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Getting the basic rights – the role of water, sanitation and hygiene in maternal and reproductive health: a conceptual framework

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Abstract

OBJECTIVE To explore linkages between water, sanitation and hygiene (WASH) and maternal and perinatal health via a conceptual approach and a scoping review.

METHODS We developed a conceptual framework iteratively, amalgamating three literature-based lenses. We then searched literature and identified risk factors potentially linked to maternal and perinatal health. We conducted a systematic scoping review for all chemical and biological WASH risk factors identified using text and MeSH terms, limiting results to systematic reviews or meta-analyses. The remaining 10 complex behavioural associations were not reviewed systematically.

RESULTS The main ways poor WASH could lead to adverse outcomes are via two non-exclusive categories: 1. 'In-water' associations: (a) Inorganic contaminants, and (b) 'water-system' related infections, (c) 'water-based' infections, and (d) 'water borne' infections. 2. 'Behaviour' associations: (e) Behaviours leading to water-washed infections, (f) Water-related insect-vector infections, and (g-i) Behaviours leading to non-infectious diseases/conditions. We added a gender inequality and a life course lens to the above framework to identify whether WASH affected health of mothers in particular, and acted beyond the immediate effects. This framework led us to identifying 77 risk mechanisms (67 chemical or biological factors and 10 complex behavioural factors) linking WASH to maternal and perinatal health outcomes.

CONCLUSION WASH affects the risk of adverse maternal and perinatal health outcomes; these exposures are multiple and overlapping and may be distant from the immediate health outcome. Much of the evidence is weak, based on observational studies and anecdotal evidence, with relatively few systematic reviews. New systematic reviews are required to assess the quality of existing evidence more rigorously, and primary research is required to investigate the magnitude of effects of particular WASH exposures on specific maternal and perinatal outcomes. Whilst major gaps exist, the evidence strongly suggests that poor WASH influences maternal and reproductive health outcomes to the extent that it should be considered in global and national strategies.

keywords water, sanitation, hygiene, maternal health, reproductive health, perinatal health, life course

Introduction

As 2015 draws closer, there is much debate at an international level as to what will follow the Millennium Development Goals (MDGs) (Horton 2012). The unfinished MDG agenda has been discussed and a desire to complete work on current MDGs stated (The United Nations 2012). Yet it has also been argued that the sector-specific goals and targets embodied in the MDGs resulted in missed opportunities in terms of potential implementation synergies (Waage *et al.* 2010). Elsewhere, the limited progress on reducing the 'equity gap' under the MDGs has been raised as a major concern (Chopra *et al.* 2012). This article focuses directly on the potential synergies and links between improving maternal, newborn and reproductive health and safe water, sanitation and hygiene (WASH) and proposes a conceptual framework for understanding them.

The MDG7 target for water and sanitation calls for the 'halving of the proportion of the population without

sustainable access to safe drinking water and basic sanitation' by 2015 (United Nations General Assembly 2000). The water target was declared as met in 2010, although 780 million people remain without safe water, whilst the sanitation target is seriously off track and unlikely to be met by 2015, with 2.5 billion people still lacking access (UNICEF, WHO 2012). Coverage of these services is lowest in the poorest regions and countries of the world, and most acute among the poorest populations in these settings (UNICEF, WHO 2011). There was no target for hygiene in MDG7, nor it is consistently measured in global or national WASH monitoring systems.

Assessments of the disease burden associated with poor WASH are dominated by diarrhoeal disease mortality and acute morbidity (Guerrant *et al.* 2002). Whilst diarrhoeal mortality is reducing, it still accounts for 10% of all child deaths (Liu *et al.* 2012) and morbidity has declined only slightly since 1990 (Fischer Walker *et al.* 2012). There is good evidence for the effect of WASH on a range of other health outcomes, including acute respiratory infections (Rabie & Curtis 2006), soil-transmitted helminth infections (Ziegelbauer *et al.* 2012) and diseases associated with chemical contamination of water (Fewtrell *et al.* 2005). Combining multiple health effects, WHO estimates that unsafe WASH is responsible for almost one-tenth of the global disease burden (Prüss-Üstün *et al.* 2008). To date however, we are unaware of any quantification of the effects of poor WASH on maternal and perinatal health.

Under MDG5, target 5a is 'to reduce maternal mortality by three-quarters by 2015' (United Nations General Assembly 2000). Influential frameworks for improving maternal mortality – such as the 'Three Delays' (Thaddeus & Maine 1994) and the 'Continuum of Care' (Partnership for Maternal Newborn & Child Health 2011) models – focus almost exclusively on improving access to, and the quality of, maternal health services, with little focus on the wider social and environmental determinants. This emphasis on health services recurs for the MDG5b targets, which address contraceptive coverage and antenatal care services.

