHDEV*, arsenic, fluoride, and HMs each accounted for roughly 2–3% of articles. Arsenic and fluoride each accounted for <2% of *WHC* presentations, and HMs <0.5% of presentations. Ten *JWASHDEV* studies (2.1%) and 12 *WHC* presentations (0.7%) were identified that addressed one or more organic chemical contaminants. In *JWASHDEV*, five studies (1%) addressed chemicals in the NO subcategory, four studies (0.8%) addressed DBPs, three studies (0.6%) addressed chemicals in the LHC subcategory, two studies (0.4%) addressed chemicals in the P/H category, one study (0.2%) addressed PPCPs, one study addressed DY compounds, and no studies addressed chemicals in the FR/P or PFAS subcategories. The review of *WHC* revealed six studies (0.3%) in the P/H subcategory, three studies (0.2%) each in the DPB and PPCP compound categories, two studies (0.1%) of compounds in the DY subcategory, one study (0.06%) each in the LHC, FR/P, and NO subcategories, and no studies of PFASs.

Time trends

The upper panel of Figure 1 shows the number of studies published in *JWASHDEV* on inorganic and organic chemical contaminants by year. Total studies published per year and the number of studies identified using search terms 'pathogen' and 'coliform' are shown for comparison. From the journal's inception until the end of 2018, it published an average of 1.3 studies per year addressing organic chemical contaminants (all compound subcategories combined). *JWASHDEV* published an average of 1.4 studies per year on arsenic, 1.9 studies per year on HMs, and 2.1 studies per year on fluoride. These averages have been consistent over the journal's history (Figure 1). In contrast, *JWASHDEV* published 116 articles identified using the search term 'pathogen', nearly one-quarter of all articles published 2011–2018. Over the past five years, *JWASHDEV* has published on average 21 out of 71 articles per year (range 9–33 articles, 12–52% of yearly totals) on 'pathogens'.

The lower panel of Figure 1 shows the number of combined O and P presentations at *WHC* on inorganic and organic chemical contaminants by year for 2010–2018. Over this time, an average of 1.3 presentations were made per year addressing organic chemical contaminants (all compound subcategories combined). *WHC* exposited an average of 3.6 presentations per year on arsenic, 3.8 presentations per year on fluoride, and 0.9 presentations per year on HMs. With around 200 combined O and P presentations made at *WHC* each year, this translates to, on average, fewer than 2% of presentations focused on arsenic or fluoride and fewer than 0.7% of presentations addressing HMs or organic chemical contaminants.

CALL FOR ACTION

As an initial step in addressing the gap in WaSH sector programming, the interdisciplinary *WaSH-Toxics Working Group* (WTWG 2016) has been formed. Its mission is to advance research and deployment of innovative, affordable, and sustainable technologies to control chemical toxicants and supply safe water to resource constrained and developing communities around the world. The major objectives of the *WaSH-Toxics Working Group* are to:

- Raise the problem of hazardous chemical contaminants to prominence in the global WaSH sector.
- Stimulate targeted innovation of affordable treatment technologies, along with evaluation of existing pathogen-reducing drinking water interventions for potential chemical removal.
- Generate feedback from experts regarding technical merit and real-world applicability of proposed solutions in an iterative design process.
- Elicit commitment to support research, field testing, deployment, and scale-up of toxic chemical control technologies from major WaSH agencies.
- Provide a forum for networking and collaboration among an interdisciplinary cohort of scholars and practitioners to drive progressive awareness and innovation on the topic of Toxics-in-WaSH.

It is free to join, and we encourage the participation of environmental toxicology and health experts, environmental engineers and scientists, water treatment specialists, researchers, development agency program officers, and WaSH practitioners working in the academic, government, non-profit, non-governmental, and private sectors. More information can be found at washtoxics.wordpress.ncsu.edu.

