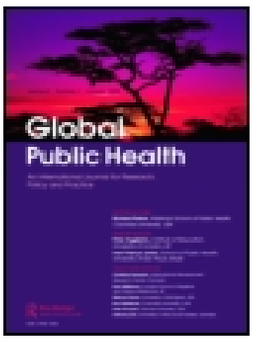

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REVIEW ARTICLE

Food, water, and sanitation insecurities: Complex linkages and implications for achieving WASH security

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ABSTRACT

Food, water and sanitation insecurities are complex, multi-dimensional phenomena that entail more than availability and access; food, water, and sanitation resources must be safe and culturally appropriate. Researchers and implementers concerned with these insecurities have demonstrated that there are notable interactions between them resulting in significant psychological and biological outcomes. Recent randomised controlled trials (RCTs) in Bangladesh, Kenya (WASH Benefits) and Zimbabwe (SHINE) demonstrated no effect from water, sanitation and hygiene (WASH) interventions on linear growth, and mixed evidence on enteropathogen burden and risk of diarrhoea in young children. These data suggest a need for a more comprehensive understanding of WASH security. The risks posed by multiple resource insecurities shift depending on the individual, their movement throughout their day, their economically and socially prescribed roles, and ecological features such as seasonality and precipitation. By more fully integrating food, water and sanitation security in interventions and subsequent impact evaluations, we can achieve WASH security—one that addresses myriad transmission pathways and co-occurring diseases —that ultimately would improve health outcomes throughout the world. In this critical review, we outline the complexity of combined resource insecurities as a step towards transformative WASH.

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Introduction

Food insecurity and water insecurity are complex phenomena that entail more than resource availability and access. Achieving food and water security requires that food and water sources are also sufficient, safe and culturally appropriate and can be utilized as needed for health and well-being (FAO, 2021; Rosinger & Young, 2020). Social science research concerned with food and water security has similarly demonstrated substantial co-occurrence that independently and together result in significant psychosocial and biological outcomes (Boateng et al., 2018; Brewis et al., 2020a; Brewis et al., 2020b; Collins et al., 2018; Jepson, 2014; Krumdieck et al., 2016; Stevenson et al., 2012; Stevenson, Ambelu, Caruso, Tesfaye, & Freeman, 2016; Thompson et al., 2020; Workman et al., 2021; Workman & Ureksoy, 2017; Wutich & Ragsdale, 2008). Because food and water security span multiple disciplines, the topical literature demonstrates a wide range of methodologies but little consistency in the operationalisation of food and/or water insecurity.

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For example, macro-scale approaches that use agricultural output as a proxy for food security may miss local experiences of food insecurity that can occur even in surplus. Agriculture is necessary for good health but is also linked with adverse health outcomes such as malnutrition, malaria, foodborne illnesses, and livestock-related diseases, and with significant occupational health risks for agricultural workers (Hawkes & Ruel, 2006). Given that there are bidirectional linkages between agriculture and the social determinants of health, Hawkes and Ruel (2006) assert that agricultural and health sciences need better integration. We begin with this proposition and employ a broad definition of food insecurity that considers malnutrition and additional sequelae such as undernutrition, vitamin deficiency, and enteric illnesses from unsafe food or animal-based foods. That is, there is a suite of illnesses associated with food insecurity and these are indelibly linked to water insecurity and sanitation (Brewis et al., 2020; Chase & Ngure, 2016; Fanzo, 2014; Workman et al., 2021).

Closely tied to water security, sanitation security entails the provisioning of adequate and appropriate resources for the hygienic management of urine, faeces, and menses in ways that foster dignity for all people. Moreover, sanitation insecurity is similarly shaped by one's physical and social environment. Recent studies have refined our understanding of sanitation insecurity by demonstrating that it—like food and water insecurity—is associated with both biological and psychoemotional outcomes (Caruso et al., 2017; Hulland et al., 2015; Panchang et al., 2021).

Both academic researchers and practitioners have observed how water-sanitation-hygiene (WASH) and nutritional insecurities co-occur, overlap, and mutually reinforce each other (e.g. Fanzo, 2014; Ngure et al., 2014). Nutrition-sensitive WASH, for example, outlines the interrelated pathways through which inadequate sanitation, animal separation, and water resources contribute to inadequate and unsafe food and caregiving behaviours resulting in underweight and stunting in children (Chase & Ngure, 2016). These connections occur within cultural, economic, and political contexts and are driven by inequity and poverty (Cumming & Cairncross, 2016). However, scholars posit that more research is needed to identify the totality of risk pathways along with methods to tailor interventions to specific risk environments to achieve 'transformative WASH' (Cumming et al., 2019).

