Trends in Parasitology

CellPress REVIEWS

Opinion

Tailoring Water, Sanitation, and Hygiene (WASH) Targets for Soil-Transmitted Helminthiasis and Schistosomiasis Control

Suzy J. Campbell,[1,6,*] Nana-Kwadwo Biritwum,[2] Geordie Woods,[3] Yael Velleman,[4] Fiona Fleming,[5] and J. Russell Stothard[1]

The World Health Organization's (WHO) 2015–2020 Global Strategy on water, sanitation, and hygiene (WASH) and neglected tropical diseases (NTDs) encourages integration, whilst maintaining existing structured NTD investments, and acceleration towards Sustainable Development Goal (SDG) targets. Accordingly, SDG-associated and WASH–NTD indicators have been developed, commencing important intersectoral dialogue, alongside opportunities for future disease-specific refinements. The rationale for soil-transmitted helminthiasis (STH)- and schistosomiasis-specific WASH considerations, and a traffic-light figure, are presented here to indicate where current international definitions may, or may not, suffice. Certain unique aspects in control dynamics and parasitic lifecycles, however, necessitate additional implementation research with more appropriate measurement indicators developed to record programmatic interventions and to define strategic priorities more effectively.

Trends

The World Health Organization (WHO) strongly advocates for countries to prioritise integration of WASH with preventive chemotherapy for NTD control.

The WHO's first WASH for NTDs Global Strategy 2015–2020 provides strategic objectives to accelerate NTD Roadmap targets through increased WASH–NTD integrated approaches.

Sustainable Development Goal WASH indicators were developed as strategic targets for countries to benchmark performance against, and strive to meet. Additional WASH–NTD indicators were developed as standardised programmatic measures for WASH and NTD programmes, aimed to incentivise collaboration, facilitate cross-sectoral planning, and enhance accountability between the two sectors.

Soil-transmitted helminthiasis and schistosomiasis cannot be controlled without primary prevention strategies. The development of appropriate WASH targets and indicators is an important component of the NTD agenda.

Why Integrated Control Strategies for Soil-Transmitted Helminthiasis and Schistosomiasis Are Needed

Since the early 2000s, preventive chemotherapy has been recommended by the WHO as the cornerstone control strategy for the neglected tropical diseases (NTDs) lymphatic filariasis, onchocerciasis, STH, schistosomiasis, and a major component for trachoma elimination efforts.[i] Preventive chemotherapy for STH and schistosomiasis is mainly provided by repeated mass drug administration (MDA) campaigns, usually targeting treatment to school-attending children through school-based platforms.[i] For STH and schistosomiasis, however, as reinfection can be rapid, preventive chemotherapy alone will not achieve a complete control or stable elimination endpoint. Moreover, schistosomiasis transmission can continue or re-establish from very few infected individuals who contaminate the aquatic environment and subsequently infect intermediate snail hosts that boost local infection potential by exponential release of millions of cercariae. Similarly, STH in their terrestrial stage can viably survive as eggs for up to several months (*Ascaris lumbricoides* and *Trichuris trichiura*) and as larvae for several weeks (hookworms) [1], thus maintaining the environmental transmission potential well beyond the temporal reach of chemotherapeutic intervention. Notably, the roundworm *Strongyloides*

[1]Department of Parasitology, Liverpool School of Tropical Medicine,

Pembroke Place, Liverpool, L3 5QA, UK
[2]National Neglected Tropical Disease Control Programme, Ghana Health Services, Accra, Ghana
[3]Sightsavers, Haywards Heath, RH16 3BW, UK
[4]WaterAid, London, SE11 5JD, UK
[5]Schistosomiasis Control Initiative, Imperial College, London, W2 1PG, UK
[6]Present address: Deworm the World Initiative, Evidence Action, Brisbane, 4020, Australia

*Correspondence: suzy.campbell@evidenceaction.org (S. J. Campbell).

stercoralis has a nonparasitic cycle that can be independently sustained in the environment. Over a billion people with low socioeconomic status live in environments where inadequate water and sanitation infrastructure and unsafe **hygiene** (see Glossary) practices means a constant risk of infection from these parasites. Given country-level resources, any declining international funding or breaks in funding, including for drug deliveries, could jeopardise the gains made with preventive chemotherapy [2], and significantly curtail global progress. Investing resources in WASH and other strategies will augment preventive chemotherapy to have the greatest impact towards WHO Roadmap[i] targets.

Unlike other NTDs targeted by preventive chemotherapy, for STH and schistosomiasis, the approach has been framed as either **morbidity control**, or as **transmission control**, and in many areas there can be problems in reaching target populations and sustaining satisfactory progress with this strategy alone. Recent modelling indicates that preventive chemotherapy for schoolchildren may break STH and schistosomiasis transmission cycles in specific epidemiological settings, defined as having prevalence of less than 10% in school-based programmes [3], usually in countries with strong health systems and drug-delivery mechanisms [4]. Settings with higher prevalence are likely to require high-coverage, high-frequency, and broader community-based treatment, and additional WASH efforts [4–7]. Field verification of these modelling studies in different transmission settings is required. The emphasis of morbidity control is to reduce heavy-intensity infections in school-aged children, as a proxy measure of heavy morbidity from infection. Five years after the London Declaration for NTDs[ii] was signed, and significant international headway in addressing the NTDs made, there is a need for further refinement of the very important agenda of WASH for STH and schistosomiasis control. The goal of this manuscript is to highlight recent policy progress, and articulate some essential implementation research and intervention requirements to ensure that WASH access is significantly improved in endemic populations to successfully contribute to helminth control.