CONCLUSIONS

This systematic review concludes that chemical toxicants, particularly organic chemicals of emerging concern, constitute severely underrepresented groups in WaSH sector safe water research and implementation. This journal and the UNC *Water and Health Conference* serve as bellwethers for WaSH researchers and practitioners. However, addressing organic chemical toxins in ~2% of journal articles and fewer than 1% of conference presentations is disproportionate to the large and growing impact that these substances have on the environment, water quality, and human health at the global scale, including their contributions to the burden of disease in LMICs. For example, approximately 200 million people in more than 70 countries around the world are exposed to elevated levels of arsenic in their water (Antonova & Zakharova 2016). Despite this, arsenic is addressed in only ~2% of journal articles and conference presentations each year. Exposure to immunotoxins such as arsenic and many synthetic organic chemicals is known to contribute to acute illnesses; NCDs such as cancer, diabetes, and kidney disease; greater susceptibility to pathogen infections; and reduced effectiveness of vaccinations (Winans *et al.* 2011; Erickson 2019). However, chemicals remain a blindspot in the WaSH sector. A rapid, pioneering effort is therefore required to focus attention on chemical dimensions of global drinking water quality. Innovative approaches are especially called for given the challenges of chemical contaminant treatability in low-resource settings. As an initial step in addressing this challenge, the interdisciplinary

WaSH-Toxics Working Group (washtoxics.wordpress.ncsu.edu) has been formed (WTWG 2016).

SUPPLEMENTARY MATERIAL

The Supplementary Material for this paper is available online at http://dx.doi.org/10.2166/washdev.2019.059.

ACKNOWLEDGEMENT

The authors are grateful to Janhavi Kulkarni and Michaela Bate for assistance with compiling and crosschecking the systematic review database.

REFERENCES

Alfa, D., Rathilal, S., Pillay, V. L., Pikwa, K. & Chollom, M. N. 2016 Development and evaluation of a small scale water disinfection system. *Journal of Water Sanitation and Hygiene for Development* **6** (3), 389–400.

Antonova, S. & Zakharova, E. 2016 Inorganic arsenic speciation by electroanalysis. From laboratory to field conditions: a mini-review. *Electrochemistry Communications* **70**, 33–38.

Bernhardt, E. S., Rosi, E. J. & Gessner, M. O. 2017 Synthetic chemicals as agents of global change. *Frontiers in Ecology and the Environment* **15** (2), 84–90.

Broadfoot, M. 2019 Pollution is a global but solvable threat to health, say scientists. *Environmental Factor*. (K. Lenox & R. Arnette, eds). National Institute for Environmental Health Sciences, Durham, NC.

Burleson, G. R., Lebrec, H., Yang, Y. G., Ibanes, J. D., Pennington, K. N. & Birnbaum, L. S. 1996 Effect of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) on influenza virus host resistance in mice. *Fundamental and Applied Toxicology* **29** (1), 40–47.

Burton Jr, G. A., Di Giulio, R., Costello, D. & Rohr, J. R. 2017 Slipping through the cracks: why is the U.S. Environmental Protection Agency not funding extramural research on chemicals in our environment? *Environmental Science & Technology* **51** (2), 755–756.

Canbaz, D., Logiantara, A., van Ree, R. & van Rijt, L. S. 2017 Immunotoxicity of organophosphate flame retardants TPHP and TDCIPP on murine dendritic cells *in vitro*. *Chemosphere* **177**, 56–64.

CDC. 2009 *Fourth National Report on Human Exposure to Environmental Chemicals. Centers for Disease Control and Prevention, 2009 (Report), and 2013 (Updated Tables)*. 2009/2013.

Daniels, M. E., Donilon, T. E. & Bollyky, T. J. 2014 *The Emerging Global Health Crisis: Noncommunicable Diseases in Low- and Middle-Income Countries. Independent Task Force* Report. Council on Foreign Relations, New York.

Erickson, B. E. 2019 *Linking Pollution and Infectious Disease: Chemicals and Pathogens Interact to Weaken the Immune System, Reduce Vaccine Efficacy, and Increase Pathogen Virulence*. Chemical & Engineering News. American Chemical Society, Washington, DC, pp. 28–33.

Grandjean, P., Heilmann, C., Weihe, P., Nielsen, F., Mogensen, U. B., Timmermann, A. & Budtz-Jørgensen, E. 2017 Estimated exposures to perfluorinated compounds in infancy predict attenuated vaccine antibody concentrations at age 5-years. *Journal of Immunotoxicology* **14** (1), 188–195.

