COVID-19: urgent actions, critical reflections and future relevance of 'WaSH': lessons for the current and future pandemics

Guy Howard, Jamie Bartram, Clarissa Brocklehurst, John M. Colford Jr, Federico Costa, David Cunliffe, Robert Dreibelbis, Joseph Neil Spindel Eisenberg, Barbara Evans, Rosina Girones, Steve Hrudey, Juliet Willetts and Caradee Y. Wright

ABSTRACT

The COVID-19 pandemic placed hygiene at the centre of disease prevention. Yet, access to the levels of water supply that support good hand hygiene and institutional cleaning, our understanding of hygiene behaviours, and access to soap are deficient in low-, middle- and high-income countries. This paper reviews the role of water, sanitation and hygiene (WaSH) in disease emergence, previous outbreaks, combatting COVID-19 and in preparing for future pandemics. We consider settings where these factors are particularly important and identify key preventive contributions to disease control and gaps in the evidence base. Urgent substantial action is required to remedy deficiencies in WaSH, particularly the provision of reliable, continuous piped water on-premises for all households and settings. Hygiene promotion programmes, underpinned by behavioural science, must be adapted to high-risk populations (such as the elderly and marginalised) and settings (such as healthcare facilities, transport hubs and workplaces). WaSH must be better integrated into preparation plans and with other sectors in prevention efforts. More finance and better use of financing instruments would extend and improve WaSH services. The lessons outlined justify no-regrets investment by government in response to and recovery from the current pandemic; to improve day-to-day lives and as preparedness for future pandemics.

Key words | COVID-19, coronavirus, hygiene, pandemics, WASH, water

HIGHLIGHTS

- This is the first comprehensive review of WASH and COVID-19.
- The paper analyses the key ways in which water, hygiene and sanitation can help reduce transmission of COVID-19.
- The paper presents analysis of the wider role for water, hygiene and sanitation in combatting pandemic disease.
- The paper analyses the structural deficiencies in the WASH 'sector' that limits its impact on COVID-19.
- The paper identities key evidence gaps, including on behaviour change, that are priorities for maximising the role of WASH in addressing pandemics of disease.

Guy Howard† (corresponding author)
Department of Civil Engineering,
University of Bristol,
Bristol, UK
E-mail: *guy.howard@bristol.ac.uk*

Jamie Bartram†
Barbara Evans‡
School of Civil Engineering,
University of Leeds,
Leeds, UK

Jamie Bartram†
Clarissa Brocklehurst‡
Gillings School of Global Public Health,
University of North Carolina at Chapel Hill,
Chapel Hill, NC, USA

John M. Colford Jr‡
Division of Epidemiology,
University of California,
Berkeley, CA, USA

Federico Costa‡
Instituto de Saúde Coletiva,
Universidade Federal da Bahia,
Salvador, Brazil

David Cunliffe‡
Department for Health and Wellbeing,
Adelaide, South Australia, Australia

Robert Dreibelbis‡
Department of Disease Control,
London School of Hygiene and Tropical Medicine,
London, UK

Joseph Neil Spindel Eisenberg‡
Department of Epidemiology,
University of Michigan,
Ann Arbor, MI, USA

Rosina Girones‡
Department of Genetics, Microbiology and Statistics,
University of Barcelona,
Barcelona, Spain

doi: 10.2166/wh.2020.162

Steve Hrudey IWA‡
Faculty of Medicine and Dentistry,
University of Alberta,
Alberta, Canada

Juliet Willetts IWA‡
Institute for Sustainable Futures, University of Technology Sydney,
Sydney, Australia

Caradee Y. Wright
Environmental and Health Research Unit, South African Medical Research Council, Department of Geography, Geoinformatics and Meteorology,
University of Pretoria,
Pretoria, South Africa

†Co-first-authors
‡Authors in alphabetical order.

INTRODUCTION

The world in 2020 has been gripped by a pandemic of a novel coronavirus, severe acute respiratory syndrome coronavirus 2, cause of COVID-19.[1] Starting in China in late 2019, by the end of July 2020, this had spread to virtually every country in the world, with global cases escalating past 15 million and over 600,000 deaths at the time of writing.

Combatting a virus to which the population at large has no immunity, which is highly contagious and for which no vaccine exists, has forced countries to recognise the importance of foundational measures of disease control. 'Physical distancing' and 'physical isolation', accompanied by handwashing and infection prevention and control, have been the main responses. Box 1 clarifies these terms. All are challenging in low-, middle- and high-income countries, albeit for different reasons.

In this paper, we analyse the role of WaSH in reducing severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) transmission and supporting responses to COVID-19. We explore how the importance of adequate WaSH services is reinforced by evidence from other outbreaks and pandemics of contagious and infectious disease.[2] We address the roles, strengths and weaknesses of WaSH by analysing the three necessities for sustained handwashing (availability of sufficient flowing water, availability of soap and hand sanitisers where used and behaviours practiced by individuals) and then consider WaSH in settings of specific concern. We identify actions needed to ensure WaSH supports prevention and response to pandemics and identify important knowledge gaps and priorities for research.

COVID-19

Most people with COVID-19 experience mild to moderate respiratory illness and recover without requiring special treatment. Some people with COVID-19 have no symptoms and asymptomatic infections likely contribute to the spread of the disease. The infection may also cause severe illness including respiratory failure and multiorgan and systemic manifestations (sepsis, septic shock and multiple organ dysfunctions) (Cascella *et al.* 2020). Older people and those with underlying medical problems are more likely to develop serious illness.

COVID-19 transmission appears to be largely through inhalation and through respiratory droplets[3] contacting

[1] There is confusion and misuse of terminology related to the current disease pandemic. The term 'COVID-19' refers to the disease that is caused by the virus named severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2).

[2] The terms contagious and infectious are frequently conflated. Infection relates to the ability to cause infection (and thereby potentially to cause disease) while contagions are a sub-category of infections that can be transmitted from person to person, without an animal or environmental reservoir or intermediary.

[3] Both respiratory droplets and respiratory aerosols are liquid (mucus) particles and are potentially infectious through inhalation if they contain virus. The terms 'aerosol' and 'droplet' are often confused and some definitions are ambiguous (Vuorinen *et al.* 2020). 'Aerosols' is sometimes used to refer to a suspension of liquid droplets or droplets of smaller sizes after drying of particles in the air, but the term strictly refers to small droplets that remain suspended in the air. Droplets larger than aerosols are heavier than air and are deposited under gravity. The difference is important for inhalation exposure and to deposition of virus-containing particles on surfaces.

Box 1 | Key terms

Isolation refers to the physical separation of people with confirmed or suspected virus infections from other people for whom there is no evidence of current infection. **Quarantine** refers to the physical separation of people who are not currently ill but who are believed to have been exposed to the virus. While these terms are used widely, there are some variations in application. Isolation is sometimes conflated with quarantine and although the terms self-isolation and self-quarantine usually refer to voluntary actions, in some jurisdictions compliance with these actions is enforced.

Infection prevention and control (IPC) encompasses measures used to reduce the likelihood of virus transmission through specific actions such as physical distancing, the frequent disinfection of surfaces, the use of personal protective equipment, regular hand hygiene and the application of sneezing and coughing etiquettes.

Physical or social distancing refers to measures used to reduce contact between people, such as staying at home and maintaining physical gaps between non-cohabiting individuals. The recommendations for specific separation distances vary across countries and range from 1 to 2 m (3–6 feet). Physical distancing is a more accurate description of this measure since a continuation of social contact is encouraged (e.g. electronically).

mucosae (mouth and nose) or conjunctiva (eyes). Contact occurs directly through person–person (e.g. droplet–hand–hand–face) and indirectly (e.g. droplets–surfaces–hands–face). Consequently, the principal WaSH responses to COVID-19 relate to hand hygiene. While the relative contributions of inhalation and contact to transmission are unclear, the necessity of hand hygiene to disease control is unquestionable.

In some patients, the shedding of viral RNA via the digestive system appears to last longer than via the respiratory tract (Wu *et al.* 2020a; Xu *et al.* 2020). Infectious viruses, as distinct from RNA markers for SARS-CoV-2, have been isolated from very few stool samples (Wang *et al.* 2020), even during clinical and asymptomatic infection. Faeces are, therefore, unlikely to contribute substantially to infection.

THE IMPORTANCE OF HANDWASHING

A person infected with SARS-CoV-2, whether symptomatic or asymptomatic, is likely to have contaminated hands and may transmit the pathogen to others, directly or via surfaces and objects (fomites). Hands offer a conducive environment for virus survival as they contain creases that protect against exposure to viricidal ultra-violet (UV) light, specifically UV-C (IES 2020).

The importance of handwashing as a public health intervention is widely recognised, including for the control of respiratory disease (Rabie & Curtis 2006; Mbakaya *et al.* 2017; Prüss-Üstun *et al.* 2019). Handwashing with soap or use of hand sanitiser is therefore a mainstay of the guidance for controlling the spread of COVID-19 (WHO 2020).

Evidence on hand hygiene and influenza potentially provides useful comparisons for COVID-19. A systematic review by Saunders-Hastings *et al.* (2017) shows frequent handwashing to have a large and significant protective effect against pandemic influenza. Improved hand hygiene is linked to lower rates of hospitalisation (Godoy *et al.* 2012) and of school absenteeism (Azor-Martínez *et al.* 2014) during influenza season. However, a study in Sweden during the influenza season analysing self-reported acute respiratory symptoms in a cohort of randomly selected individuals found no significant decrease in infection with self-reported increases in handwashing (Merk *et al.* 2014). Similarly, Simmerman *et al.* (2011) in a randomised-controlled trial of handwashing and face masks in reducing influenza transmission in Bangkok, Thailand, found no reduction in transmission. In both cases, the authors note that insufficiently frequent handwashing may explain their findings.