Policy Progress in Integrating WASH and NTDs

Many countries have now developed national NTD master plans with control and, for some NTDs, elimination priorities tailored to NTD endemicity and use of resources. These plans have assisted countries in making significant progress towards achieving coverage targets and general programmatic performance on each disease,[i,iii] at this stage considerably more for STH than schistosomiasis. Whilst, thus far, emphasis has been on preventive chemotherapy, NTD master plans have fostered progress on WASH as a pillar of NTD control and elimination, by ensuring that WASH and disease management, disability, and inclusion (DMDI) actions are incorporated, although further refinements will be required over time.

Since 2012, the WHO has released three reports on progress against Roadmap targets, most recently in April 2017 [8]. Additionally, in 2015 the WHO published the first Global Strategy and Action Plan on WASH and NTDs 2015–2020 [9].[iv] This provides four strategic objectives to further accelerate progress on addressing intersectoral WASH–NTD collaboration and integration.[iv] This strategy, and the most recent progress report, provide strong WHO advocacy and impetus for countries to prioritise integration, inclusive of WASH, in conjunction with other NTD control strategies, as part of health systems strengthening [8,9].[iv]

The Need for WASH Research and Implementation Encompassing STH and Schistosomiasis Dynamics

These landmark WHO publications are much-needed. Their combined impact has been strategically planned to hasten international progress towards meeting universal health coverage (UHC) and SDG targets[iv] [8] whilst maintaining structured NTD investment (Box 1). The shift in focus to provision of **multicomponent strategies** is fundamentally important;

Box 1. Sustainable Development Goal Targets and Indicators of Significance to Neglected Tropical Diseases and Water, Sanitation, and Hygiene

Note: The Goal 6 targets and indicators are used by the WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP).[xi,xii]

Sustainable development Goal 3: Ensure healthy lives and promote wellbeing for all at all ages	
Targets	Indicators
3.3 By 2030, end the epidemics of AIDS, tuberculosis, malaria, and neglected tropical diseases and combat hepatitis, water-borne diseases and other communicable diseases	3.3.5 Number of people requiring interventions against neglected tropical diseases
Sustainable development Goal 6: Ensure availability and sustainable management of water and sanitation for all	
Targets	Indicators
6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all	6.1.1 Proportion of population using safely managed drinking water services
6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations	6.2.1 Proportion of population using safely managed sanitation services, including a handwashing facility with soap and water
6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally	6.3.1 Proportion of wastewater safely treated 6.3.2 Proportion of bodies of water with good ambient water quality
6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity	6.4.1 Change in water-use efficiency over time 6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources
6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate	6.5.1 Degree of integrated water resources management implementation (0–100) 6.5.2 Proportion of transboundary basin area with an operational arrangement for water cooperation
6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers, and lakes	6.6.1 Change in the extent of water-related ecosystems over time
6.A By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling, and reuse technologies	6.A.1 Amount of water- and sanitation-related official development assistance that is part of a government-coordinated spending plan
6.B Support and strengthen the participation of local communities in improving water and sanitation management	6.B.1 Proportion of local administrative units with established and operational policies and procedures for participation of local communities in water and sanitation management

Glossary

Hygiene: defined as 'personal and household practices aimed at preserving cleanliness and health' [12].

Morbidity control: defined as controlling the clinical consequences of infection that adversely affect an individual's health.[i]

Multicomponent strategies: defined as the augmentation of NTD chemotherapy with additional primary prevention interventions (components) to reduce NTDs. Additional to chemotherapy, this can include WASH, vaccines, vector control strategies, and interventions against zoonotic NTDs [2].

Nudging: defined as using environmental cues engaging unconscious decision-making processes to prompt behaviour change [40].

Transmission control: defined as controlling direct and/or indirect routes of transmission to prevent people from acquiring infection.

however, at this stage the major focus is on NTDs as a collective. The unique disease dynamics of STH and schistosomiasis will require considerably greater emphasis and tailoring of research and measurement indicators, programmatic implementation, and further refinement of strategic priorities. WASH as a primary prevention strategy is a fundamental determinant of STH and schistosomiasis transmission. This prevention focus means that different investments are required relative to WASH as a treatment strategy for NTDs such as leprosy (e.g., washing of affected areas for morbidity management). Recent extensive trachoma action planning includes useful prevention-oriented WASH resources and guidance on implementing the components of the SAFE

strategy[v] [8] that could be more laterally applied despite differences in STH and schistosomiasis requirements. Additionally, despite the greater disease burden attributed to STH and schistosomiasis [10], in NTDs such as leprosy, or lymphatic filariasis, morbidity tends to be more overt, leading to greater awareness of these diseases amongst affected communities. Subtle morbidity, absence of a single effective control strategy, and the requirement for horizontal preventative strategies reduce political appeal and create a risk of inadequate prioritisation of STH and schistosomiasis control strategies relative to other NTDs [2,11].