Indeed, recent randomised controlled trials (RCTs) in Bangladesh, Kenya (WASH Benefits) and Zimbabwe (SHINE) demonstrated no effect from WASH interventions on linear growth, and mixed evidence on enteropathogen burden and risk of diarrhoea in young children (Ercumen et al., 2019; Humphrey et al., 2019; Lin et al., 2018; Pickering et al., 2019a; Pickering et al., 2019; Rogawski McQuade et al., 2020). These data suggest a need for a more comprehensive approach to WASH security, one that incorporates not only nutrition but also additional social and ecological determinants of health. This evidential gap and lack of definitional precision have direct relevance for WASH measurement and programme implementation.

Environmental health stressors exhibit dynamic, interrelated, and mutually reinforcing relationships that must be addressed holistically. These intersections occur distally and proximately, allowing different risk processes to interact, driving differential health outcomes through time. In this critical review article, we situate the health effects of multiple resource insecurities, focusing on intersections throughout the lifespan, seasonal shifts, and fluid daily connections. By engaging literature focused on low and middle-income regions, we present conceptual linkages between WASH and food insecurities to demonstrate the suite of adverse health effects resulting from these connections.

The results of the WASH Benefits and SHINE trials suggest that important exposure pathways may be overlooked—or that key interactions are being overlooked—thereby missing important drivers of biological outcomes. Second, food, water, and sanitation insecurities must be considered in tandem to achieve comprehensive WASH security, with important implications for WASH and nutritional development programming. Complex interactions that exhibit spatial and temporal variability drive differential health effects in ways that are difficult to model and predict. Third, in light of this, mixed-method approaches engaging frameworks from the social sciences are likely

the best-available tools to assess and advance WASH security in pursuit of transformative WASH outcomes.

Persistent WASH insecurity: Interpreting the null results of the WASH benefits and shine trials to reduce child stunting and diarrhoea

Observational studies have shown associations between WASH conditions and stunting and diarrhoea in children. However, the recent WASH-Benefits studies in rural Kenya and Bangladesh (Arnold et al., 2013) and SHINE trials in rural Zimbabwe (Humphrey et al., 2015) yielded mixed evidence. Combining water treatment, sanitation, hygiene and nutritional interventions, these studies assessed outcomes in children under 2 years old including stunting, diarrhoea, gut colonisation with enteropathogens, anaemia, biomarkers of intestinal health, soil-transmitted helminth and protozoan infections, and social markers such as child development scores. Evaluations of the findings of these studies have challenged WASH researchers to reconsider current approaches for existing WASH interventions.

There is ongoing debate among WASH researchers about the importance or feasibility of assessing the effects of community-level interventions (see Arnold et al., 2018). In contrast, the medical anthropology literature suggests that it is essential to capture intra-household and community-level effects. For example, households use multiple public and private water sources for a variety of household activities as an adaptation to water insecurity (Elliott et al., 2019; Workman, 2019). Likewise, intra-household sharing of water and food is prevalent (Brewis et al., 2019b). Young children often rely on open defecation rather than use latrines (Ellis et al. 2020). Additionally, latrines may be ineffective at separating human waste as intended, for example, through processes such as 'flooding out,' there can be spillover of waste between households and within communities (Jenkins et al., 2015).

A variety of environmental and behavioural risks apply specifically to children, including a range of community resource insecurities with effects that are exacerbated during vulnerable childhood years. A study of environmental enteric dysfunction (EED) among a subset of children enrolled in the Bangladesh RCT that included water, sanitation, hygiene and nutrition interventions observed a reduction in permeability and inflammation of the gut at ages 3 and 14 months, but by 28 months, children showed elevated EED biomarkers (Lin et al., 2019). Thus, children one year and younger benefitted from the interventions, but not children older than two years, suggesting different pathogenic exposures for one-year-olds compared to two-year-olds. As we shall see, data from India further demonstrate the complex, multifactorial relationship between malnutrition and stunting and non-linear effects of feeding practices, including breastfeeding and nutritional diversity throughout childhood (Fenske et al., 2013). Thus, there are important differences in risks and outcomes for adults compared to children, but also significant differences across age groups among children. Moreover, the role of maternal health, prenatal and postnatal exposures may all be important distal predictors of linear growth in children, and there might not have been a sufficient reduction in pathogenic burden in young children in the intervention group to reduce symptomatology (Arnold et al., 2018).