Hygiene behaviours and facilities

Effective handwashing requires access to facilities (water, containers, soap) that enable hygiene behaviours. Wolf *et al.* (2019) report that 95% of the population in high-income countries has access to a 'designated handwashing facility', but only 70% in low-income countries; and in sub-Saharan Africa, the population in households with access to handwashing facilities with soap and water is 26% (UNICEF & WHO 2019). UNICEF & WHO (2019) report that around 60% of the world's population has at least a basic handwashing facility in the household, defined as a location where both soap and water are available that are either fixed (i.e. a sink) or mobile (jugs or basins). Mobile handwashing facilities are unlikely to be adequate to support the levels of hygiene sought in response to COVID-19. A systematic review by Brauer *et al.* (2020) found that, in 2019, 2.4 billion people worldwide lack access to handwashing with available soap and water. They note substantial regional variation, with over 50% of the population in the sub-Saharan Africa and Oceania regions lacking access, and that access was particularly low in rural areas and urban slums in low-income countries.

Construction of handwashing stations (e.g. 'tippy-taps', which do not require running water) encourage handwashing with soap (Contzen *et al.* 2015; Coultas *et al.* 2020). An integrative review on determinants of hand hygiene found good and consistent evidence that handwashing infrastructure in the household was a determinant of handwashing (White *et al.* 2020). Wolf *et al.* (2019) show that people with access to a handwashing facility with soap and water were 2.6 times as likely to wash hands with soap before food contact compared to those people without access to a handwashing facility.

Sufficient flowing, reliable water

Adequate hand hygiene requires sufficient water from reliable and easily accessible sources, preferably piped to their premises. UNICEF & WHO (2019) estimate that 90% of the global population uses at least an 'improved water supply' and 64% of this population has access to piped water, some of whom use shared taps and many who experience intermittent supply (Kumpel & Nelson 2016). Majuru *et al.* (2016) found that unreliable water supplies have been associated with poorer domestic hygiene, which may increase the spread of COVID-19 via fomites. Three-quarters of the global population has some form of water supply on-premises (UNICEF & WHO 2019), which includes households with their own wells. While such water sources can provide a reliable and abundant supply of water, they will not provide running water for washing hands.

UNICEF & WHO (2019) report that one-quarter of the global population uses water collected from off-premises water sources that are shared between households. Reliance on such sources creates two challenges to the pandemic response: sufficiency of water for handwashing and inter-household contact associated with water collection, the latter disproportionately exposing women and girls. The amount of water typically collected by households from such sources is around 20 litres per person per day (Howard & Bartram 2003), which Howard et al. (in press) note that is unlikely to be sufficient to support the greater frequency and duration of handwashing required in pandemics and outbreaks. Shared water sources are places of inter-household contact. Their use increases the risk of transmission because handles and taps used by numerous people facilitate contact transmission.

There is no evidence that the SARS-Cov-2 virus can be transmitted via contact with water. Thus, frequent handwashing with lower quality water is preferable to infrequent handwashing in high-quality water when a pandemic response is paramount.

Effectiveness and availability of soap

Frequent hand hygiene interrupts transmission in two ways: pathogens are removed from the hands, particularly through handwashing with soap and water; and the virus is inactivated, for example, by soap or alcohol-containing hand sanitisers (Kratzel *et al.* 2020). Washing with soap and water both inactivates and physically removes coronaviruses.

The evidence base on the effectiveness of soap in inactivating SARS-CoV-2 in real-world conditions is sparse. One very small study on the viricidal effect of a range of disinfectants found all substantially reduced in virus concentration after 5 min, such that virus was not detected in samples (one of the triplicate tests with soap contained some virus after 5 min but no virus was found after 15 min) (Chin *et al.* 2020). A small health worker study during the 2013–2016 West African Ebola virus outbreak found little variation among several cleansing agents (including soap) in reducing the persistence of Phi6 (an enveloped bacteriophage) in rinse waters (Wolfe *et al.* 2017). These results suggest the mechanical action of rubbing hands together may be the major factor in removing viruses.

The extent to which soap is available is unknown. An analysis of MICS data by Kumar et al. (2017) found that the presence of any soap – including laundry detergent – in households in the surveyed low- and middle-income countries ranged from 20 to 99%, with large inequalities between wealth groups and between urban and rural populations. 'Soapy Water' – hand hygiene materials made at home using laundry detergent or soap shavings – has been promoted as an alternative to a bar or liquid soap (Ashraf et al. 2017), but it is unclear whether such materials inactivate the SARS-Cov-2 virus.

Alcohol-based hand sanitisers inactivate viruses and enable increased frequency of hand hygiene, especially where handwashing is unlikely to be practiced in locations of risky contacts, such as transport hubs and shop entrances and exits. They are also common in healthcare settings where very frequent hand hygiene is demanded; for instance, half of all African healthcare facilities have these sanitisers (WHO & UNICEF 2019).

WASH IN SETTINGS OF SPECIFIC CONCERN FOR COVID-19

Most countries have promoted physical isolation at home for people who suspect they may have the disease. While effective (Bi et al. 2020; Hellewell et al. 2020; Leung et al. 2020), this depends on adequate hygiene facilities with sufficient water, soap and materials to keep bathrooms, kitchens and other places clean. For large numbers of ordinary households worldwide, ensuring all these requirements is practically impossible.

There are a number of extra-household settings of concern (Table 1). Healthcare facilities, transportation systems and forcibly displaced people are of particular concern either because of the potential to act as hubs of infection or the vulnerability of their populations.

PREPARING FOR 'FUTURE WAVES' OF OUTBREAKS

The preceding review concerns challenges to, and immediate needs for, WaSH during the first active phase of the pandemic. This paper was prepared as cases escalated in some countries, re-escalated in others and some countries lifted initial 'lockdown' restrictions. Local increases in the reproductive rate (R_0)[4] and fears that infection, and potentially vaccination, may not induce lasting immunity increased concern for 'future waves' of infection. Under all these circumstances, as restrictions are eased, frequent hand hygiene will be critical to keeping the reproductive rate (R_0) below 1, as will restrictions on inter-personal contact, especially for cases and their contacts.

WaSH facilities in workplaces and social settings have frequent use under normal conditions and will become more used as social constraints are lifted. Facilities at such venues may need to be increased and require adaptation to enable physical distancing and safe use. Frequent deep cleaning is required to prevent transmission; taps, soap dispensers and door handles on toilets merit special attention; and improvements in design, including the use of sensors on taps and large levers as opposed to wheel taps, may reduce transmission.

Some settings can act as 'hot spots' and initiate or propagate a second wave. These include settings where vulnerable persons are concentrated (e.g. care settings where vulnerable populations are concentrated and interact directly and indirectly through caregivers); and where inter-personal and inter-household contact is frequent especially if accompanied by deficient hand hygiene. Opportunities for reducing transmission and new-wave prevention concern easy-access hygiene/washing facilities that minimise inter-individual and inter-household contact.

WaSH, COVID-19 and human rights obligations

COVID-19 disproportionately affects the lives and livelihoods of certain individuals and groups and the pandemic therefore has the potential to exacerbate long-standing inequalities and unequal determinants of health (Laurencin & McClinton 2020). In consequence, 'States have a responsibility to ensure that everyone is protected from this virus and its impact', which may require special measures to ensure 'that national and local response and recovery

[4] R_0 is the reproduction rate of the disease – that is the average number of people who will contract the disease from one infected individual.

Table 1 | Settings of concern for COVID-19

Setting	Issues
Healthcare facilities	Separating COVID-19 patients and surges in the number of severe cases, overburden water systems and facility hygiene. Deficient healthcare facilities can become epicentres of infection, as with cholera (Mhalu *et al.* 1984) and Ebola (Faye *et al.* 2015). In many low- and middle-income countries, facilities are chronically under-staffed (WHO 2006) and resources for cleaning and disinfection are insufficient. Only 2% of facilities, in low- and middle-income countries with data, had adequate water, sanitation, hygiene, waste management services and standard precaution items (i.e. PPE) (Cronk & Bartram 2018). WHO & UNICEF (2019) note that 74% of healthcare facilities had at least an improved water source on premises (55% for 'least developed' countries and 51% in sub-Saharan Africa); and 16% had no hygiene service (no water and no sanitation and no handwashing facilities). Conventional sanitation facilities require hand-surface contact (door handles, taps, seats, etc.).
Transport	National responses to COVID-19 restrict movement because disease spreads through transportation corridors, as with cholera (Lee & Dodgson 2000), SARS (Ruan *et al.* 2005) and influenza (Grais *et al.* 2020). Persons from different households are crowded together in transport and at transport hubs. Transport hubs (bus and train stations, shared taxi boarding points, ports and airports) are high-risk locations. They require more frequent hygiene behaviours and enhanced facility cleaning and disinfection during pandemics. Pay-to-use facilities discourage desired behaviours and impede frequent hand hygiene. Public or shared transport (buses, trains, shared taxis, ferries, aeroplanes) is often over-crowded and hand sanitiser on entry and exit and frequent disinfection are needed. Regulating hygiene, regular cleaning and eliminating over-crowding demand assertive action by governments. In many countries, migrant labourers have left towns and cities to return their home villages and are exposed to high-risk environments during travel. Facilities in home villages may be insufficient to cope with the increased demand.
Forcibly displaced populations – refugees and internally displaced people	Numbered over 70 million people in 2018 (UNHCR 2019), more than 60% live in urban host communities rather than camps. Most refugees flee to nations that have not met the WaSH needs of their citizens. Governments anticipate displaced population return to their country of origin, but the average refugee spends 17 years displaced (Behnke *et al.* 2018). Camp settings in emergency (Banner-Shackelford *et al.* 2020), transitional (Cooper *et al. submitted*) and protracted (Behnke *et al.* 2020) phases have deficient environmental health, poor access to hygiene facilities and close proximity and frequent interaction of households and individuals. Sharing and queuing for water sources, toilets, laundry and bathing facilities are frequent. Insufficient water for hand hygiene. For COVID-19 positive households, the burden of water collection may mean health and hygiene suffer. Travel for work or returning home can seed continued or second-wave transmission.
Residential care homes for the elderly	Dense populations allow viral spread in a highly vulnerable population. Movement of employees in and out of facilities increases transmission risks. Ensuring facilities are hygienic and ensuring good hygiene among residents is challenging.
Penal institutions, children's homes, homeless shelters and migrant hostels	Tendency for over-crowding and deficient environmental health (Moffa *et al.* 2018, 2019; Guo *et al.* 2019). Migrant hostels represent a specific setting of concern as they are often over-crowded with limited WaSH facilities; migrants may be indebted as part of arrangements for their employment meaning they must continue to work; and the rights of migrants may be limited. Penal institutions and homeless shelters tend to have higher proportions of people with other health problems that may increase susceptibility.