For prevention of environmental contamination, WASH components of water, sanitation, and hygiene (including health education or outreach activities as an entry point for hygiene promotion, and quality, maintenance, and correct usage of infrastructure), are mutually necessary [2,12,13]. As noted in reviews [2,14–16], evidence for single or integrated WASH activities for either STH or schistosomiasis control is relatively weak and needs to be continued as a research priority, to determine the elements of WASH programmes that are most beneficial for control, including where to invest human and financial resources. However, important caveats to recognise are that impact evidence of WASH interventions is difficult to establish through reviews, largely because of challenges in conducting underlying field research and demonstrating evidence of impact, upon which such reviews are based. Reasons include logistical and ethical difficulties in conducting randomised controlled trials, including for sufficient time periods to gauge effects such as behavioural change, inability to conceal interventions in trials and/or self-reporting of WASH behaviours (potentially introducing bias), insufficient assessment of compliance to interventions, and insufficient coherence across existing studies [2,17]. Further, many studies have focused on household-level WASH access, whereas both STH and schistosomiasis are likely to be affected by community-level access. Few, relatively recent studies have investigated the impact of community-level WASH coverage [18–21], or school-level coverage; more is urgently needed, on a large scale such as recent national mapping in Ethiopia [22].

Absence of evidence does not imply evidence of lack of WASH and helminth connection. The soil or aquatic life cycle requirements of STH and schistosomiasis leave no doubt that WASH is a key causal pathway to reduce environmental contamination and eventually break transmission [23]. New research should not try to re-establish this unassailable link, but rather should examine which WASH interventions are most effective at reducing exposure to infection, in which settings. For specific aspects of WASH, such as water quality, there is a fundamental shortage of research, and no widely accepted standards about how to best design WASH infrastructure or interventions that are appropriate for STH and schistosomiasis-endemic regions, for example, how to design a chlorination system, and what chlorine doses and incubation times may be required, to adequately disinfect water containing *Schistosoma* cercariae (which may not necessarily be the same for routine control of coliform bacteria). The lack of information regarding aspects of WASH design for STH and schistosomiasis constitutes a major research gap that urgently needs to be addressed with rigorous laboratory and field studies, under realistic quality conditions. However, on the sanitation side, where there is sufficient information on the type of infrastructure needed to safely remove faeces from the environment, many low-cost latrines that are constructed fall short of basic standards, precisely because emphasis is on coverage rather than on public health. In many cases, even the most basic coordination and targeting of infrastructure, investment, and behaviour change activities to endemic areas is lacking, and not because of lack of evidence. Action is still needed, whilst operational research carries on into areas where further evidence is needed. Broader than research, whilst vertical siloes around the components of WASH in addressing disease-specific goals must not be created, any WASH strategies must address the underlying disease dynamics.

The Importance of Monitoring to Ensure Targeting Appropriate Services to Endemic Groups

The WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP) has for many years provided benchmark service ladders for safe drinking water supply and safe disposal of human excreta. In line with the SDGs, the JMP has recently revised the service ladders, continuing to recognise underlying 'basic' versus 'unimproved' drinking water and sanitation infrastructure, amending the ladder tiers, and adding a 'safe management' top tier. This recognises that total sanitation and drinking water chains are necessary, including safe faecal sludge management, sufficient quantities of safe drinking water, and an additional handwashing service ladder.[vi]

The JMP definitions form the basis for much of the national (sector performance) WASH management and reporting for the SDGs.[vii] However, there is significant national variation in WASH access monitoring and reporting. For example, many ministries responsible for water supply and sanitation measure coverage, with infrastructure as the starting point and built-in assumptions on the population served by it. This differs from data presented in JMP reports, which relate to household access to services, with data often collected via demographic health surveys, multiple indicator cluster surveys, and censuses. WASH programmes are monitored in a variety of ways depending on whether they are administered by government, UN agencies, multilaterals, or nongovernment organisations.

The vast majority of NTD-endemic countries do not explicitly link WASH access monitoring with burden-of-disease data. Consequently, and following-up on two roundtable discussions on WASH and NTDs [9,24], the WASH working group of the Non-Government Development Organisation NTD Network (NNN) used a broad intersectoral consultation to develop a set of minimum NTD–WASH indicators, sensitised specifically to joint WASH and NTD initiatives, for intended programmatic use (Box 2). This important and welcome development[viii] [24] aims to incentivise collaboration, facilitate cross-sectoral planning, and enhance accountability between these two sectors.[iv] As these are intended to be programmatic indicators they fit very closely (in some cases, exactly) with international and national sector indicators, with further intended amendment based on coendemicity of diseases and other specific programmatic considerations. The need for development of disease-specific indicators [24], and of guidelines for their measurement [13,25,26], has been identified and the NNN WASH Working Group is planning development of these as key next steps that will benefit academic research and programmatic activities, and contribute to the evidence base.

STH and Schistosomiasis Considerations for Joint WASH and NTD Monitoring Initiatives

Figure 1 provides a traffic-light ranking of the JMP service ladders, showing the potential transmission risks associated with each tier. This demonstrates that additional requirements will be necessary for helminth control. STH and schistosomiasis need to be considered firstly per biological aspects of their transmission routes, and less as either undifferentiated NTDs, 'intestinal helminths', or even 'schistosomiasis', which does not sufficiently differentiate urinary versus faecal contamination routes. Water supply and excreta disposal risks will differ by terrestrial or aquatic parameters, and further, by age–prevalence–exposure interactions (e.g., hookworm in adults versus *A. lumbricoides* or *T. trichiura* in children, likely linked to non-use of toileting facilities by toddlers and their environmental playing habits and subsequent impact on other household and community members, household floor type, shoe wearing, or other exposure-related activities and infrastructure [27,28]) or biological parameters (e.g., intestinal versus genitourinary schistosomiasis with associated faecal versus urinary transmission routes). Indeed, aside from defecating or urinating into water, or using hanging latrines directly over water, the transmission associations with different latrine types have greater relevance for

Box 2. Neglected Tropical Disease (NTD) and Water, Sanitation, and Hygiene (WASH) Indicators Developed to Increase National Program Monitoring and Linkages between NTD and WASH Activities[viii]