In this study, we explore tentative and confirmed linkages between WASH and maternal and perinatal health using scoping review methods and present a conceptual approach for systematically describing these. Our aim is to provide a broad-ranging conceptualisation that may then be used to guide a process of gathering epidemiologic data on the potential impact of the various risk factors on the ill health of mothers and foetuses/newborns. Although beyond the scope of this study, estimating the contribution of these risk factors to ill health at the population level (population attributable fractions) could then form the basis for identifying and harnessing policy, advocacy and programming synergies that will lead to more effective, efficient and equitable investments in both sectors. We end by identifying research gaps, which, if addressed, would strengthen this framework and lead to greater policy coherence and more effective interventions.

Methods

Miles and Huberman (1994) state that a conceptual framework 'lays out the key factors, constructs or variables, and presumes relationships among them'. Methods for developing frameworks vary, but ours was developed iteratively, using our experiential knowledge (including our technical knowledge and research background) and our literature review that included previous related theory and research, and concepts that had been used to represent similar problems (Novak & Canas 2008). The aim of the framework was to classify and organise the concepts and emphasise connections between them. Our conceptual framework amalgamated three main perspectives: a gender-based lens focusing on health inequalities (Kirschstein 1991), the classification of WASH-related health outcomes (White *et al.* 1972) and the longer-term perspective afforded by a life course approach (Kuh *et al.* 2003; Mishra *et al.* 2010). We applied these perspectives to information extracted from an exploratory literature review that, whilst not systematic, included electronic searches of PubMed and Google Scholar among others, and manual searching of references within key articles. We also searched all the 'mode of transmission' and 'susceptibility' headings in the Control of Communicable Disease Manual, 19th edition (Heymann 2008), to assess whether transmission for each infectious disease was WASH-related and whether women (or pregnant women and their foetuses/newborns) were at particular risk. We ended by further refining the framework in the light of this targeted search. Through these searches, we identified 77 potential factors that we categorised within our framework.

We followed with a more targeted scoping with the objective of providing an overview of the existing evidence linking the identified 77 exposures to reproductive and maternal health outcomes, whilst recognising evidence gaps (Arksey & O'Malley 2005; Levac *et al.* 2010). We systematically searched Medline and Embase databases, combining text and MeSH terms for maternal and newborn health among humans with text and MeSH terms for identified 67 chemical and biological mechanisms of exposure. We limited the results of each search to references containing text or MeSH terms for systematic reviews or meta-analyses. We placed no limitations on the date of publication or the language of manuscript.

All search results were exported to an EndNote database and screened by one co-author (LB or GG). Systematic reviews that considered the association between any aspect of reproductive or maternal health and the presence or prevention of any of the 67 exposures were identified. The remaining ten behavioural exposures are complex phenomena and would require collaboration with experts from fields beyond public health, such as anthropology, economics and sociology to identify target search terms, databases and grey literature. We did not do a systematic scoping review for these exposures as it was beyond our resources. However, we present individual studies and reports linking reproductive and maternal health to these ten exposures. Webtable S1 presents the complete listing of the 77 identified mechanisms and indicates availability of systematic reviews and other evidence based on our searches. Only the mechanisms for which links (systematic or other) with reproductive and maternal health were identified are presented in Webtable S2, along with a brief summary of the findings.

We first present the lens or framework (gender lens, WASH transmission framework and the life course perspective) and then the evidence to support posited effects.

Results

Gender inequalities

Much of the debate in recent decades around the need for epidemiological theory has been in relation to understanding and addressing health inequalities (Krieger & Zierler 1996; Susser & Susser 1996). Our first lens is explicitly gender inequality, although we refer to other inequalities such as poverty or urban/rural divides where they have been described.

Both biology and gendered behaviour contribute to differences in men's and women's health (Kirschstein 1991; Weisman 1997). The National Institutes of Health (NIH) distinguishes women's health as diseases or conditions 'unique to women or some subgroup of women; more prevalent in women; more serious among women or some subgroup of women; for which the risk factors are different for women or some subgroup of women; and for which the interventions are different for women or some subgroup of women' (Kirschstein 1991). As most WASH-related diseases or conditions affect both men and women, we used this definition to highlight those particularly relevant to women in general and to mothers more specifically. If pregnant women were not particularly susceptible, exposed, or affected, but their exposure to WASH-related hazards affected the foetus or newborn, we also highlighted such effects (Kourtis *et al.* 2014).

WASH impacts

Figure 1 summarises the main ways in which water or sanitation or hygiene can plausibly lead to ill health, distress, harmful behaviours or other adverse outcomes, grouped in two main dimensions: (i) 'in water' – microorganisms or chemicals in water and (ii) 'behaviour' – actions or cultural aspects related to WASH, including aspects relating to the location of the water point or sanitation facility. We sought to understand how WASH affects health in general and where women, pregnant women, foetuses or newborns are particularly affected.