(*continued*)

Table 1 | continued

Setting	Issues
Schools	In 2016, only 69% of schools had at least a basic drinking-water supply (an 'improved water source' with water available at the time of the survey); and 53% had at least a 'basic handwashing facility' (with water and soap available at the time of the survey) (UNICEF & WHO 2018). Compliance with handwashing protocols may be difficult to enforce even where facilities are available.
Workplaces	Workplaces include formal, informal and mobile/itinerant settings and have been the locus of COVID clusters. Data on WaSH in workplaces are few (Cronk *et al.* 2015) especially for informal and mobile workers. Typical WaSH facilities or work practices often require substantive modification to accommodate enhanced hand hygiene and physical distancing. Entertainment centres (bars, cafes, restaurants, etc.) are typically crowded and maintenance of hygiene in toilets and provision of sufficient hand washing facilities in toilets may be challenging. Where alcohol is consumed, ensuring hand hygiene behaviours are maintained can be challenging.
Markets	Sufficient handwashing and sanitation facilities in markets are critical and should be supplemented with hand sanitising facilities; cleaning and disinfection should be frequent. Pay-to-use facilities may discourage desired behaviours, impede frequent hand hygiene and be insufficiently protective. Lessons must be learnt from the 2013–2016 West African Ebola outbreak on special provision of handwashing stations in public places.

plans identify and put in place targeted measures to address the disproportionate impact of the virus on certain groups and individuals, including … those without access to water and sanitation …' (United Nations 2020).

A group of UN independent human rights experts, in March 2020, called on utilities to provide water free of cost to certain population groups, saying: 'We call on governments to immediately prohibit water cuts to those who cannot pay water bills. It is also essential that they provide water free of cost for the duration of the crisis to people in poverty and those affected by the upcoming economic hardship. Public and private service providers must be enforced to comply with these fundamental measures' (OHCHR 2020).

Ensuring that all people have access to sufficient water must be accompanied by ensuring the viability and sustainability of water service providers. The indirect effects of the COVID-19 pandemic on staff and supply chains may affect WaSH services and consumables. For example, utilities may face immediately reduced and in the longer-term slower customer growth, deferrals of planned water rate increases and deferred maintenance. Financial losses may reduce capital spending. These short- and long-term costs will be substantial, for instance, in the USA, financial losses to utilities are estimated to be US$13.9 billion and the economic impacts US$32.7 billion (Raftelis 2020). Globally, the water supply services that are most likely to fail are smaller systems with single operators.

Improved governance, in particular strong and supportive regulation, is essential to prevent failures and minimise drain on public finance by ensuring utilities have finance available and make sensible investments. Supply-side direct subsidies may prove difficult to unwind. While the short-term response may be a time-limited supply of water, the medium-term response is likely to involve demand-side subsidies that allow households to take responsibility and that can be better targeted and monitored.

LESSONS FOR WASH FROM EMERGING DISEASES AND MANAGING WASH-RELATED OUTBREAKS

Pandemics in which WaSH has a role in prevention and control, and the emergence of new diseases linked to

WaSH, raise questions about the contribution of WaSH in prevention, control and preparedness. Lessons can be learned from past and present pandemics and from what can be known about future pandemic causes.

WaSH and infectious disease emergence

Emerging diseases are those appearing in a human population for the first time, while re-emerging diseases appear in new areas, reappear after apparent control or emerge as drug resistant (Morens & Fauci 2013). More than 300 emerging diseases have been recognised since 1940 (Jones *et al.* 2008) and many others are predicted (Carroll *et al.* 2018). Predicting disease emergence is difficult because of high pathogen diversity, complex disease dynamics and paucity of data (Morse *et al.* 2012). However, the drivers of emergence are not randomly distributed in time or space (Allen *et al.* 2017). General determinants include geographic regions (hot spots) and interactions between humans, wildlife, livestock and environment (Cotruvo *et al.* 2004; Morse *et al.* 2012). Table 2 describes four categories of WaSH-related determinants, which reveal the diversity of stakeholders implicated in WaSH aspects of disease emergence.

Pathogen discovery is a frequent strategy for disease emergence prediction (WHO 2015; Carroll *et al.* 2018). Identification of novel pathogens has been undertaken in environmental matrices and all groups of organisms but is targeted on animals because 60% of emerging and re-emerging diseases are zoonoses, with most (72%) originating in wildlife (Jones *et al.* 2008). The most frequent pathogen group is viruses, which present great adaptive potential conferred by high mutation rates coupled with short generation times and large population sizes. All recent pandemic zoonoses, for example, Ebola virus, SARS and SARS-CoV-2, have a viral aetiology (Carroll *et al.* 2018). Preparedness and response to these global threats demand interdisciplinarity and community involvement (WHO 2015). While significant in response, WaSH could increase engagement with those disciplines aimed at improving preparedness to zoonotic emergent events. One example is the gap in knowledge on zoonotic pathogens movement and survival, after release into the environment (critically water), and its influence on human (and other animal) exposure and disease emergence (Plowright *et al.* 2017).

Understanding emergence mechanisms is critical to prevent pandemics. The risk of emergence of a pathogen seems

Table 2 | WaSH-related categorization of factors affecting pathogen emergence (from WHO 2003a)

Potential drivers of the emergence and re-emergence of pathogens in water

New environments: ▪ Climate shifts/deforestation ▪ Water resources development projects (dams and irrigation) ▪ Water-cooled air conditioning plants ▪ Changing industrial and agricultural practices (e.g. intensive livestock rearing) ▪ Piped water systems and their inadequate design and operation ▪ An increasing number of humanitarian emergencies	**New technologies:** ▪ Water resources development projects (dams and irrigation) ▪ Water-cooled air conditioning plants ▪ Changing industrial and agricultural practices ▪ Waterborne sewage and sewage treatment alternatives
Changes in human behaviour and vulnerability: ▪ Human circulation and the accessibility and rapidity of transport worldwide ▪ Demographic changes ▪ Increasing size of high-risk populations ▪ Deliberate and accidental release of pathogens to water ▪ An increasing number of humanitarian emergencies	**Scientific advances:** ▪ Inappropriate, excessive use of antibiotics, anti-parasitic drugs and public health insecticides ▪ Changing industrial and agricultural practices ▪ Improved methods of detection and analysis ▪ Inappropriate use of new generation insecticides

to be determined by contact frequency of, and chance of successful adaptation to, humans. Some pathogens, including SARS-CoV-2, have reached human-to-human transmission removing the need for other reservoir species in its cycle. Morse *et al.* (2012) propose three stages in pandemic emergence, here adapted to zoonoses as (i) pre-emergence (where the pathogen circulates among one or more host animal species), (ii) localised emergence (initial spill-over to humans directly from the original host or indirectly through other animals, such as livestock) (for SARS-CoV-2, pangolins are suggested intermediate hosts between bats and humans (Li *et al.* 2020)) and (iii) full pandemic emergence. Most WaSH interventions aim to decrease transmission during the full pandemic stage. However, other stages also offer opportunities for WaSH interventions.

In the pre-emergence stage, the protection of drinking water in animal husbandry can prevent inter-species transmission of pathogens by avoiding livestock consumption of water contaminated by wildlife or pest hosts. Water resources management may be important in reducing interactions between humans and animals forced to adapt to human-induced changes in the water environment.

In the localised emergence stage, behavioural interventions, such as handwashing, decrease the risk of reservoir-to-human transmission among occupational risk groups (hunters, food handlers and livestock workers) as previously tested in agricultural settings for H5N1 (Janes *et al.* 2012). Integrating WaSH behaviours into models of disease emergence will assist identification of barriers to early epidemics of pandemic potential (Janes *et al.* 2012).

WaSH interventions are likely to contribute to preventing transmission of emerging zoonoses but systematic assessments are lacking (Costa *et al.* 2017). Recent studies highlight the scale of animal faeces (Berendes *et al.* 2018) as an under-recognised threat to human health calling for adapted WaSH strategies (Dufour *et al.* 2012; Prendergast *et al.* 2019).

Lessons about WaSH in outbreaks, epidemics and other pandemics

The foundations of WaSH were established in the 1800s following John Snow and William Budd investigating outbreaks and discovering that cholera and typhoid, respectively, were transmitted via faecally contaminated drinking water (Hrudey & Hrudey 2004). Widespread drinking-water supply filtration and disinfection and improved sanitation including wastewater treatment virtually eliminated drinking waterborne transmission of cholera and typhoid high-income countries. In low- and middle-income countries, short-term WaSH provision in response to outbreaks of these diseases, particularly cholera, masks insufficient progress in sustainable access that would prevent outbreak recurrence and the spread of disease (D'Mello-Guyett *et al.* 2020).