Output 1	Activity 1.1
Promotion of healthy hygiene behaviours	Number of health workers or health volunteers receiving training on NTDs and WASH related topics (disease specific depending on NTDs relevant)
	Activity 1.2
	Number of organizations (gov. or non-governmental) receiving training on NTDs and WASH-related topics
	Activity 1.3
	Number of schools where hygiene and NTD-related activities held
	Activity 1.4
	Number of teachers/PTO[a] members trained related to WASH/NTD activities
	Activity 1.5
	Number of people in target population who have basic knowledge of hygiene practices
	Activity 1.6
	Number of people in target population who recall key messages about NTD prevention and treatment (disease specific depending on NTDs relevant)
Output 2	Activity 2.1
Increase environmental cleanliness and improve sanitation practices	Number of communities triggered (using an adapted CLTS[b] hygiene-focused approach with face washing and trachoma messaging)
	Activity 2.2
	Number of community champions or health development army trained (community members not health people)
Output 1 and 2	Activity 3.1
	Activity 3.3
	Proportion of existing WASH programs incorporating NTD prevention messaging/ components (e.g., face washing)
	Activity 3.4
	Number of advocacy information papers prepared for external use
	Activity 3.5
	Number of forums attended to promote WASH to support the elimination of NTDs
	Activity 3.6
	Number of people in target population that perceive that they are at risk for getting specific NTD
	Activity 3.8
	Number of radio/TV spots developed
	Activity 3.9
	Number of radio talk shows held
	Activity 3.7
	Number of print materials re/designed

STH than for schistosomiasis, because cercariae will die if water used for/near latrines is separated from the snail host for at least 24 h [29]. Schistosomiasis is more impacted by water contact behaviours and cessation of any defecation/urination into water than sanitation

Sanitation[a]	Safety for soil-transmitted helminthiasis (STH) and schistosomiasis
Safely managed Use of an improved[b] sanitation facility which is not shared with other households and where excreta is safely disposed *in situ* or transported and treated off-site.	**Safe if clean and maintained; otherwise unsafe** Minimal transmission risk (except adding soil/compost to composting toilets could increase transmission). Seal ad flushing mechanism prevent contact with excreta/wastewater. A slab reduces risk of STH eggs/larvae surviving in surrounding soil. Safe (contactless) removal, treatment and disposal of waste (via piped sewer system, septic tank, or pit) has minimal transmission risk if well-maintained. For all toilets (particularly squat toilets), transmission risk also depends on user exposure to excreta/wastewater from spillage. Regular cleaning and maintenance is required. New-technology latrines require the same principles of nil contact, plus cleanliness and maintenance, to be safe.
Basic Use of improved facilities which are not shared with other households.	**Safe if clean, maintained, and faeces safely disposed of; otherwise unsafe** Seal and flushing mechanism prevent risk of transmission, although as above toilets require regular cleaning and maintenance. STH transmission risk could be retained depending on where excreta is flushed to (and disposed of), for example, if human waste requires regular removal, or if it leaches into surrounding environment.
Limited Use of improved facilities shared between two or more households.	**Unsafe** As above with regards seal, flushing mechanism and excreta disposal. Transmission risk is considered to increase with more frequent sharing between households, largely due to cleanliness and maintenance requirements. Latrine sharing could also influence an array of different 'risky' scenarios, for example, permission/ability for both genders to use the facility, payment of fees for use, etc.
Unimproved Use of pit latrines without a slab or platform, hanging latrines, and bucket latrines.	**Unsafe** Unimproved latrines may facilitate STH transmission as users may have direct contact with faeces, for example, from spillage. For schistosomiasis, transmission may continue if urinary run off enters waterways. Lack of slab further adds to STH risk as eggs/larvae could survive in surrounding soil. Risk also depends on where and how excreta is disposed. of. Hanging latrines facilitate direct faeces deposit into water, creating a schistosomiasis (and potentially STH) transmission risk for all others who use this water supply.
Open defecation Disposal of human faeces in fields, forest, bushes, open bodies of water, beaches, or other open spaces or with solid waste.	**Unsafe** Open defecation and urination is considered the riskiest way of continuing transmission. The direct depositing of faeces onto the soil, usually with minimal covering, facilitates continuation of the STH life cycle. Open defecation/urination into a water body will facilitate continuation of the schistosome life cycle.