The SHINE trial found no reduction in the prevalence of gut colonisation with enteropathogens following either the WASH (improved pit latrine, hand-washing stations, liquid soap, point-of-use water chlorination, and clean play space) or infant and young child feeding interventions in children less than 1 year old (Rogawski McQuade et al., 2020). Clearly, children are being exposed to enteropathogens, and future WASH interventions must account for these extra-sanitary pathways; that is, there may be additional intra- and extra-household or community-level pathways that are important, even for small children (Luby et al., 2018; Null et al., 2018). As we shall discuss, movement of older children, adults, and animals in and around the home can contribute to the presence of enteropathogens.

Previous work linking WASH and nutrition has identified several pathways through which inadequate sanitation (including insufficient latrines, unsafe child faeces disposal, inadequate or absent animal penning, incomplete septic management) combined with water insecurity (i.e. supply and quality) results in diarrhoea, enteric infections, parasite infection, and malaria (Chase & Ngure, 2016). These infections subsequently lead to anaemia, undernutrition and stunting along with psychosocial effects related to time and caregiving (2016). Overall, the large WASH RCTs reveal that the intersections of resource insecurities experienced by children are more fluid and varied than previously understood.

Given this complexity, we define WASH security as 'the ability to prevent exposure to human and zoonotic pathogens and related illnesses by fostering socio-environmental and infrastructural equality required for the provision of sufficient safe, sustainable and culturally-preferred water, food, and hygiene resources, to support health and wellbeing.' As with other resource insecurities, unless all dimensions are addressed, insecurity occurs. Thus, we must understand the spatial and temporal interconnections of overlapping resource insecurities if we are to address them effectively through transformative WASH interventions.

Outlining multi-scale effects of resource insecurity

Community-level resource insecurity

Household experiences with WASH and food insecurities may be complicated by community-level effects. Grace and colleagues (2017) found clean water sources to be positively correlated with children's linear growth and weight, but assert that community-level food production is an important consideration in predicting health outcomes regardless of the household water source (Grace et al., 2017). Using evidence from Demographic Health Surveys and Multiple Indicator Cluster Surveys, Larsen and colleagues (2017) found that community-level, and not household-level sanitation, predicted child stunting and diarrhoea. Similarly, Harris et al. (2017) found that community-level sanitation coverage was a better predictor of child growth than was household access to a latrine. A literature review indicates that increased access to adequate sanitation facilities in school reduces gastrointestinal diseases (Jasper et al., 2012). These studies suggest that extra-household factors influence individual health, particularly community-level food and sanitation security. Moreover, as children develop, play and exploration is critical yet may introduce pathogens. WASH security, then, requires an understanding of the role of caregivers, including mothers and others who are responsible for child-minding, feeding, and child toileting practices (Arriola et al., 2020; Menon & Frongillo, 2018; Ngure et al., 2014) within the home and communally. Scholars have speculated that the WASH Benefits and SHINE trials may have missed community-level effects as they assessed only household-level interventions (Luby et al., 2018; Null et al., 2018). However, because most WASH research has been conducted at the household level, we now turn to household-level interactions between food and WASH insecurity to help contextualise these findings.

Household-level resource insecurity

Water insecurity can exacerbate food insecurity via several pathways within a household (Brewis et al., 2020b). It can limit a household's food production for consumption and sale, and ultimately food choices; the purchase of water or water treatment can undermine a household's food budget; the opportunity cost of fetching water can disrupt food preparation tasks; nutritious foods can be unsafe if there is no water to wash them before eating; and animals, while protective against food insecurity, are themselves vulnerable if there is insufficient water. In analyses using data from households in 27 sites, food insecurity and water insecurity were significantly associated across the sites, and water insecurity was associated with higher scores for all subdomains of food insecurity (2020b).