Granum, B., Haug, L. S., Namork, E., Stølevik, S. B., Thomsen, C., Aaberge, I. S., van Loveren, H., Løvik, M. & Nygaard, U. C. 2013 Pre-natal exposure to perfluoroalkyl substances may be associated with altered vaccine antibody levels and immune-related health outcomes in early childhood. *Journal of Immunotoxicology* **10** (4), 373–379.

Heilmann, C., Grandjean, P., Weihe, P., Nielsen, F. & Budtz-Jørgensen, E. 2006 Reduced antibody responses to vaccinations in children exposed to polychlorinated biphenyls. *PLoS Medicine* **3** (8), 1352–1359.

Hodges, E. & Tomcej, V. 2016 Is there a link between pollutant exposure and emerging infectious disease? *The Canadian Veterinary Journal = La Revue Veterinaire Canadienne* **57** (5), 535–537.

Humphrey, J. H., Mbuya, M. N. N., Ntozini, R., Moulton, L. H., Stoltzfus, R. J., Tavengwa, N. V., Mutasa, K., Majo, F., Mutasa, B., Mangwadu, G., Chasokela, C. M., Chigumira, A., Chasekwa, B., Smith, L. E., Tielsch, J. M., Jones, A. D., Manges, A. R., Maluccio, J. A. & Prendergast, A. J. 2019 Independent and combined effects of improved water, sanitation, and hygiene, and improved complementary feeding, on child stunting and anaemia in rural Zimbabwe: a cluster-randomised trial. *Lancet Global Health* **7** (1), E132–E147.

Laborde, A., Tomasina, F., Bianchi, F., Bruné, M.-N., Buka, I., Comba, P., Corra, L., Cori, L., Duffert, C. M., Harari, R., Iavarone, I., McDiarmid, M. A., Gray, K. A., Sly, P. D., Soares, A., Suk, W. A. & Landrigan, P. J. 2015 Children's health in Latin America: the influence of environmental exposures. *Environmental Health Perspectives* **123** (3), 201–209.

Landrigan, P. J. & Fuller, R. 2016 Pollution, health and development: the need for a new paradigm. *Reviews on Environmental Health* **31** (1).

Landrigan, P. J., Fuller, R., Acosta, N. J. R., Adeyi, O., Arnold, R., Basu, N., Baldé, A. B., Bertollini, R., Bose-O'Reilly, S., Boufford, J. I., Breysse, P. N., Chiles, T., Mahidol, C., Coll-Seck, A. M., Cropper, M. L., Fobil, J., Fuster, V., Greenstone, M., Haines, A., Hanrahan, D., Hunter, D., Khare, M., Krupnick, A., Lanphear, B., Lohani, B., Martin, K., Mathiasen, K. V., McTeer, M. A., Murray, C. J. L., Ndahimananjara, J. D., Perera, F., Potočnik, J., Preker, A. S., Ramesh, J., Rockström, J., Salinas, C., Samson, L. D., Sandilya, K., Sly, P. D., Smith, K. R., Steiner, A., Stewart, R. B., Suk, W. A., van Schayck, O. C. P., Yadama, G. N., Yumkella, K. & Zhong, M. 2018 The Lancet Commission on Pollution and Health. *Lancet* **391**(10119), 462–512.

Luby, S. P., Rahman, M., Arnold, B. F., Unicomb, L., Ashraf, S., Winch, P. J., Stewart, C. P., Begum, F., Hussain, F., Benjamin-Chung, J., Leontsini, E., Naser, A. M., Parvez, S. M., Hubbard, A. E., Lin, A., Nizame, F. A., Jannat, K., Ercumen, A., Ram, P. K., Das, K. K., Abedin, J., Clasen, R. F., Dewey, K. G., Fernald, L. C., Null, C., Ahmed, T. & Colford Jr, J. M. 2018 Effects of water quality, sanitation, handwashing, and nutritional interventions on diarrhoea and child growth in rural Bangladesh: a cluster randomised controlled trial. *Lancet Global Health* **6** (3), E302–E315.