Drinking water[a]	Safety for STH and schistosomiasis
Safely managed Drinking water from an improved[c] water source which is located on premises, available when needed and free of faecal and priority contamination.	**Safe depending on source** Piped water into dwelling is generally safe, but also depends on original source being improved: protected sources prevent infected faeces from entering the water supply (the well and cover need to be properly built and maintained). Location on premises generally facilitates sufficient quantities being available, preventing supplementation from a secondary (potentially unsafe) source. Rainwater is safe against STH transmission (but not other pathogens), however is often stored outside the house in large, uncovered, containers. Drinking water from an improved but unpiped source may pose a possible STH transmission risk dependent on household water storage and extraction: containers may not be routinely cleaned, and people extracting water (e.g., if there is hand contact with the water), could contaminate the contents. STH eggs are denser than water, so they may just sink; this needs to be further explored.
Basic Drinking water from an improved source provided collection time is not more than 30 minutes for a round trip including queueing.	**Safe depending on source and 'run off'** Piped water – using constructed pipes (i.e., not hollow bamboo) – to an outside tap may generally be safe (depending on source, as per above). Surrounding areas, which often get muddy, may present a transmission risk, particularly if shoes are not worn. The more public the shared taps, compared to piped water to households, could increase transmission risk due to potential spillage. Proximity to the household environment facilitates sufficient quantities to avoid using a secondary source.
Limited Drinking water from an improved source where collection time exceeds 30 minutes for a round trip to collect water, including queueing.	**Safe depending on source, 'run off', and proximity** As above for improved source, piping, storage, and environmental surrounds. Significantly reduced proximity to the household environment increases potential for possibly riskier secondary sources, or unsafe practices, to augment household supply. Bottled water with an unbroken seal carries no transmission risk, but needs to be available in sufficient quantity; refilled bottles must be regarded as unsafe.
Unimproved Drinking water from an unprotected dug well or unprotected stream.	**Unsafe** No protection against faeces/contaminants from entering the water supply. Runoff may permeate the surrounding environment or flow into other surface water. Household treatments should be applied before drinking.
Surface water Drinking water directly from a river, dam, lake, pond, stream, canal, or irrigation channel.	**Unsafe** No protection against faeces or other contaminants. Surface water is often located downhill from a community, and may receive run-off from springs/surrounds when it rains. Household treatments should be applied before drinking.

Handwashing[a]	Safety for STH and schistosomiasis
Basic Handwashing facility with soap and water in the household.	**Safe** Handwashing with soap or ash will remove faecal/soil contamination from hands if scrubbed vigorously, and dried with a clean cloth. Cleanliness and maintenance of facility is required.
Limited Handwashing facility without soap or water.	**Unsafe** Handwashing without soap or ash may not sufficiently remove faecal/soil contamination from hands. Handwashing technique, cleanliness, and maintenance of facility is required.
No facility No handwashing facility.	**Unsafe** No handwashing facility reduces any opportunity to provide safe hand hygiene at any time and faecal/soil contamination is unlikely to be removed.

Trends in Parasitology

Figure 1. Water, Sanitation, and Hygiene Service Ladders and Their Applicability in Addressing Soil-Transmitted Helminth and Schistosomiasis Transmission Dynamics. Colour coding as per the WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP) service ladders.[vi] These use a gradient traffic-light style scale whereby dark green (for sanitation), dark blue (for drinking water), and purple (for handwashing) denote the most improved levels, yellow and light orange (for any category) denote limited or unimproved levels, and dark orange is used for the most unsafe levels. The JMP service ladder concept was commenced for the Millennium Development Goals (MDGs) preceding the Sustainable Development Goals (SDGs), and enabled tracking of progress and performance, helping to shed light on areas of progress and the extent to which water and sanitation targets under the MDGs were achieved.[vi] The ladders, in turn, have been refined and have helped to identify future priorities to be addressed in the SDGs.

infrastructure. However, in a genetic study in Brazil [30], schistosome gene flow seemed to be more strongly influenced by human movement between communities than by movement of aquatic larval forms or snails. The control implications of potentially nonwater transmission pathways require further investigation.

Latrines and water infrastructure are important requirements to guide investment, but there is negligible evidence of 'basic/safely managed' versus 'unimproved' water or sanitation on STH outcomes (reviewed in [2]), including whether adding a cement slab to an existing latrine is beneficial [31]. Conceivably, an improperly cleaned or maintained latrine could be worse than open defecation if it is a focal point for transmission, demonstrating why behaviour is intrinsically linked to any infrastructure. Research should investigate quality of WASH infrastructure, for example, differences in transmission associated with toilet cleanliness and also whether people are using and maintaining infrastructure as intended, where such infrastructure exists. Floods and inclement weather can also severely exacerbate transmission, for example, via flooding latrines releasing contents across communal areas. Zoonotic infection via contact with animal faeces also requires more consideration [32]. With regard to water supply and STH, there is currently

Box 3. Hygiene Considerations That Should Be Considered in Neglected Tropical Disease (NTD) Control Measures

Hygiene can be considered to include:

(i) Safe body cleansing (including handwashing as well as other bathing) with soap/ash and hand-drying at times most relevant to reduce transmission risk, for example, before food preparation, eating or feeding children, after toileting, assisting others with toileting, contact with human/animal waste, soil or dirt, or animals
(ii) Usage behaviours, sharing and cleanliness (including splashback) of latrines
(iii) Disposal of baby/toddler faeces and washing of soiled clothes
(iv) Uncontaminated playing environments for children, mainly avoiding indiscriminate soil contact
(v) Materials used or re-used when toileting
(vi) Collection and management of stored household water, including treatment, receptacle cleanliness, hygienic access, and covering
(vii) Source, supply (quantity and quality), and use of household water for all domestic purposes other than drinking/cooking, for example, bathing, laundry, house cleaning, etc.
(viii) Disposal of grey water and run-off water
(ix) Shoe-wearing, especially whilst toileting or outside the home
(x) Food preparation and clean-up
(xi) Treatment and subsequent use of night-soil as fertiliser
(xii) Disposal of animal faeces given zoonotic potential for some helminths
(xiii) Disposal of household/village rubbish
(xiv) Treatment/use of human/animal faeces as fertiliser, especially if on food garden
(xv) Water and sanitation infrastructure maintenance (household, school, community)
(xvi) Legislation and community management of WASH infrastructure
(xvii) Health education and health promotion as a key conduit for hygiene awareness
(xviii) Recognising the importance of, and using, WASH infrastructure when it is available

insufficient knowledge (although some reported associations [13,33]) about waterborne infective STH eggs and/or larvae, but it is unknown whether this could be at levels that sustain transmission.