Brewis and colleagues (2020) also found notable differences between urban and rural populations in terms of how water and food insecurity intersect. Rural households were better buffered against water insecurity's effects on food quantity, whereas urban sites were better buffered against variability in food quality. Inconsistent access to water, among other factors, was associated with increased odds of severe food insecurity in two urban cities in Mozambique (McCordic & Abrahamo, 2019). Excess water, too, poses risks as flooding is associated with diarrhoea (Rosinger, 2018) and having insufficient quantities of food (Zakari et al., 2014), highlighting how floods can perpetuate complex resource insecurity by spreading infectious agents, destroying crops, or washing away fertile topsoil.

There are also combined effects of food and water insecurity on mental health. While mental health is clearly an individual-level outcome, in many studies, water insecurity and food insecurity were measured at the household-level. In three low-resource communities in Haiti, household water insecurity had a direct and independent association on depression and anxiety, and the effect of food insecurity on mental health was shaped, at least in part, by water insecurity (Brewis, Choudhary, & Wutich, 2019a). Boateng et al. (2020) found that household water insecurity predicted food insecurity at later time points and interacted with HIV to predict depression among postnatal women in Kenya. In Lesotho, household water insecurity and food insecurity together were associated with increased anxiety and depression, and worry over water safety proved to be particularly salient (Workman & Ureksoy, 2017).

Sanitation security, like food and water security, is contingent on social and cultural contexts surrounding latrine use and hygiene norms and preferences (Caruso et al., 2017). WASH security must address not only absolute scarcity but relative scarcity and perceptions of inequity. The persistence of faecal-oral transmissions in households with improved toilets and water for hygiene implores us to account for additional dimensions to ensure WASH security. We now turn to outlining the myriad linkages between food, water insecurity and infectious disease to demonstrate how ineffective interventions fail to account for key exposure pathways at the intra-household and individual levels.

Intra-Household and individual-level effects

Gendered risk

One weakness of prior research is the use of household- or community-level measures to approximate individual outcomes. To understand the linkages between multiple resource insecurities, we outline several connections that are specific to individuals and highlight important intra-household differences. Specifically, these insecurities may manifest differently in women and men; that is, different gendered spaces and activities introduce different risk pathways for individuals.

Research in the Global South has demonstrated that women often experience the brunt of insecurity, as they are responsible for the majority of household management. This resource insecurity manifests as increased psycho-emotional and psycho-social stress over both water and food (Boateng et al., 2018; Brewis et al., 2020a; Collins et al., 2018; Hadley & Wutich, 2009; Krumdieck et al., 2016; Stevenson et al., 2012; Tsai et al., 2012; Wutich & Ragsdale, 2008). Experiences with sanitation insecurity are similarly gendered, with women responsible for toilet/latrine maintenance yet who may be unable to safely manage urine, faeces, and menses, and may thus internalise shame (Caruso et al., 2017). Collectively, these studies demonstrate that psycho-emotional distress represents the embodiment of inequality.

There are important risk differentials due to gendered behaviour. In a study of 600 households in rural Bangladesh, the presence of enteric pathogens on mothers' hands was associated with the presence of animal faecal markers; the authors ascribed this to domestic duties such as cleaning household floors (Fuhrmeister et al., 2019). There are also risks posed to women responsible for food preparation, which can increase female caregiver hand contamination

(Pickering et al., 2011). The risk for schistosomiasis is similarly gendered: men are exposed through agricultural activities, and women and children are exposed during domestic activities such as washing and bathing (Manderson & Huang 2005). Workers who manually empty latrines—and are more likely to be men—are at significant risk of exposure to pathogens (Jenkins et al., 2015). However, the intra- and inter-cultural fluidity of these gendered roles makes assessment of risk more complex.

There are also risks specific to pregnant women with potentially severe repercussions for their unborn children. Researchers in Bogota, Colombia, found an association between maternal malnutrition and low birthweight with thinness and stunting among children (Dekker et al., 2010). Recent evidence suggests that early life water restriction may play an important role in later health status, including growth and obesity (Rosinger, 2020). Malaria infection during pregnancy has been found results in increased risk of miscarriage, foetal parasite exposure and congenital infection and, in live-birth children, intrauterine growth restriction, and lower birthweight (Steketee et al., 2001). There is significant pathogenicity associated with co-occurring malnutrition and malaria (O'Reilly et al., 2012). Water-related chemical exposures in utero and among infants and young children may result in significant immunologic impairment (see Kearns, 2020 for a review).