The lessons from WaSH-related outbreaks point to the need for context-adapted, disease-focused approaches that involve diverse stakeholders and actors, and in particular:

- The significance of life-threatening and life-changing consequences of some WaSH-associated pathogens (e.g. haemolytic uraemic syndrome associated with *E. coli* O157, Guillain–Barré syndrome associated with *Campylobacter*, and the interactions of infection and nutrition in child development).
- The importance of accounting for specific characteristics of diverse WaSH-associated pathogens in engineering and other interventions (e.g. the resistance of *Cryptosporidium* to disinfection) and the role of good operations in minimising risk as exemplified in WHO's Framework for Drinking-water Safety and Water Safety Plans (WHO 2003b).
- The existence of transmission routes and control targets in addition to waterborne (e.g. *Legionella* from engineered water systems, SARS and faecal droplet transmission (Yu *et al.* 2004; McKinney *et al.* 2006).
- The importance of understanding places and population groups of concern (e.g. the elevated risk to pregnant women from hepatitis E virus (Kamar *et al.* 2014); the elevated risks to people who are HIV+ or live with AIDS from *Cryptosporidium* (Wang *et al.* 2018).
- The importance of engagement with professionals and systems of other sectors (*Campylobacter* and *Cryptosporidium* and food production; catchment management for diverse pathogens).

Experience shows that large disease outbreaks, such as that in Milwaukee, USA in the early 1990s (MacKenzie *et al.* 1994) can drive commitments to improve water supplies, whether through upgraded treatment requirements or improved catchment management. The WaSH response to COVID-19 should learn from these lessons and identify investments, good practices and regulation to help prepare against future pandemics.

HOW WELL PREPARED WAS THE WASH COMMUNITY TO RESPOND TO THE COVID-19 PANDEMIC?

Several themes suggest it would have been possible for the 'WaSH community' to have been better able to respond to the COVID-19 pandemic and associated demands for information. These point to opportunities to improve evidence and enhance theory and practice in WaSH.

Some types of evidence needed by policy-makers and the public were predictable but poorly serviced by prior information. For example, most research into the public health effects of WaSH interventions has not explored the disaggregated effects on specific pathogens nor considered predominant environmental transmission routes of pathogens that lead to similar outcomes. Such evidence was called for and could have influenced pandemic communications and response.

Similarly, while the importance of handwashing is recognised, there is an unmet call for evidence about the efficacy of different behaviour change approaches among specific target groups under pandemic conditions. Despite increases in evidence-based approaches to changing hygiene behaviours, most focus on interrupting faecal–oral transmission for the protection of child health by improving hand hygiene behaviours among caregivers. These are ill-suited to the epidemiology of other agents including COVID-19. Key moments for hand hygiene around respiratory viruses will be distinct. Ensuring convenient and accessible handwashing stations in kitchens and near toilets may improve hand hygiene for key moments for faecal contact but are inadequate for the challenges posed by respiratory viruses where more attention may be needed on entering or leaving the household, public places after high-touch surface contact or after coughing or sneezing. Interventions for caretakers of young children are less relevant for person-to-person transmission among adults. The importance of robust formative research is shared across most modern behaviour change theories and frameworks, yet methods rely on direct observations and in-depth in-person surveys or interventions with individuals and their communities – methods that are largely impossible under lockdown conditions.

The need for a reliable, continuous water supply, piped into household premises and places such as healthcare settings, schools, workplaces, transport hubs and markets, is evident to ensure sufficient and accessible water for hygiene purposes at all times. This would be an advance on the current target and monitoring of SDG6.1, as non-piped water supplies, such as wells fitted with handpumps, are included in monitoring progress towards the achievement of on-premises water. To date, however, those making public policy have been reluctant to embrace the challenge of achieving widespread piped on-premises water, and the WaSH community has not provided evidence and persuasive arguments for the investments needed.

A similar argument applies to WaSH (and indeed hygiene more generally) in healthcare settings. This represents a no-regrets investment, given its benefits in reducing healthcare-acquired infections. Despite the self-evident priority, when WHO developed its *Essential Environmental Health Standards in Health Care* (Adams *et al.* 2008), the effort relied on a sparse evidence base and therefore necessarily on expert opinion. Despite the essential importance of environmental health in healthcare, the first attempt to assess the situation globally was made only in 2015 (Cronk & Bartram 2015). Improving WaSH in healthcare facilities will be central to achieving universal health coverage.

It is important that WaSH be better integrated into initiatives to improve understanding of community infection before robust tests and large-scale testing of persons becomes available. For example, there have been rapidly implemented initiatives (Ahmed *et al.* 2020; Medema *et al.* 2020; Nemudryi *et al.* 2020; Randazzo *et al.* 2020; Wu *et al.* 2020b) in surveillance for SARS-CoV-2 in community wastewater to inform public health decision-making around general and local responses, such as physical distancing and quarantines. Such approaches have been demonstrated for polio virus (Hovi *et al.* 2001). Preliminary evidence suggests that such monitoring can identify the presence of SARS-CoV-2 before the detection of clinical cases, in part because asymptomatic cases shed SARS-CoV-2. These approaches should be part of pandemic preparedness.

In some countries, responses to COVID have included closing public toilets. They represent the only practical means for handwashing where hand sanitiser is not available or used, and for those travelling (e.g. for work or to purchase necessities) and are the primary resort of the homeless for sanitation and hygiene. Whether such closures are justified based on the balance between facilitating hygiene and surface contact risk is poorly understood, as are the means to minimise the latter.

A cross-cutting concern is the need for the sometimes insular 'WaSH sector' to engage more extensively and effectively with other 'sectors' and professional communities. The constrained scope of WaSH means engagement in the prevention of disease emergence and in emergency preparedness is slight. This is also manifest in prevention through adequate WaSH in healthcare facilities and is applicable to transport, workplaces, schools and care for the elderly. Understanding the specific roles of the health sector in relation to WaSH, as described by Rehfuess *et al.* (2009), can inform effective engagement.

WASH IN PREPAREDNESS AND RESPONSE TO FUTURE PANDEMICS

The prevention and control of pandemics is a common good – it merits support because of the significance to the population at large as well as individual benefits. This is more than a conceptual issue – history shows that then-unprecedented investment in public water and sanitation systems in eighteenth-century Europe were elicited by self-preservation by the wealthy against diseases that showed no respect for class or wealth (Hamlin 1998). History also shows that, in the face of existential threats, there is a strong appetite for public expenditure and that speedy transformational investments can be made.

The introduction of this pandemic prevention and response perspective to WaSH modifies and expands the SDG commitments. Firstly, it highlights and confirms the targets adopted for household level access to water to support the called-for hygiene behaviours. However, here we call for the target and its monitoring to be upgraded to piped water on premises and for discontinuous piped supply to be aggressively tackled. Secondly, common-good arguments have been made for sanitation (Langford *et al.* 2017) as well as water supply and can be extended to goods such as soap during times of pandemic threat. Thirdly, a pandemic perspective and common-good outlook call attention to the meaning of 'universal' which must embrace all populations including homeless shelters, prisons, orphanages, refugee and internally displaced persons camps, schools and all settings of human interaction, especially those related to transport and necessary for sustaining populations during pandemic response, e.g. markets.

International governance and coordination for WaSH fit for pandemic prevention and response

Pandemic diseases present specific challenges for governance and coordination. Their nature encourages political responses that are temporary, despite the opportunities for no-regrets actions and long-term legacy benefits, such as improvement of existing facilities or new infrastructure.

The present international public health arrangements were founded in large part on the need for an international perspective on pandemic prevention and control, including ensuring that measures taken do not unnecessarily interfere with international travel and trade. In relation to pandemic preparedness and response, the principal roles of the international system are performed by the World Health Organization. The approach adopted, however, has changed when comparing between the assertive stance taken by the organization to the SARS pandemic under the leadership of Gro Harlem Brundtland and the 'technical advisor to national governments' stance of her successors.

In the field of WaSH, WHO's relevant activities include global monitoring and normative (standard setting), convening to advance the state of knowledge, informing evidence-based intervention options and identifying new and emerging threats. Through the World Health Assembly and the organisation's headquarters, regional and country offices, it has substantively influenced progressive development of WaSH under 'normal circumstances' in low-, medium- and high-income countries, especially through its normative work ('guidelines'), and global monitoring (JMP, with UNICEF). We call for this 'normal circumstances' perspective to be accompanied by a greater focus on WaSH in preparedness for and response to known, re-emerging and newly emerging diseases. This would require engagement with other components of the organisation, of the UN system and professional bodies, and extending beyond narrow health or WaSH constituencies, which would be facilitated by WHO's convening role.

Financing and instruments

A common thread from repeated outbreaks concerns finance, and in particular, the role of public financing from tax revenues. The common-good justification for public finance in pandemics is that people who cannot purchase sufficient soap and water pose a public health risk to society.

There is a major water and sanitation infrastructure deficit in many countries, particularly because of the evident need for water piped on-premises. Investments in water supply infrastructure by households, governments and development partners will be a critical part of the solution. The 2019 GLAAS report (WHO 2019) notes a funding shortfall across WaSH, with low- and middle-income countries reporting between 0.08 and 2.54% of GDP invested in WaSH. Grant funding from official development assistance, foundations and charities and loans from international sources accounted for 12% of finance in 2016–2018. To properly prepare for pandemics, governments must increase their spending on WaSH and target investment on achieving universal access to piped water on-premises. It is also clear that the international development community must reaffirm its commitment to WaSH in both policy engagement and investment.