The updated JMP criteria cover handwashing with soap and water, because international consultation has identified this as a top priority in all settings.[vi] There are relative difficulties in measuring a global hygiene indicator, and using handwashing structures as a proxy for handwashing behaviour is a starting point. Other hygiene activities and measurement will be important for specific NTDs, such as shoe-wearing for hookworm, and overall corporal hygiene. Inherently important to hygiene is its link to behavioural change; more evidence is needed on what hygiene promotion works, under what criteria, and in what contexts of greatest relevance for helminth control. For example, shoe-wearing has been associated with STH reductions [15,34]; however, the reasons for people not wearing shoes, such as cost, quality, sharing within families etc., have been insufficiently investigated.

For schistosomiasis, any percutaneous or even oral contact with environmentally drawn water likely or actually infested with schistosome cercariae is a tangible risk. Additional to drinking water, this has implications for water collection, water playing, fishing, and other occupational and recreational exposures; both contamination and exposure routes of transmission need to be considered [35], although it is agreed that transmission control requires cessation of human excretion into water, notwithstanding zoonotic sources as well. Human behaviour is key, but often insufficiently amenable to meaningfully reduce exposures or cease transmission to levels where infections are prevented. People need to feel capable of adopting behaviours to prevent these diseases, and know how they can safely avoid them in endemic and impoverished environments where, inevitably, some people will continue contributing to transmission. Hygiene will always be culturally-specific; Box 3 provides a summary of hygiene considerations that can be considered in research and development of interventions for NTD programmes extending well beyond MDA and handwashing. The JMP criteria are not designed to prioritise transmission pathways, but they add a global priority to hygiene from which national WASH programmes can address specific disease prevention needs. Most national programmes will

miss potential STH or schistosomiasis transmission routes unless additional WASH components are considered: even if 100% coverage of 'safely managed' drinking water, sanitation, and handwashing is ultimately achieved, more will need to be done.

Support for Integrated WASH–NTD Implementation

Concerted integration of WASH with the existing preventive chemotherapy strategy will not be easy. Achieving universal access to WASH on a large scale is one of the most costly and difficult undertakings, extending far beyond disease control to broader economic development [36–38]. At national levels, WASH provision often remains separate from NTD control: better coordination and collaboration is needed; NTD guidance to the WASH sector is required to inform planning, resourcing, and services targeted to endemic communities [9]. Importantly, a percentage of in-country NTD programmatic budgets should be dedicated, and synergise with externally funded WASH resources, to specifically address WASH requirements, otherwise the NTD focus will not sufficiently shift from drug administration approaches. This allocation of NTD resources for WASH is likely to be best spent on stakeholder meetings and joint planning rather than on actual WASH infrastructure. Further, NTD programmes have extensive within-country reach and can be used as a platform for initial WASH surveillance activities [26]. Similarly, well-developed national Water Sanitation Hygiene Management Information Systems (WASHMIS) or other WASH platforms could incorporate NTD-specific indicators; for example, trachoma indicators, as has commenced in Zambia.[ix] The key will be to identify mutual benefits. Countries will need to be supported to incrementally achieve WASH goals themselves, possibly by establishing within-country coordinating units to target high-prevalence STH and/or schistosomiasis areas (hotspots), or challenging areas that have suboptimal WASH facilities or uptake. Interventions may need to be applied in focal, even micro-geographic, areas as opposed to a single national, regional, or district-level programme. Existing disease-prevalence data and WASH information will need to be utilised, followed by refinement of existing surveying strategies [39], and advanced diagnostic techniques, to ensure that hotspots are not missed. Behavioural change may be generational; hygiene and health-education programmes delivered in classroom settings utilise the potentially influential role of children as agents of broader family and/or community change. Inclusion of WASH and NTD-specific promotion content in programmes and/or school curricula, or other innovative behaviour change strategies such as '**nudging**' [40] could be a comparatively lightweight investment compared to costs of infrastructure. With potential to increase awareness and aid capacity building, these approaches are starting to be implemented in some areas [9].[x] This requires further exploration: health education programs may not guarantee uptake of interventions; numerous local issues, including risk perception, intervention acceptability, sociocultural factors, and practical issues, also influence behaviour [41,42]. Situational analyses should be undertaken to investigate STH, schistosomiasis, and WASH needs, followed by community-led planning and multistakeholder actions, with appropriate formative research guiding specific interventions. These then need to be supported, monitored, and evaluated, and further tailored if necessary.

Concluding Remarks and Future Perspectives

Major investment in NTD preventive chemotherapy has beneficially reduced disease morbidity, but the requirement for detailed epidemiological research into, and implementation of, WASH for NTDs is now clearly recognised. For STH and schistosomiasis, where WASH is so important for control, additional evidence and targeted strategies are required (see Outstanding Questions). Breaking helminth transmission cycles through primary prevention is not a new concept. However, generation of evidence is complex and, as yet, under-researched. The paucity of experimental WASH evidence impacting on helminths presents a unique challenge, yet the underlying plausibility of benefit is sound. The recent WASH–NTD indicators are vital to assess integration progress; however, additional STH and schistosomiasis indicators are required,

Outstanding Questions

What WASH aspects are most beneficial for reducing exposure to STH and schistosomiasis? What study designs will be able to demonstrate these?

What WASH indicators are of greatest relevance for assessing progress towards STH and schistosomiasis control, and how can these be appropriately measured in national programme contexts?

In the absence of clear evidence of benefit, which WASH activities should be prioritised internationally, nationally, and locally?