Helminth infection, too, results in child height and weight related outcomes. As Casapía and colleagues (2007) found in children under five ($n = 252$) in Belen, Peru, helminth infection, decreasing maternal body mass index and/or height were associated with child stunting, wasting and underweight, demonstrating a linkage between WASH insecurity, presence of helminths, food insecurity and undernourished mothers. These studies demonstrate that water insecurity and food insecurity experienced by the mother result in effects evident in her children years later. This underscores the importance of assessing resource insecurities through time and suggests the need for longitudinal studies that incorporate inter-generational perspectives to contextualise the role of poverty and inequity in health outcomes.

Risks specific to children

Children face differential risks compared to adults, as children consume more calories, drink more water, and breathe more air per unit of body weight (Karr, 2012). Consequently, children consume proportionately more toxicants than adults—two to three times higher rate for food, and five to seven times more through water—and toddlers ingest twice as much soil (2012). While these results are from US-based studies, they have global implications.

Diarrhoea is a leading cause of death for children under five in the global south. Globally, more than half of all episodes and two thirds of fatalities occur in 15 countries, with over half the deaths occurring in sub-Saharan Africa (Bulled et al., 2014; Kotloff et al., 2013). Bulled et al. (2014) suggest that childhood diarrhoea results from syndemic conditions. They situate the pathogenic interactions that cause diarrhoea within biosocial interactions driving disparity. Thus, diseases are both biological and social. Water insecurity is associated with increased diarrhoeal incidence in children (Nounkeu et al., 2019). In areas where children experience endemic diarrhoea, children also face disproportionate exposure to non-enteric pathogens and to malnutrition. Indeed, malnutrition was a risk factor for death from severe diarrhoea in a study of children under five presenting to a hospital in Nyanza Province, Kenya (O'Reilly et al., 2012). Diarrhoea is both a cause and effect of malnutrition (Caulfield et al., 2004). Additionally, the role of polymicrobial infections in health outcomes may be significant for outcomes (Bulled et al., 2014).

Malnutrition due to breastfeeding cessation exacerbates the risks from diarrhoea, with the majority of deaths among children under two. Risks are highest between 6 and 11 months of age, when weaning can decrease immunological protection from breastmilk, and when children begin to have increased exposure via food consumption, water consumption, and contact with fomites and vectors (Bulled et al., 2014).

Mediated by malnutrition and early cessation of breastfeeding, there are well-identified transmission pathways for young children. Dubbed 'the five Fs,' pathways include: fluids, fingers, food, floors, and flies. Thus, food, water, lack of hygiene and presence of vectors all pose risks to young children. For example, children in Bagamoyo, Tanzania ingest more faecal matter via hand-to-mouth than drinking water (Mattioli et al., 2015). Longitudinal observations of hand and object mouthing among 30 rural Bangladeshi children revealed that the frequency of object-mouthing was higher in Bangladesh than US counterparts and found low intra-child correlation over longitudinal visits (Kwong et al., 2019). This study highlights the cultural differences in mouthing behaviour and underscores how children engage in different frequencies of mouthing and different mouthing behaviours (i.e. hand vs. object) at different ages.

Pickering et al. conducted a prospective analysis of multiple transmission pathways in rural Bangladesh ($n = 1843$) (2018). Of the pathways assessed, *E. coli* on child hands predicted incident child diarrhoea, and *E. coli* on hands and food were predictors of bloody stool. Children aged 6–23 months, i.e. those who crawl, had the highest levels of *E. coli* . These findings indicate that a narrow emphasis on safe water for drinking misses the importance of hand hygiene and food-borne pathogens in causing diarrhoea.

In addition to direct association with morbidity and mortality, chronic exposure to pathogens is believed to be associated with stunting and poor growth via chronic gut inflammation associated with EED (Harper et al., 2018; Humphrey, 2009). However, Harper et al. (2018) conducted a systematic review on studies of EED and hold that pathways and biomarkers need reconsideration, but evidence suggests chronic inflammation may be an important pathway to stunting. Chemical exposures may additionally contribute to chronic inflammation (Kearns, 2020). That the pathways are not well understood may explain, in part, conflicting results in the literature.