There is a fundamental misalignment between crisis responses to pandemics and the long-term outlooks: for infrastructure-heavy investments in water supply and sanitation, for building sustained behaviours and for resilient production and supply chains for household consumables. While most of the services shortfalls are in low- and middle-income countries (e.g. Foster *et al.* 2019); they affect under-served populations in high-income countries, such as the homeless.

Even where infrastructure and services exist many people, particularly poorer households, are priced out of water services. A view, commonly held since the 1980s, is that operational and consumption subsidies in WaSH undermine service sustainability (Yepes 1999; Foster *et al.* 2000, 2002; Brook & Smith 2001). In large part, this is because consumption subsidies primarily benefit wealthier households and communities because of poor subsidy design and weak governance (Andres *et al.* 2019). The principles of a good subsidy design are a clear policy intention, appropriate targeting, financial sustainability and transparency.

There is a strong argument for providing free soap to all poor and low-income families during the active phase pandemics, either through supply-side subsidy (i.e. public funding of distribution to reduce cost) or demand side (through providing poor families funds to purchase soap). Where households cannot afford to connect to a utility water supply that has the capacity to meet greater demand, or where the capacity of the water supply is being increased to serve more people, cash transfers may be appropriate. Conditional cash transfers have successfully improved nutrition, including in humanitarian settings (Fernald *et al.* 2008; Fernald *et al.* 2009; Renzaho *et al.* 2019; Kurdi *et al.* 2020) and in health and education (Lomeli 2008; Mostert & Vall Costello 2020). Renzaho *et al.* (2018), in evaluating an enhanced unconditional cash transfer scheme in Nepal, found increased use of protected water sources and de Groot *et al.* (2017) noted positive impacts on WaSH from conditional cash transfer focused on nutrition.

Evidence needs and research priorities

Encouraging adequate hand hygiene requires both access to washing materials (water and soap) and appropriate behaviours. Responses that target either in isolation are likely to be ineffective and may be unwelcome. Behaviour change theory is integral in successfully promoting handwashing behaviour change and moving beyond 'information' focused communication; however, there is only emerging understanding of its effective application. In healthcare settings, only recently, have behaviour change theories been applied to hand hygiene among healthcare workers. Newer approaches, such as nudge-based interventions, have been explored in institutional settings (Caris *et al.* 2018; Grover *et al.* 2018), but the extent to which these can complement message-based interventions requires exploration. Given the focus of most hygiene behaviour change programmes on faecal–oral transmission, there are substantive data gaps about psychological, social and habitual drivers of respiratory hygiene.

While introspection within WaSH has focused research on broad questions such as determining the reduction in diarrhoeal or respiratory disease attributable to handwashing, the results of such studies are confounded by the diversity of pathogens and pathogen classes and their differing responses. Wolfe *et al.* (2017) noted the sparse evidence base for the inactivation and removal of specific pathogens from hands. Hygiene in relation to respiratory infections is insufficiently understood despite its importance in SARS control and in preventing acute respiratory infections (Luby *et al.* 2005; Fung & Cairncross 2006). Handwashing among carers-of-adults has received little attention from WaSH professionals, yet in a response in which much 'care' is in fact household level without resort to trained health professionals, such guidance is essential.

The exigencies of contact minimisation to reduce transmission demand changes in individual behaviours, operational activities and infrastructure design. Using the example of public toilet and handwashing facilities, more attention has been paid to behaviours and operations than to technology aspects; and where design has been considered, more attention has been paid to high-income settings (such as no-contact taps and door handles) and less to the application of these principles elsewhere. Research is needed on how better toilet and handwashing technology can be deployed in low- and middle-income countries.

Despite the potential for cash transfers to deliver demand-side subsidies to increase the access to soap and water, the evidence base on how to structure programmes, the elements to target, integration with existing schemes targeting different behaviours and the use of new technology for transfer delivery, is sparse.

CONCLUSIONS

COVID-19 is only the most recent emerging infectious disease with pandemic potential. Concerns over pandemics since the 1800s provided an impetus for the development of the science of public health and systems of international governance of public health – a history in WaSH has played important and at times foundational roles.

The pandemic highlights that adequate hygiene and access to safe and reliable water and sanitation are essential to preparedness, prevention and response; as well as protecting human life at other times. There is a widespread implicit assumption by policy-makers and health planners that they can call on a 'WaSH sector' that is able to respond to information needs and to provide basic services to support pandemic control. This is manifestly incorrect in many countries.

In the current pandemic, we have seen water supply treated as an essential service; however, there is little evidence for policy responses to increase access to, or reduce intermittence in, supply that would support households in accessing sufficient water and sustaining the handwashing required. Reliance on communal water sources lessens the ability to adopt physical distancing and prevents households reliant on such sources from self-isolating. These are policy failures within the WaSH sector and in wider public policy. They arise from structural deficiencies that result in poor planning, weak governance, mis-focused prioritisation and under-investment. Financing instruments that could help reduce inequalities in service provision should be urgently considered.

Ensuring universal access to safe and reliable water, hygiene and sanitation services for all populations and in all settings is justified: from both a common-good perspective, for pandemic preparedness, and as 'no regrets' longevity use of resources mobilised during pandemic response. Both success and failure in these endeavours will disproportionately affect (benefit or undermine the precarious conditions of) the poor and the vulnerable. Action solely at the time of need cannot provide a sufficient response, long-term investment and engagement with key actors and stakeholders are essential to both preparedness and response.

COVID-19 exemplifies the critical need for safe healthcare facilities. Some responses will involve temporary treatment centres, with associated full WaSH facilities. One consequence is that investments to improve WaSH in stressed existing facilities may be perceived as less critical. However, upgrading of existing facilities would provide a lasting beneficial legacy from the pandemic. Funding and management of WaSH in healthcare facilities are challenged by mixed financing and responsibilities between healthcare and WaSH. We call for concerted action and investment in improving the environmental health and hygiene of all healthcare facilities as an integral part of universal health coverage and to meet SDG 3.

Even in high-income countries, bureaucratic, regulatory and academic silos undermine effective WaSH action through inadequate common understanding and knowledge exchange among professionals, such as public health decision-makers, health scientists and engineers. The examples provided throughout this paper highlight the precarious evidence base underlying much WaSH activity and illustrate its deficiency when deployed to other stakeholder groups in relation to pandemic response. The WaSH sector is weak at relating risks it recognises to the risks identified in other sectors. We call on research funders to invest in high-quality, comparable research that targets key decision-critical unknowns, supported by coordination and timely synthesis of findings.

COVID-19 reminds us that hygiene, safe water and sanitation are essential to protect human life. Short-term action should rapidly ensure that everyone can access sufficient water and soap to practice good hygiene and hygiene facilities are available in all public places. In the medium term, a priority is reliable sustained water supplies and sanitation systems that meet enhanced SDG targets, as we propose here. In the long term, WaSH systems must be sustainable and resilient to future threats, including those associated with climate change, and contribute to preparedness for, prevention of and response to pandemic disease.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

REFERENCES

Adams, J., Bartram, J. & Chartier, Y. 2008 *Essential Environmental Health Standards in Health Care*. World Health Organisation, Geneva. Available from: https://www.who.int/water_sanitation_health/publications/ehs_hc/en/

Ahmed, W., Angel, N., Edson, J., Bibby, K., Bivins, A., O'Brien, J. W., Choi, P. M., Kitajima, M., Simpson, S. L., Li, J., Tscharke, B., Verhagen, R., Smith, W. J. M., Zaugg, J., Dierens, L., Hugenholtz, P., Thomas, K. V. & Mueller, J. F. 2020 First confirmed detection of SARS-CoV-2 in untreated wastewater in Australia: a proof of concept for the wastewater surveillance of COVID-19 in the community. *Science of the Total Environment* **748**. doi:10.1016/j.scitotenv.2020.138764.

Allen, T., Murray, K. A., Zambrana-Torrelio, C., Morse, S. S., Rondinini, C., Di Marco, M., Breit, N., Olival, K. J. & Daszak, P. 2017 Global hotspots and correlates of emerging zoonotic diseases. *Nature Communications* **8**, 1124.

Andres, L. A., Thibert, M., Cordoba, C. L., Danilenko, A. V., Joseph, G. & Borja-Vega, C. 2019 *Doing More with Less: Smarter Subsidies for Water Supply and Sanitation.* World Bank, Washington, DC.

Ashraf, S., Nizame, F. A., Islam, M., Dutta, N. C., Yeasim, D., Akhter, S., Abedin, J., Winch, P. J., Ram, P. K., Unicomb, L., Leonstini, E. & Luby, S. 2017 Nonrandomized trial of feasibility and acceptability of strategies for promotion of soapy water as a handwashing agent in rural Bangladesh. *American Journal of Tropical Medicine and Hygiene* **96** (2), 421–429. doi:10.4269/ajtmh.16-0304.

Azor-Martínez, E., Gonzalez-Jimenez, Y., Seijas-Vazquez, M. L., Cobos-Carrascosa, E., Santisteban-Martínez, J., Martínez-López, J. M., Jimenez-Noguera, E., del Mar Galan-Requena, M., Garrido-Fernández, P., Strizzi, J. M. & Gimenez-Sanchez, F. 2014 The impact of common infections on school absenteeism during an academic year. *American Journal of Infection Control* **42** (6), 632–637. doi:10.1016/j.ajic.2014.02.017.

Banner-Shackelford, B., Cronk, R., Behnke, N., Cooper, B., D'Souza, M., Tu, R., Bartram, J., Schweitzer, R. & Jaff, D. 2020 Environmental health in forced displacement: a systematic scoping review of the emergency phase. *Science of the Total Environment* **714**, 136553.