Should WASH targets be set for STH and schistosomiasis control programmes? What is implementable, and at what scale?

How can WASH be financed, and best integrated, in STH and schistosomiasis control priorities?

backed by research that has investigated evidence of benefit, and of their feasibility for national programme purposes. The integration of WASH with preventive chemotherapy for helminth control will not be a rapid solution but hopefully, with adequate investment, it will become a lasting one.

Acknowledgments

This work is a result of two multistakeholder sessions held in 2016: the WASH on Worms breakout session at the annual COR-NTD meeting (Atlanta, November) funded in part by the Task Force for Global Health, and the 7th Annual Non-Government Development Organisation NTD Network (NNN) session (Washington DC, September). JRS, SJC, and NKB participate in the four-country research programme consortium COUNTDOWN, which receives funding from the Research and Evidence Division of the Department for International Development, UK. The funders had no role in preparation of the manuscript or decision to publish. We thank Amadou Garba, Louis-Albert Tchuem Tchuenté, Stefanie Knopp, Jack Grimes, Lorenzo Savioli, and Sophie Boisson for their contributions to presentations and advice on session development at COR–NTD and the NNN meetings. We are additionally grateful for the broader audience contributions at these two meetings.

Resources

[i] http://apps.who.int/iris/bitstream/10665/70809/1/WHO_HTM_NTD_2012.1_eng.pdf?ua=1
[ii] www.dfid.gov.uk/Documents/publications1/NTD%20Event%20-%20London%20Declaration%20on%20NTDs.pdf
[iii] http://unitingtocombatntds.org/resource/download-scorecard
[iv] http://apps.who.int/iris/bitstream/10665/182735/1/WHO_FWC_WSH_15.12_eng.pdf?ua=1
[v] www.trachomacoalition.org/sites/default/files/content/resources/files/ICTC%20TAP%20planning%20guide%20eng.pdf
[vi] www.wssinfo.org/fileadmin/user_upload/resources/JMP-WASH-in-the-2030-Agenda-factsheet.pdf
[vii] www.undp.org/content/undp/en/home/sustainable-development-goals/goal-6-clean-water-and-sanitation/targets/
[viii] www.ntd-ngonetwork.org/sites/default/files/uploaded/BEST%20FRAMEWORK%202%20pager_150417.pdf
[ix] http://akros.com/health/trachoma/
[x] http://apps.who.int/iris/bitstream/10665/255563/1/WHO-FWC-WSH-17.02-eng.pdf?ua=1
[xi] https://sustainabledevelopment.un.org/sdg3
[xii] https://sustainabledevelopment.un.org/sdg6

References

1. Brooker, S. *et al.* (2006) Global epidemiology, ecology and control of soil-transmitted helminth infections. *Adv. Parasitol.* 62, 221–261
2. Campbell, S.J. *et al.* (2016) A critical appraisal of control strategies for soil-transmitted helminths. *Trends Parasitol.* 32, 97–107
3. World Health Organization (2011) *Helminth Control in School Age Children: A Guide for Managers of Control Programmes.* (2nd edn), World Health Organization
4. Brooker, S.J. *et al.* (2015) Global feasibility assessment of interrupting the transmission of soil-transmitted helminths: a statistical modelling study. *Lancet Infect. Dis.* 15, 941–950
5. Anderson, R. *et al.* (2014) The coverage and frequency of mass drug administration required to eliminate persistent transmission of soil-transmitted helminths. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* 369, 20130435
6. Anderson, R.M. *et al.* (2015) What is required in terms of mass drug administration to interrupt the transmission of schistosome parasites in regions of endemic infection? *Parasit. Vectors* 8, 553
7. Turner, H.C. *et al.* (2017) Evaluating the variation in the projected benefit of community-wide mass treatment for schistosomiasis: Implications for future economic evaluations. *Parasit. Vectors* 10, 213
8. World Health Organization (2017) *Integrating Neglected Tropical Diseases into Global Health and Development: Fourth WHO Report on Neglected Tropical Diseases,* World Health Organization
9. Waite, R.C. *et al.* (2016) Integration of water, sanitation and hygiene for the control of neglected tropical diseases: a review of progress and the way forward. *Int. Health* 8 (Suppl. 1), i22–i27
10. GBD 2016 DALYs and HALE Collaborators (2017) Global, regional, and national disability-adjusted life-years (DALYs) for 333 diseases and injuries and healthy life expectancy (HALE) for 195 countries and territories, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016. *Lancet* 390, 10100
11. Campbell, S.J. *et al.* (2016) Complexities and perplexities: a critical appraisal of the evidence for soil-transmitted helminth infection-related morbidity. *PLoS Negl. Trop. Dis.* 10, e0004566
12. Campbell, S.J. *et al.* (2014) Water, sanitation, and hygiene (WASH): a critical component for sustainable soil-transmitted helminth and schistosomiasis control. *PLoS Negl. Trop. Dis.* 8, e2651
13. Campbell, S.J. *et al.* (2017) Urogenital schistosomiasis and soil-transmitted helminthiasis (STH) in Cameroon: An epidemiological update at Barombi Mbo and Barombi Kotto crater lakes assessing prospects for intensified control interventions. *Infect. Dis. Poverty* 6, 49
14. Ziegelbauer, K. *et al.* (2012) Effect of sanitation on soil-transmitted helminth infection: systematic review and meta-analysis. *PLoS Med.* 9, e1001162
15. Strunz, E.C. *et al.* (2014) Water, sanitation, hygiene, and soil-transmitted helminth infection: a systematic review and meta-analysis. *PLoS Med.* 11, e1001620
16. Grimes, J.E.T. *et al.* (2014) The relationship between water, sanitation and schistosomiasis: a systematic review and meta-analysis. *PLoS Negl. Trop. Dis.* 8, e3296
17. Freeman, M.C. *et al.* (2014) Hygiene and health: systematic review of handwashing practices worldwide and update of health effects. *Trop. Med. Int. Health* 19, 906–916
18. Arnold, B.F. *et al.* (2013) Cluster-randomised controlled trials of individual and combined water, sanitation, hygiene and nutritional interventions in rural Bangladesh and Kenya: the WASH Benefits study design and rationale. *BMJ Open* 3, e003476
19. Clasen, T. *et al.* (2014) Effectiveness of a rural sanitation programme on diarrhoea, soil-transmitted helminth infection, and