Finally, subclinical infections may be an important and overlooked risk factor for children (Kotloff et al., 2013). Evidence suggests that enteropathogens are excreted for several weeks following recovery from acute diarrhoea and researchers posit that some individuals may not experience diarrhoea following exposure (Levine & Robins-Browne, 2012). A study in Peru, for example, found high rates of asymptomatic campylobacteriosis (Oberhelman et al., 2003). These subclinical infections would not be captured with symptom self-reports even though they may result in diseases transmission within or between households and ultimately influence health outcomes.

Seasonal, spatial and source fluidity of food and water insecurity

Where people are reliant on rain-fed agriculture and/or subsistence agriculture, there are important seasonal differences for the availability of food. During the dry season, there may be more hunger and food insecurity, and rain immediately following the dry season often results in significant loss of surface soil through run-off (Small & Raizada, 2017).

There are seasonal risks associated with infectious agents as well, for example, with higher concentrations of *E. coli* along all transmission pathways in rural Bangladeshi households during the rainy season compared to the dry season (Ercumen et al., 2017). In contrast, a retrospective study of children presenting to Morogoro Regional Hospital, found diarrhoea, and, counter-intuitively, comorbid malaria, more common during dry season (Oketcho et al., 2012). Taken together, these studies indicate seasonal WASH-related transmission dynamics that vary by agent and locale.

In addition to seasonal, temporal risks, there are spatial risks associated with water sources. For example, there are risks from different water sources and different water management practices. Elliott et al. (2019) assert that scholars must recognise that individuals and households utilize a 'portfolio of sources' to procure water. For example, in Lesotho, households used between one and eight sources of water (Workman 2019). Many respondents reported multiple primary sources for drinking, with community taps, unprotected spring water, and even river water identified as sources. Poor quality 'dam' or pond water was routinely used for gardening, and without additional cleaning or thorough cooking of leafy vegetables, posed risk during food preparation and

consumption, and could serve as a vehicle for contamination of other surfaces including hands or water containers. One third reported using unprotected springs, river water, and even dam water for personal hygiene, introducing potential transmission pathways through indirect ingestion of water. Indeed, there are many socio-environmental behaviours that can limit the success of water interventions (Smiley & Stoler, 2020).

Even if the water fetched is safe, there is substantial risk of post-supply contamination of drinking water sources (cf. Bain et al., 2014; Wright et al., 2004). In Bagamoyo, Tanzania, researchers found statistically significant loadings of faecal indicator bacteria immediately after filling storage containers, and loads were dependent on water extraction methods such as using a ladle or cup (Harris et al., 2013). Importantly, in some cases, pathogenic *E. coli* was found in the household but not in the source water. In Lesotho, research participants considered source water pristine and did not see the need to take steps to prevent contamination nor did they routinely boil their water (Workman, 2019). Thus, water within the home used for drinking or food preparation may expose individuals to pathogens.

There are seasonal and spatial risks associated with sanitation as well. During the rainy season, latrines may 'flood out,' releasing human waste into the environment and into water sources (Jenkins et al., 2015). Latrines in lower-lying areas are clearly more prone to flooding. At the same time, water is required for cleaning a bathroom or toilet, for hand hygiene, and to separate human waste (i.e. through pouring or flushing depending on the latrine construction). Moreover, faecal sludge requires sufficient water for effective removal through vacuum emptying. Thus, hygiene and faecal sludge management are key challenges in areas facing concomitant water insecurity.

Spatially, there is differential risk in urban areas compared to rural. As people live closer together, they face increased risk from infectious and mosquito-borne diseases (Adams et al., 2020). A study in Malawi found that 70% of urban residents lived in informal settlements and faced a water insecurity through insufficient water kiosks, with those available often broken resulting in long wait times and multiple trips to fetch enough water (Adams, 2018). Additionally, in closely quartered urban areas, sanitation infrastructure may not be sufficient or may prove challenging. For example, vacuum trucks may not be able to reach all latrines, forcing people to rely on manual pit emptying, and the loss of permeable soil increases flood risk.

There are seasonal and spatial risks associated with farming and animal husbandry. For example, ruminant faecal markers are more likely in agricultural areas compared to urban and peri-urban locales and *E. coli* concentrations in groundwater often exceed WHO recommended thresholds (Malla et al., 2018). There are risks to children in rural areas from agricultural production activities (i.e. dusts, chemicals, including pesticides, and zoonotic infections) that beckon more research into the combined effects on children (Karr, 2012; Kearns, 2020).