Null, C., Stewart, C. P., Pickering, A. J., Dentz, H. N., Arnold, B. F., Arnold, C. D., Benjamin-Chung, J., Clasen, T., Dewey, K. G., Fernald, L. C. H., Hubbard, A. E., Kariger, P., Lin, A., Luby, A. P., Mertens, A., Njenga, S. M., Nyambane, G., Ram, P. K. & Colford Jr, J. M. 2018 Effects of water quality, sanitation, handwashing, and nutritional interventions on diarrhoea and child growth in rural Kenya: a cluster-randomised controlled trial. *Lancet Global Health* **6** (3), E316–E329.

Pennings, J. L. A., Jennen, D. G. J., Nygaard, U. C., Namork, E., Haug, L. S., van Loveren, H. & Granum, B. 2016 Cord blood gene expression supports that prenatal exposure to perfluoroalkyl substances causes depressed immune functionality in early childhood. *Journal of Immunotoxicology* **13** (2), 173–180.

Pickering, A. J., Null, C., Winch, P. J., Mangwadu, G., Arnold, B. F., Prendergast, A. J., Njenga, S. M., Rahman, M., Ntozini, R., Benjamin-Chung, J., Stewart, C. P., Huda, T. M. N., Moulton, L. H., Colford Jr, J. M., Luby, S. P. & Humphrey, J. H. 2019 The WASH benefits and SHINE trials: interpretation of WASH intervention effects on linear growth and diarrhoea. *Lancet Glob Health* **7** (8), e1139–e1146.

Prüss-Ustün, A., Wolf, J., Corvalán, C., Bos, R. & Neira, M. 2016 *Preventing Disease Through Healthy Environments: A Global Assessment of the Burden of Disease From Environmental Risks*. World Health Organization, Geneva.

Rahman, A., Vahter, M., Ekström, E.-C. & Persson, L.-A. 2011 Arsenic exposure in pregnancy increases the risk of lower respiratory tract infection and diarrhea during infancy in Bangladesh. *Environmental Health Perspectives* **119** (5), 719–724.

Redmon, J. H., Elledge, M. F., Wanigasuriya, K. P., Wickremasinghe, R. & Levine, K. E. 2016 Deciphering chronic kidney disease of unknown etiology in Sri Lanka. *Improving Outcomes For Noncommunicable Diseases in Low- and Middle-Income Countries*. (K. A. Labresh, ed.). RTI Press, Research Triangle, NC.

Suk, W. A. & Mishamandani, S. 2016 Changing exposures in a changing world: models for reducing the burden of disease. *Reviews on Environmental Health* **31** (1), 93–96.

UN-SDP 2015 *United Nations Sustainable Development Knowledge Platform, Open Working Group Proposal for Sustainable Development Goals*.

Wang, L. 2019 *CAS Reaches 150 Millionth Substance*. Chemical & Engineering News. American Chemical Society, Washington DC.

Weiss, F. T., Leuzinger, M., Zurbrügg, C. & Eggen, R. I. L. 2016 *Chemical Pollution in Low- and Middle-Income Countries*. Eawag: Swiss Federal Institute of Aquatic Science and Technology, Dübendorf, Switzerland.

WHO (ed.) 2019 *Results of Round II of the WHO International Scheme to Evaluate Household Water Treatment Technologies*. World Health Organization, Geneva.

Winans, B., Humble, M. C. & Lawrence, B. P. 2011 Environmental toxicants and the developing immune system: a missing link in the global battle against infectious disease? *Reprod Toxicol* **31** (3), 327–336.

Woodruff, T. J. 2015 Making it real – the environmental burden of disease. What does it take to make people pay attention to the environment and health? *Journal of Clinical Endocrinology & Metabolism* **100** (4), 1241–1244.

WTWG 2016 *WASH-Toxics Working Group*. Available from: https://washtoxics.wordpress.ncsu.edu (accessed 2016).

First received 30 April 2019; accepted in revised form 23 August 2019. Available online 1 October 2019