child malnutrition in Odisha, India: a cluster-randomised trial. *Lancet Glob. Health* 2, e645–e653

20. Nery, S.V. *et al.* (2015) WASH for WORMS: a cluster randomized controlled trial integrating a community-based water, sanitation and hygiene program with mass albendazole to reduce intestinal parasites in Timor-Leste. *BMJ Open* 5, e009293
21. Oswald, W.E. *et al.* (2017) Active trachoma and community use of sanitation, Ethiopia. *Bull. World Health Organ.* 95, 250–260
22. Grimes, J.E.T. *et al.* (2016) School water, sanitation, and hygiene, soil transmitted helminths, and schistosomes: national mapping in Ethiopia. *PLoS Negl. Trop. Dis.* 10, e0004515
23. Campbell, S.J. *et al.* (2017) Water, sanitation and hygiene (WASH) and environmental risk factors for soil-transmitted helminth intensity of infection in Timor-Leste, using real time PCR. *PLoS Negl. Trop. Dis.* 11, e0005393
24. Waite, R.C. *et al.* (2016) Collaborating to develop joint water, sanitation and hygiene (WASH) and neglected tropical disease (NTD) sector monitoring: an expert consultation. *Int. Health* 14, 1–11
25. Freeman, M.C. *et al.* (2013) Integration of water, sanitation, and hygiene for the prevention and control of neglected tropical diseases: a rationale for inter-sectoral collaboration. *PLoS Negl. Trop. Dis.* 7, e2439
26. Freeman, M.C. *et al.* (2015) Associations between school- and household-level water, sanitation and hygiene conditions and soil-transmitted helminth infection among Kenyan school children. *Parasit. Vectors* 8, 412
27. Steinbaum, L. *et al.* (2017) Detecting and enumerating soil-transmitted helminth eggs in soil: New method development and results from field testing in Kenya and Bangladesh. *PLoS Negl. Trop. Dis.* 11, e0005522
28. Benjamin-Chung, J. *et al.* (2015) The interaction of deworming, improved sanitation, and household flooring with soil-transmitted helminth infection in rural Bangladesh. *PLoS Negl. Trop. Dis.* 9, e0004256
29. Farley, J. (1991) *Bilharzia: A History of Imperial Tropical Medicine,* Cambridge University Press
30. Curtis, J. *et al.* (2002) Schistosome genetic diversity: the implications of population structure as detected with microsatellite markers. *Parasitology* 125, S51–S59
31. Luby, S. (2014) Is targeting access to sanitation enough? *Lancet Glob. Health* 2, e619–e620
32. Penakalapati, G. *et al.* (2017) Exposure to animal feces and human health: A systematic review and proposed research priorities. *Environ. Sci. Technol.* Published online September 19, 2017. http://dx.doi.org/10.1021/acs.est.7b02811
33. Udonsi, J.K. (1988) Experimental and field studies on the viability of eggs, and the infectivity of third-stage larvae of the human hookworm *Necator americanus* recovered from the creek waters of the Niger Delta, Nigeria, and their epidemiological significance. *Parasitology* 96, 111–117
34. Tomczyk, S. *et al.* (2014) Association between footwear use and neglected tropical diseases: a systematic review and meta-analysis. *PLoS Negl. Trop. Dis.* 8, e3285
35. Stothard, J.R. *et al.* (2017) Interruption of schistosomiasis transmission in sub-Saharan Africa: developing an appropriate environmental surveillance framework to guide and to support 'end game' interventions. *Infect. Dis. Poverty* 6, 10
36. Cairncross, S. *et al.* (2010) Hygiene, sanitation, and water: what needs to be done? *PLoS Med.* 7, e1000365
37. Huttly, S.R.A. (1990) The impact of inadequate sanitary conditions on health in developing countries. *World Health Stat. Q.* 43, 118–126
38. Asaolu, S.O. and Ofoezie, I.E. (2003) The role of health education and sanitation in the control of helminth infections. *Acta Trop.* 86, 283–294
39. Knowles, S.C.L. *et al.* (2017) Optimising cluster survey design for planning schistosomiasis preventive chemotherapy. *PLoS Negl. Trop. Dis.* 11, e0005599
40. Dreibelbis, R. *et al.* (2016) Behavior change without behavior change communication: nudging handwashing among primary school students in Bangladesh. *Int. J. Environ. Res. Public Health* 13, 129
41. Atkinson, J.A. *et al.* (2010) Community participation for malaria elimination in Tafea Province, Vanuatu: Part I. Maintaining motivation for prevention practices in the context of disappearing disease. *Malar. J.* 9, 93
42. Mehta, L. and Movik, S. (2010) *Shit Matters: The Potential of Community-Led Total Sanitation,* Practical Action Publishing