Behnke, N., Cronk, R., Snel, M., Moffa, M., Tu, R., Banner, B., Folz, C., Anderson, D., McIntyre, A., Stowe, E. & Bartram, J. 2018 Improving environmental conditions for involuntarily displaced populations: water, sanitation, and hygiene in orphanages, prisons, and refugee and IDP settlements. *Journal of Water Sanitation and Hygiene for Development* **8** (4), 785–791. doi:10.2166/washdev.2018.019.

Behnke, N., Cronk, R., Banner, B., Cooper, B., Tu, R., Heller, L. & Bartram, J. 2020 Environmental health conditions in protracted displacement: a systematic scoping review. *Science of the Total Environment* **726**, 138234.

Berendes, D. M., Yang, P. J., Lai, A., Hu, D. & Brown, J. 2018 Estimation of global recoverable human and animal faecal biomass. *Nature Sustainability* **1**, 679–685.

Bi, Q., Wu, Y., Mei, S., Ye, C., Zou, X., Zhang, Z., Liu, X., Wei, L., Truelove, S. A., Zhang, T., Gao, W., Cheng, C., Tang, X., Wu, X., Wu, Y., Sun, B., Huang, S., Sun, Y., Zhang, J., Ma, T., Lessler, J. & Fe, T. 2020 Epidemiology and transmission of COVID-19 in 391 cases and 1286 of their close contacts in Shenzhen, China: a retrospective cohort study. *Lancet Infectious Disease*. doi:10.1016/S1473-3099(20)30287-5.

Brauer, M., Zhao, J. T., Bennitt, F. B. & Stanaway, J. D. 2020 Global access to handwashing: implications for COVID-19 control in low-income countries. *Environmental Health Perspectives* **128**(5). Doi:10.1289/EHP7200.

Brook, P. & Smith, W. 2001 *Improving Access to Infrastructure Services by the Poor: Institutional and Policy Responses.* World Bank, Washington, DC, USA.

Caris, M. G., Labuschagne, H. A., Dekker, M., Kramer, M. H. H., van Agtmael, M. A. & Vandenbroucke-Grauls, C. M. J. E. 2018 Nudging to improve hand hygiene. *Journal of Hospital Infection* **98** (4), 352–358. doi:10.1016/j.jhin.2017.09.023.

Carroll, D., Daszak, P., Wolfe, N. D., Gao, G. F., Morel, C. M., Morzaria, S., Pablos-Méndez, A., Tomori, O. & Mazet, J. A. K. 2018 The global virome project. *Science* **359** (6378), 872–874. doi:10.1126/science.aap7463.

Cascella, M., Rajnik, M., Cuomo, A., Dulebohn, S. C. & Di Napoli, R. 2020 *Features, Evaluation and Treatment Coronavirus (COVID-19).* StatPearls Publishing, Treasure Island, FL. Available from: https://www.ncbi.nlm.nih.gov/books/NBK554776 [Updated 2020 Apr 6].

Chin, A. W. H., Chu, J. T. S., Perera, M. R. A., Hui, K. P. Y., Yen, H.-L., Chan, M. C. W., Peiris, M. & Poon, L. L. M. 2020 Stability of SARS-CoV-2 in different environmental conditions. *Lancet Microbe.* doi:10.1016/ S2666-5247(20)30003-3.

Contzen, N., Meili, I. H. & Mosler, H.-J. 2015 Changing handwashing behaviour in southern Ethiopia: a longitudinal study on infrastructural and commitment interventions. *Social Science and Medicine* **124**, 103–114. doi:10.1016/j.socscimed.2014.11.0060277-9536.

Cooper, B., Cronk, R., Behnke, N. L., Anthonj, C., Shackelford, B. B., Tu, R. & Bartram, J. Submitted Environmental health conditions in the transitional stage of forcible displacement: a systematic scoping review. *Paper Submitted to Science of the Total Environment*.

Costa, F., Carvalho-Pereira, T., Begon, M., Riley, L. & Childs, J. 2017 Zoonotic and vector-borne diseases in urban slums: opportunities for intervention. *Trends in Parasitology* **33** (9), 660–662.

Cotruvo, J. A., Dufour, A., Rees, G., Bartram, J., Carr, R., Cliver, D. O., Craun, G. F., Feyer, R. & Gannon, V. P. J. (eds) 2004 *Waterborne Zoonoses: Identification, Causes and Control.* IWA Publishing, London and WHO, Geneva, p. 560.

Coultas, M., Iyer, R. & Myers, J. 2020 *Handwashing Compendium for Low Resource Settings: A Living Document, Edition 1, The Sanitation Learning Hub.* IDS, Brighton.

Cronk, R. & Bartram, J. 2015 *Water, Sanitation and Hygiene in Health Care Facilities: Status in Low- and Middle-Income Countries and Way Forward.* World Health Organization, Geneva. Available from: https://www.who.int/water_sanitation_health/publications/wash-health-care-facilities

Cronk, R. & Bartram, J. 2018 Environmental conditions in health care facilities in low- and middle-income countries: coverage and inequalities. *International Journal of Hygiene and Environmental Health* **221** (3), 409–422.

Cronk, R., Slaymaker, T. & Bartram, J. 2015 Monitoring drinking-water sanitation and hygiene in non-household settings: priorities for policy and practice. *International Journal of Hygiene and Environmental Health* **218**, 694–703. doi:10.1016/j.ijheh.2015.03.003.

de Groot, R., Palermo, T., Handa, S., Ragno, L. P. & Peterman, A. 2017 Cash transfers and child nutrition: pathways and impacts. *Development Policy Review* **35**, 621–643. doi:10.1111/dpr.12255.

D'Mello-Guyett, L., Gallandat, K., Van den Bergh, R., Taylor, D., Bulit, G., Legros, D., Maes, P., Checchi, F. & Cumming, O. 2020 Prevention and control of cholera with household and community water, sanitation and hygiene (WaSH) interventions: a scoping review of current international guidelines. *PLoS One* **15** (1), e0226549. doi:10.1371/journal.pone.0226549.

Dufour, A., Bartram, J., Bos, R. & Gannon, V. (eds) 2012 *Animal Waste, Water Quality and Human Health.* IWA-Publishing, London on behalf of the World Health Organization.

Faye, O., Boëlle, P.-Y., Heleze, E., Faye, O., Loucouber, C., Magassouba, N., Soropogue, B., Keita, S., Gakou, T., Bah, E. H. I., Koivpogui, L., Sal, A. A. & Cauchemez, S. 2015 Chains of transmission and control of Ebola virus disease in Conakry, Guinea, in 2014: an observational study. *Lancet Infectious Disease* **15**, 320–326. doi:10.1016/S1473-3099(14)71075-8.

Fernald, L. C. H., Gertler, P. J. & Neufeld, L. M. 2008 Role of cash in conditional cash transfer programmes for child health, growth, and development: an analysis of Mexico's oportunidades. *Lancet* **371** (9615), 828–837. doi:10.1016/S0140-6736(08)60382-7.

Fernald, L. C. H., Gertler, P. C. J. & Neufeld, L. M. 2009 10-year effect of oportunidades, Mexico's conditional cash transfer programme, on child growth, cognition, language, and behaviour: a longitudinal follow-up study. *Lancet* **374** (9706), 1997–2005. doi:10.1016/S0140-6736(09)61676-7.

Foster, V., Gomez-Lobo, A. & Halpern, J. 2000 *Designing Direct Subsidies for the Poor – A Water and Sanitation Case Study*. Note No. 211. Public Policy for the Private Sector. The World Bank, Washington, DC, USA.

Foster, V., Pattanayak, S. & Stalker-Prokopy, L. 2002 *Distributional Incidence of Current and Potential Water tariffs and Subsidies in Bangalore, India and Kathmandu, Nepal*. WSP World Bank, Washington, DC, USA.

Foster, T., Furey, S., Banks, B. & Willetts, J. 2019 Functionality of handpump water supplies: a review of data from sub-Saharan Africa and the Asia-Pacific region. *International Journal of Water Resources Development* doi:10.1080/07900627.2018.1543117.

Fung, I. C.-H. & Cairncross, S. 2006 Effectiveness of handwashing in preventing SARS: a review. *Tropical Medicine and International Health* **11** (11), 1749–1758. doi:10.1111/j.1365-3156.2006.01734.x.

Godoy, P., Castilla, J., Delgado-Rodríguez, M., Martín, V., Soldevila, N., Alonso, J., Astray, J., Baricot, M., Cantón, R., Castro, A., González-Candelas, F., Mayoral, J. M., Quintana, J. M., Pumarola, T., Tamames, S. & Domínguez, A. 2012 Effectiveness of hand hygiene and provision of information in preventing influenza cases requiring hospitalization. *Preventive Medicine* **54** (6), 434–439. doi:10.1016/j.ypmed.2012.04.009.

Grais, R. F., Ellis, J. H. & Glass, G. E. 2020 Assessing the impact of airline travel on the geographic spread of pandemic influenza. *European Journal of Epidemiology* **18** (11), 1065–1072. doi:10.1023/A:1026140019146.

Grover, E., Hossain, M. K., Uddin, S., Venkatesh, M., Ram, P. K. & Dreibelbis, R. 2018 Comparing the behavioural impact of a nudge-based handwashing intervention to high-intensity hygiene education: a cluster-randomised trial in rural Bangladesh. *Tropical Medicine and International Health* **23** (1), 10–25. doi:10.1111/tmi.12999.

Guo, W., Cronk, R., Scherer, E., Oommen, R., Brogan, J., Sarr, M. M. & Bartram, J. 2019 A systematic review of environmental health conditions in penal institutions. *International Journal of Hygiene and Environmental Health* **222** (5), 790–803. doi:10.1016/j.ijheh.2019.05.001.

Hamlin, C. 1998 *Public Health and Social Justice in the Age of Chadwick*. Cambridge University Press, UK.