Research & policy: recommendations for measurement and impact assessment

The synthesis of co-occurring food, water and sanitation insecurities into WASH insecurity presents implications for monitoring and evaluation. We posit that outlining complex resource insecurity allows us to assess myriad interconnections between a suite of illnesses associated with each (Workman et al., 2021). A broad definition of food insecurity entails having enough food, diverse food, and safe food. Food safety is, by definition, contingent on water and sanitation security.

Social and behavioural scientists have defined and adopted broad definitions of food insecurity (FAO, 2021), water insecurity (Jepson et al., 2017), and sanitation insecurity (Caruso et al., 2017) beyond simply access. That is, security is dependent on entitlements to sufficient, safe and culturally acceptable sources and is situated in larger political economic processes. In this vein, we have proposed a definition of WASH insecurity that parallels the advances made by scholars in food, water and sanitation securities. Scholars have demonstrated the difficulty in safe management of faecal waste and maintenance of hygiene practices. The failure of recent RCTs to produce meaningful reductions in stunting, diarrhoea, and enteropathogen burden in children indicates that

interventions are missing key pathways or are otherwise not effecting sufficient change in this vulnerable population. WASH experts have suggested that household WASH must also consider additional transmission pathways and extra-household environmental exposures (Chase & Ngure, 2016; Cumming et al., 2019; Cumming & Cairncross, 2016; Smiley & Stoler, 2020). Animals (Prendergast et al., 2019), air (Clasen & Smith, 2019), and/or chemical contamination and exposure (Kearns, 2020; Kearns et al., 2019) are under-examined and important precursors to WASH-related health outcomes. Researchers must consider sequalae of food insecurity beyond malnutrition including, for example, micronutrient deficiencies or anaemia (Ngure et al., 2014). While not within the scope of this paper, solid waste also poses risks and WASH should address the management of solid waste in addition to faecal sludge management. Our definition of WASH security incorporates these risks as well.

A. Harris asserts that we must conceive of health risks through food consumption, occurring 'from farm to feeding.' That is, along the food value chain, the risk permutations change; spatially and temporally, the relationship between the two are different in different places and at different time points (Harris et al., 2018). As discussed previously, there are exposure pathways for farmers while farming, and for farmers, food preparers and consumers when foodstuffs have been contaminated. Lack of adequate hygiene and safe water also poses a risk to family members who work outside the home or eat outside of the home as take-away food, for example, may be contaminated (Nonga et al., 2015).

Anthropologists argue that a broader anthropology of resource security should also consider the role of coping (Wutich & Brewis, 2014). Animal ownership serves as a coping strategy for economic insecurity as animals can be sold in times of financial distress. Animals also act as buffers against food insecurity. Yet, they are a significant source of pathogens and contribute directly to unsafe food and water, and challenge safe hygiene. Research indicates that because animals are culturally significant, behaviour change must be contextualised within specific animal-human relationships and preferences, such as, for example, allowing chickens to roam free (Ngure et al., 2014 Padmawati & Nichter, 2008;). Additionally, households may cope with water insecurity by compromising food security, for example, through the use of contaminated or low-quality water to irrigate crops when safe water is unavailable. We do not suggest that animals not be kept domestically or that farmers must stop irrigating their crops with the water available. We do, however, recognise that these risks occur and are important in environmental exposures and are often neglected in WASH interventions.

There are significant spatiotemporal considerations in the linkages between multiple resource insecurities. Methods assessing complex household resource insecurity or WASH insecurity must account for these connections. Longitudinal quantitative studies are critical, but a spatiotemporal perspective also speaks to the importance of qualitative and experiential data. Ethnography and qualitative methods allow individuals to articulate perceptions of risk and experiences with resource insecurity—that is, the lived experience in different places, and for different people. These connections may remain unmeasured through *a priori* identification of risk factors and are often difficult to measure empirically. Importantly, interviews and conversations allow people to telescope multiple time points and long-term experiences with resource insecurity and inequity. The expression 'you can't cook the food if you don't have the water' links food insecurity and water insecurity at multiple time points in one statement; people are able to articulate risk over time qualitatively that is difficult to capture even with extensive longitudinal designs. The connections between food and WASH are fluid and constantly shifting, reconnecting, and re-emerging, and it is critical that we allow people to articulate these linkages as they experience them directly. Syndemic theory, which is predicated on the notion that health and disease are biocultural, that diseases cluster and interact, and that individual health is shaped by one's political economic reality (Singer et al., 2017), may also offer a useful framework to understand these complex interactions and disease manifestations (Workman et al., 2021).