Hellewell, J., Abbott, S., Gimma, A., Bosse, N. I., Jarvis, C. I., Russell, T. W., Munday, J. D., Kucharski, A. J., Edmunds, W. J., Centre for the Mathematical Modelling of Infectious Diseases COVID-19 Working GroupFunk, S. & Eggo, R. M. 2020 Feasibility of controlling COVID-19 outbreaks by isolation of cases and contacts. *Lancet Global Health* **8** (4), e488–e496. doi:10.1016/S2214-109X(20)30074-7.

Hovi, T., Stenvik, M., Partenan, H. & Kangas, A. 2001 Poliovirus surveillance by examining sewage specimens. quantitative recovery of virus after introduction into sewerage at remote upstream location. *Epidemiology and Infection* **127**, 101–106.

Howard, G. & Bartram, J. 2003 *Domestic Water Quantity, Service Level and Health*. World Health Organization, Sustainable Development and Healthy Environments, SDE/WSH/03.02, Geneva, Switzerland.

Howard, G., Bartram, J., Williams, A. R., Overbo, A., Geere, J.-A. & Fuente, D. in press *Domestic Water Quantity, Accessibility and Health*, 2nd edn. World Health Organisation, Geneva.

Hrudey, S. E. & Hrudey, E. J. 2004 *Safe Drinking Water – Lessons From Recent Outbreaks in Affluent Nations*. IWA Publishing, London, p. 514.

IES 2020 *IES Committee Report: Germicidal Ultraviolet (GUV) – Frequently Asked Questions*. Illuminating Engineering Society. Available from: https://www.igvlift.com/wp-content/uploads/2020/05/IES-CR-2-20-V1-6d-1.pdf.

Janes, C., Corbet, K. K., Jones, J. H. & Trostle, J. 2012 Emerging infectious diseases: the role of social sciences. *The Lancet* **380** (9857), P1884–P1886. doi:10.1016/S0140-6736(12)61725-5.

Jones, K. E., Patel, N. G., Levy, M. A., Storeygard, A., Balk, D., Gittleman, J. L. & Daszak, P. 2008 Global trends in emerging infectious diseases. *Nature* **451** (7181), 990–993. doi:10.1038/nature06536.

Kamar, N., Dalton, H. R., Abravanel, F. & Izopet, J. 2014 Hepatitis E virus infection. *Clinical Microbiology Reviews* **27** (1), 116–138. doi:10.1128/CMR.00057-13.

Kratzel, A., Todt, D., V'kovski, P., Steiner, S., Gultom, M. L., Thao, T. T. N., Ebert, N., Holwerda, M., Steinmann, J., Niemeyer, D., Dijkman, R., Kampf, G., Drosten, C., Steinmann, E., Thiel, V. & Pfaender, S. 2020 Efficient inactivation of SARS-CoV-2 by WHO-recommended hand rub formulations and alcohols. *BioRxiv* doi:10.1101/2020.03.10.986711.

Kumar, S., Loughman, L., Luyendijk, R., Hernandez, O., Weinger, M., Arnold, F. & Ram, P. K. 2017 Handwashing in 51 countries: analysis of proxy measures of handwashing behavior in multiple indicator cluster surveys and demographic and health surveys, 2010–2013. *The American Journal of Tropical Medicine and Hygiene* **97** (2), 447–459. doi:10.4269/ajtmh.16-0445.

Kumpel, E. & Nelson, K. L. 2016 Intermittent water supply: prevalence, practice, and microbial water quality. *Environmental Science and Technology* **50**, 542–553. doi:10.1021/acs.est.5b03973.

Kurdi, S., Fugueroa, J. L. & Ibrahim, H. 2020 Nutritional training in a humanitarian context: evidence from a cluster randomized trial. *Maternal and Child Nutrition* e12973. doi:10.1111/mcn.12973.

Langford, M., Bartram, J. & Roaf, V. 2017 Revisiting dignity: the human right to sanitation. In: *The Human Right to Water: Theory, Practice and Prospects (*M. Langford & A. Russell, ed.). Cambridge University Press, Cambridge.

Laurencin, C. T. & McClinton, A. 2020 The COVID-19 pandemic: a call to action to identify and address racial and ethnic disparities. *Journal of Racial and Ethnic Health Disparities* **18**, 1–5. doi:10.1007/s40615-020-00756-0.

Lee, K. & Dodgson, R. 2000 Globalization and cholera: implications for global governance. *Global Governance* **6** (2), 213–236.

Leung, K., Wu, J. Y., Liu, D. & Leung, G. M. 2020 First-wave COVID-19 transmissibility and severity in China outside hubei after control measures, and second-Wave scenario planning: a modelling impact assessment. *Lancet* **395** (10233), 1382–1393. doi:10.1016/S0140-6736(20)30746-7.

Li, X., Zai, J., Zhao, Q., Nie, Q., Li, Y., Foley, B. T. & Chaillon, A. 2020 Evolutionary history, potential intermediate animal host, and cross-species analyses of SARS-CoV-2. *Journal of Medical Virology* **92**, 602–611. doi:10.1002/jmv.25731.

Lomeli, E. V. 2008 Conditional cash transfers as social policy in Latin America: an assessment of their contributions and limitations. *Annual Review of Sociology* **34**, 475–499.

Luby, S. P., Agboatwalla, M., Feikin, D. R., Painter, J., Billhimer, W., Altaf, A. & Hoekstra, R. M. 2005 Effect of hand washing on children's health: a randomised controlled trial. *Lancet* **366**, 225–233.

MacKenzie, W. R., Hoxie, N. J., Proctor, M. E., Gradus, S., Blair, K. A., Peterson, D. E., Kazmeirczak, J. J., Addiss, D. G., Fox, K. R., Rose, J. B. & Davies, J. P. 1994 A massive outbreak in Milwaukee of cryptosporidium infection transmitted through the public water supply. *New England Journal of Medicine* **331** (3), 161–167.

Majuru, B., Suhrcke, M. & Hunter, P. R. 2016 How Do households respond to unreliable water supplies? A systematic review. *International Journal of Environmental Research and Public Health* **13** (12), 1222.

Mbakaya, B. C., Lee, P. H. & Lee, R. L. T. 2017 Hand hygiene intervention strategies to reduce diarrhoea and respiratory infections among schoolchildren in developing countries: a systematic review. *International Journal of Environmental Research and Public Health* **14** (4), 371. doi:10.3390/ijerph14040371.

McKinney, K. R., Yu, Y. G. & Lewis, T. G. 2006 Environmental transmission of SARS at amoy gardens. *J. Environ. Health.* **68** (9), 26–30.

Medema, G., Heijnen, L., Elsinga, G., Italiaander, R. & Brouwer, A. 2020 Presence of SARS-Coronavirus–2 RNA in sewage and correlation with reported COVID-19 prevalence in the early stage of the epidemic in the Netherlands. *Environmental Science & Technology Letters*. doi:10.1021/acs.estlett.0c00357.

Merk, H., Kühlmann-Berenzon, S., Linde, A. & Nyrén, O. 2014 Associations of hand-Washing frequency with incidence of acute respiratory tract infection and influenza-Like illness in adults: a population-based study in Sweden. *BMC Infectious Disease* **14**, 509. doi:10.1186/1471-2334-14-509.

Mhalu, F. S., Mtango, F. D. E. & Msengi, E. 1984 Hospital outbreaks of cholera transmitted through close person-to-Person contact. *Lancet* **324** (8394), 82–84. doi:10.1016/S0140-6736(84)90250-2.

Moffa, M., Cronk, R., Padilla, L., Fejfar, D., Dancausse, S. & Bartram, J. 2018 A systematic review of environmental health conditions and hygiene behaviors in homeless shelters. *International Journal of Hygiene and Environmental Health* **222** (3), 335–346. doi:10.1016/j.ijheh.2018.12.004.

Moffa, M., Cronk, R., Fejfar, D., Dancausse, S., Padilla, L. & Bartram, J. 2019 A systematic scoping review of hygiene behaviors and environmental health conditions in institutional care settings for orphaned and abandoned children. *Science of the Total Environment* **658**, 1161–1174. doi:10.1016/j.scitotenv.2018.12.286.

Morens, D. M. & Fauci, A. S. 2013 Emerging infectious diseases: threats to human health and global stability. *PLoS Pathology* **9** (7), e1003467. doi:10.1371/journal.ppat.1003467.

Morse, S. S., Mazet, J. A., Woolhouse, M., Parrish, C. R., Carroll, D., Karesh, W. B., Zambrana-Torrelio, C., Lipkin, W. I. & Daszak, P. 2012 Prediction and prevention of the next pandemic zoonosis. *Lancet* **380** (9857), 1956–1965. doi:10.1016/S0140-6736(12)61684-5.

Mostert, C. M. & Vall Castello, J. 2020 Long run educational and spillover effects of unconditional cash transfers: evidence from South Africa. *Economics and Human Biology* **36**, 100817.

Nemudryi, A., Nemudraia, A., Surya, K., Wiegand, T., Buyukyoruk, M., Wilkinson, R. & Wiedenheft, B. 2020 Temporal detection and phylogenetic assessment of SARS-CoV-2 in municipal wastewater. *medRxiv*. doi:10.1101/2020.04.15.20066746.

OHCHR 2020 Available from: https://www.ohchr.org/EN/NewsEvents/Pages/DisplayNews.aspx?NewsID=25794.

Plowright, R. K., Parrish, C. R., McCallum, H., Hudson, P. J., Ko, A. I., Graham, A. L. & Lloyd-Smith, J. O. 2017 Pathways to zoonotic spillover. *Nature Reviews Microbiology* **15** (8), 502–510. doi:10.1038/nrmicro.2017.45.

Prendergast, A. J., Gharpure, R., Mor, S., Viney, M., Dube, K., Lello, J., Berger, C., Siwila, J., Joyeux, M., Hodobo, T., Hurst, L., Brown, T., Hoto, P., Tavengwa, N., Mutasa, K., Craddock, S., Chasekwa, B., Robertson, R. C., Evans, C., Chidhanguro, D., Mutasa, B., Majo, F., Smith, L. E., Hirai, M., Ntozini, R., Humphrey, J. H. & Berendes, D. 2019 Putting the 'A' into WaSH: a call for integrated management of water, animals, sanitation, and hygiene. *Lancet Planetary Health* **3** (8), e336–e337. doi:10.1016/S2542-5196(19)30129-9.

Prüss-Ustün, A., Wolf, J., Bartram, J., Clasen, T., Cumming, O., Freemanc, M. C., Gordon, B., Hunter, P. R., Medlicott, K. & Johnston, R. 2019 Burden of disease from inadequate water, sanitation and hygiene for selected adverse health outcomes: an updated analysis with a focus on low and middle-income countries. *International Journal of Hygiene and Environmental Health* **222**, 765–777. doi:10.1016/j.ijheh.2019.05.004.

Rabie, T. & Curtis, V. 2006 Handwashing and risk of respiratory infections: a quantitative systematic review. *Tropical Medicine and International Health* **11** (3), 258–267.

Raftelis 2020 *The Financial Impact of the COVID-19 Crisis on U.S. Drinking Water Utilities*. Report prepared for the American Water Works Association and the Association of Metropolitan Water Agencies. Available from: https://aquadoc.typepad.com/files/awwa-covid-report_2020-04_final.pdf

Randazzo, W., Truchado, P., Cuevas-Ferrando, E., Simón, P., Allende, A. & Sánchez, G. 2020 SARS-CoV-2 RNA in wastewater anticipated COVID-19 occurrence in a low prevalence area. *Water Research*. doi:10.1016/j.watres.2020.115942.

Rehfuess, E. A., Bruce, N. & Bartram, J. K. 2009 More health for your buck: health sector functions to secure environmental health. *Bulletin of the World Health Organisation* **87** (11), 880–882.

Renzaho, A., Chitekwe, S., Chen, W., Rijal, S., Dhakal, T., Chikazaza, I. R. & Dahal, P. 2018 Impact of a multidimensional child cash grant programme on water, sanitation and hygiene in Nepal. *Journal of Water, Sanitation and Hygiene for Development* **8** (3), 520–532.

Renzaho, A. M. N., Chen, W., Rijal, S., Dahal, P., Chikazaza, I. R., Dhakal, T. & Chitek, S. 2019 The impact of unconditional child cash grant on child malnutrition and its immediate and underlying causes in five districts of the karnali zone, Nepal – A trend analysis. *Archives of Public Health* **77**, 24. doi:10.1186/s13690-019-0352-2.

Ruan, S., Wang, W. & Levin, S. A. 2005 The effect of global travel on the spread of SARS. *Mathematical Biosciences and Engineering* **3** (1), 205–218. doi:10.3934/mbe.2006.3.205.

Saunders-Hastings, P., Crispo, J. A. G., Sikora, L. & Krewskia, D. 2017 Effectiveness of personal protective measures in reducing pandemic influenza transmission: a systematic review and meta-analysis. *Epidemics* **20**, 1–20.

Simmerman, J. M., Suntarattiwong, P., Levy, J., Jarman, R. G., Kaewchana, S., Gibbons, R. V., Cowling, B. J., Sanasuttipun, W., Maloney, S. A., Uyeki, T. M., Kamimoto, L. & Chotipitayasunondh, T. 2011 Findings from a household randomized controlled trial of hand washing and face masks to reduce influenza transmission in Bangkok, Thailand. *Influenza and Other Respiratory Diseases* **5** (4), 256–267. doi:10.1111/j.1750-2659.2011.00205.x.

UNHCR 2019 *Global Trends: Forced Displacement in 2018.* United Nations High Commissioner for Refugees, Geneva. Available from: https://www.unhcr.org/5d08d7ee7.pdf

UNICEF and WHO 2018 *Drinking Water, Sanitation and Hygiene in Schools: Global Baseline Report 2018.* United Nations, New York.

UNICEF and WHO 2019 *Progress on Household Drinking Water, Sanitation and Hygiene 2000–2017. Special Focus on Inequalities.* United Nations, New York.

United Nations 2020 *COVID-19 and Human Rights We Are All in This Together*. Available from: https://www.un.org/sites/un2.un.org/files/un_policy_brief_on_human_rights_and_covid_23_april_2020.pdf.

Vuorinen, V., Aarnio, M., Alava, M., Alopaeus, V., Atanasova, N., Auvinen, M., Balasubramanian, N., Bordbarg, H., Erästöf, P., Granded, R., Haywarde, N., Hellsten, A., Hostikkag, S., Hokkanen, J., Kaario, O., Karvinen, A., Kivistöl, I., Korhonen, M., Kosonen, R., Kuusela, J., Lestinen, S., Laurila, E., Nieminen, H. J., Peltonen, P., Pokki, J., Puisto, A., Råback, P., Salmenjoki, P., Sironen, T. & Österberg, M. 2020 Modelling aerosol transport and virus exposure with numerical simulations in relation to SARS-CoV-2 transmission by inhalation indoors. *Safety Science* **130**. doi:10.1016/j.ssci.2020.104866.

Wang, R. J., Li, J. Q., Chen, Y. C., Zhang, L. X. & Xiao, L. H. 2018 Widespread occurrence of cryptosporidium infections in patients with HIV/AIDS: epidemiology, clinical feature, diagnosis, and therapy. *Acta Tropica* **187**, 257–263.

Wang, W., Xu, Y., Gao, R., Lu, R., Han, K., Wu, G. & Tan, W. 2020 Detection of SARS-CoV-2 in different types of clinical specimens. *Journal of the American Medical Association* **323** (18), 1843–1844. doi:10.1001/jama.2020.3786.

White, S., Hasund, A., Dreibelebis, T. R. & Curtis, V. 2020 The determinants of handwashing behaviour in domestic settings: an integrative systematic review. *International Journal of Hygiene and Environmental Health* **227**, 113512. doi:10.1016/j.ijheh.2020.113512.

WHO 2003a *Emerging Issues in Water and Infectious Disease.* World Health Organization, Geneva. Available from: https://apps.who.int/iris/handle/10665/42751

WHO 2003b *Guidelines From Drinking-Water Quality,* 3rd edn. World Health Organization, Geneva.

WHO 2006 *The World Health Report 2006: Working Together for Health.* World Health Organization, Geneva.

WHO 2015 *Anticipating Emerging Infectious Disease Epidemics.* World Health Organisation, Geneva. Available from: https://apps.who.int/iris/bitstream/handle/10665/252646/WHO-OHE-PED-2016.2-eng.pdf

WHO 2019 *National Systems to Support Drinking-Water, Sanitation and Hygiene: Global Status Report 2019.* UN-Water global analysis and assessment of sanitation and drinking water (GLAAS) 2019 report. World Health Organization, Geneva.

WHO 2020 *Coronavirus Disease (COVID-19) Advice for the Public.* Available from: www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public

WHO and UNICEF 2019 *WaSH in Health Care Facilities: Global Baseline Report 2019.* World Health organisation, Geneva.

Wolf, J., Johnston, R., Freeman, M. C., Ram, P. K., Slaymaker, T., Laurenz, E. & Prüss-Ustün, A. 2019 Handwashing with soap after potential faecal contact: global, regional and country estimates. *International Journal of Epidemiology* **48** (4), 1204–1218. doi:10.1093/ije/dyy253.

Wolfe, M. K., Gallandat, K., Daniels, K., Desmarais, A. M., Scheinman, P. & Lantagne, D. 2017 Handwashing and ebola virus disease outbreaks: a randomized comparison of soap, hand sanitizer, and 0.05% chlorine solutions on the inactivation and removal of model organisms phi6 and E. coli from hands and persistence in rinse water. *PLoS ONE* **12** (2), e0172734. doi:10.1371/journal.pone.0172734.

Wu, Y., Guo, C., Tang, L., Hong, Z., Zhou, J., Dong, X., Yin, H., Xiao, Q., Tang, Y. & Qu, X. 2020a Prolonged presence of SARS-CoV-2 viral RNA in faecal samples. *The Lancet Gastroenterology & Hepatology* **5** (5), 434–435.

Wu, F., Xiao, A., Zhang, G. W., Kauffman, K., Hanage, W., Matus, M., Ghaeli, N., Endo, N., Devallet, C., Moniz, K., Erickson, T., Chai, P., Thompson, J. & Alm, E. 2020b SARS-CoV-2 titres in wastewater are higher than expected from clinically confirmed cases. *medRxiv* doi:10.1101/2020.04.05.20051540.

Xu, Y., Li, X., Zhu, B., Liang, H., Fang, C., Gong, Y., Guo, Q., Sun, X., Zhao, D. & Shen, J. 2020 Characteristics of paediatric SARS-CoV-2 infection and potential evidence for persistent fecal viral shedding. *Nature Medicine* **26** (4), 502–505.

Yepes, G. 1999 *Do Cross – Subsidies Help the Poor to Benefit From Water and Wastewater Services? Lessons From Guayaquil.* WSP-World Bank, Washington, DC, USA.

Yu, I., Li, Y., Wong, T. W., Tam, W., Chan, A. T. Y., Lee, J. H. W., Leung, Y. C. & Ho, T. 2004 Evidence of airborne transmission of the severe acute respiratory syndrome virus. *New England Journal of Medicine* **350** (17), 1731–1739.

First received 26 May 2020; accepted in revised form 10 July 2020. Available online 21 July 2020