Finally, there are additional methodological challenges for how food insecurity can be integrated into WASH insecurity. The complexity of how resource insecurities interact also complicates our ability to measure progress, for example, towards zero hunger (Sustainable Development Goal 2). Specifically, the literature suggests that food insecurity cannot be reduced to agricultural outputs or measures of access, but rather, must capture the biocultural totality of what it means to be food insecure while also acknowledging the importance of safe, diverse, and culturally acceptable foods. Food and water linkage through time are much more complex than drop-per-crop approaches. Indeed, we must think beyond output to incorporate not only nutrition, but also the role of psycho-emotional distress, infectious disease and chronic illness resulting from WASH insecurity. We, too, must conceptualise indicators beyond stunting and diarrhoea as the sole measurable outcomes given the multitude of determinants for both. As humans consume animals, food security necessarily entails merging animal health and human health. The integration of food security, in its broad conceptualisation, and WASH security is a key avenue for additional future research and hypothesis generation.

A Way forward

This paper outlines complex linkages and pathways between and among resource insecurities and health. The evidence suggests a plurality of risks faced by individuals and highlights the importance of co-occurring and intersecting illnesses. Moreover, there are distal and proximate risks to human health that are important to understanding interconnections among concurrent resource insecurities. For example, there are long term physical and cognitive effects of early exposures to food and water insecurity, both in utero and among young children. Public health and biomedical research should also continue to examine the importance of polymicrobial infections or the importance of specific pathogens in severe negative outcomes, including but not limited to diarrhoea and stunting. Along with source tracking, such research would allow for more targeted interventions.

Medical anthropology has contributed much to our understanding of the social determinants of health, and syndemic theory offers one vehicle to synthesise social and natural sciences. For example, co-occurring infections challenge us to better identify unusual and atypical presentation, as is common in syndemics (Singer & Bulled, 2012). Similarly, concurrent infections may 'mask' one another for example, enteric illness may be masked by or misdiagnosed as malaria (Reyburn et al., 2007). Medical anthropology also highlights the importance of culture in how disease and risk are understood and experienced. Therefore, we must incorporate local understandings of the linkages between food and WASH insecurities and human health, particularly zoonoses and neglected tropical diseases.

Results from the WASH Benefits and SHINE trials suggests the need for increased research across scales to better identify the plurality of exposure pathways for effective interventions. Children and adults may come into contact with enteropathogens in the environs surrounding the house, or far from home, for example, at school and/or the market. Social scientists recognise the plurality of caregiving approaches globally, including those beyond the mother/child dyad. WASH infrastructure is therefore required at schools and health centres to provide a more comprehensive protection beyond the household.

We emphasise the need to also study gender relations, and other intra-household relations and entitlements of food and water. Decades of gender mainstreaming has not ensured resource equity for either food or water resources (Cornwall & Rivas, 2015). Indeed, these policies are laden with assumptions about participation and empowerment and often fall short of their desired aims (Cairns et al., 2017). Similarly, we see variation in resource security based on age, for example, dual burden households in which there are both malnutrition and obesity in children and adults, respectively (Doak et al., 2005). This speaks to the importance of ongoing research exploring differential risks.

Conclusion

Many comorbid illnesses and pathogens are exacerbated by multiple co-occurring resource insecurities. Multi-scale and biocultural frameworks, as well as quantitative and qualitative methodologies, can elucidate under-recognized risk pathways by situating disease within larger political economic processes and recognising the fluidity of human social and environmental relations. Real WASH security, we argue, goes beyond infrastructure, and entails concomitant food, water, and sanitation securities. The risks posed by multiple resource insecurities also shift depending on the individual, their movement throughout their day, their economically and socially prescribed roles, and ecological features such as seasonality and precipitation. By more fully integrating food, water, and sanitation security in interventions and subsequent impact evaluations, we can achieve WASH security—one that addresses myriad transmission pathways and syndemic diseases—to improve health outcomes throughout the world.

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