The Figure 1 framework builds on the Bradley classification which identified four principal pathways of water-related disease transmission: 'water-based', 'water-borne', 'water-washed' and 'water-related' (White *et al.* 1972). The first two categories are grouped in the 'in-water' dimension, which also incorporates subsequent adaptations (Kistemann 2004) to allow for aerosol transmission (Bartram *et al.* 2007), chemical contaminants (Dar & Khan 2011) and chemicals deliberately added to maintain water systems or as public health measures (Ashbolt 2004). The third and fourth Bradley categories are grouped under our 'behaviour' dimension, combining 'water-washed' and 'water-related' with three more 'behaviour' categories related to the hazards of location, distance and perceptions of availability or stigma. Our categorisation is influenced by Cairncross and Feachem's (1993) observation that most faecal–oral infections can be water-washed and that behaviours linked to scarce water, poor sanitation and hygiene can affect these (Wagner & Lanoix 1958). The location and nature of water supply also affects water-related insect vector transmission. For example, wastewater stabilisation ponds can increase mosquito breeding sites (Cairncross & Feachem 1993; Mukhtar *et al.* 2006). Below, we give evidence for these associations grouped by the two dimensions of 'in water' and 'behaviour' in the order shown in Figure 1. Webtable S1 presents a detailed list of various transmission routes or mechanisms that may potentially affect health or well-being and summarises the availability of evidence of their impact on women, foetuses or newborns (systematic reviews, other evidence or no evidence). We were able to identify evidence of association for 47 of the 77 identified exposure mechanisms and found at least one systematic review for 30 of the 67 mechanisms for which we conducted a search for systematic reviews.

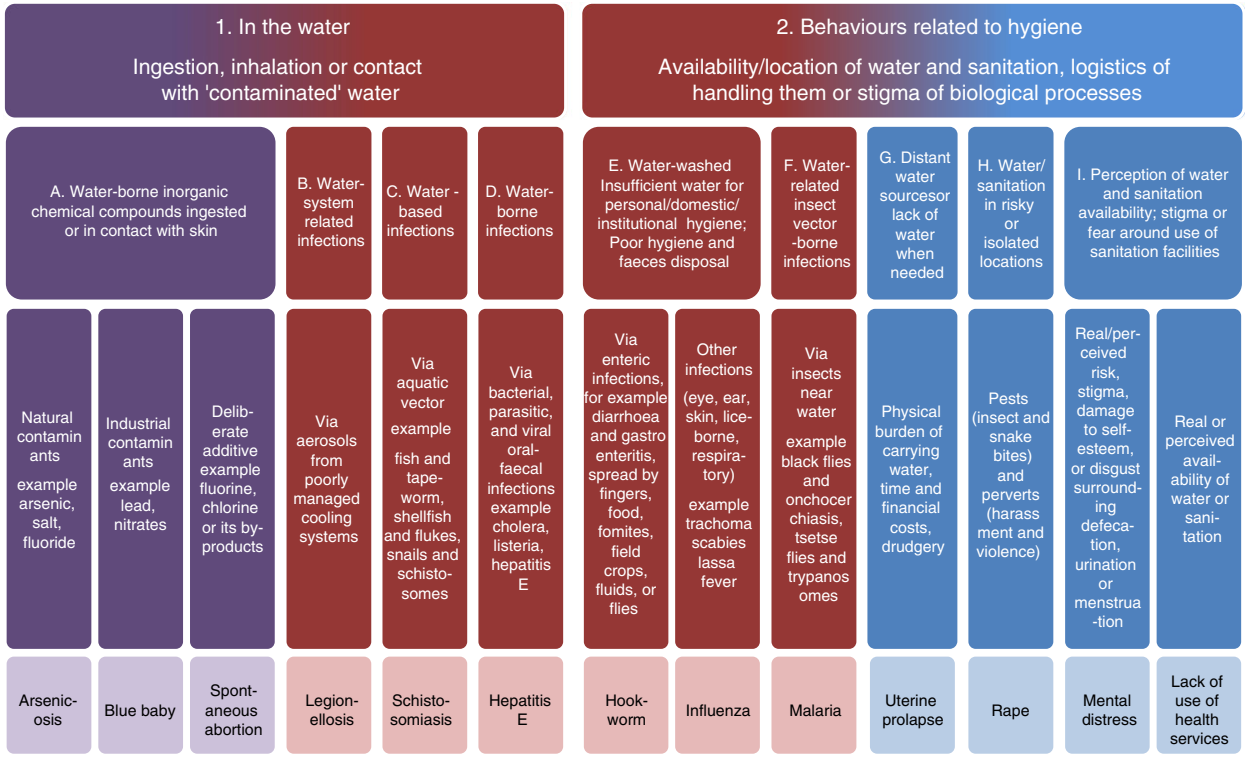

Figure 1 Dimensions, components and examples of health effects in conceptual framework linking water, sanitation and hygiene (WASH) with maternal and reproductive health.

Pathways linked to agents in water

Inorganic contaminants. The 'in-water' associations relate to two main areas: (i) inorganic contaminants and (ii) infectious agents. Many settings have high naturally occurring levels of arsenic and fluoride in groundwater. Studies have linked exposure to arsenic in drinking water with higher risks of spontaneous abortion (Milton *et al.* 2005; Rahman *et al.* 2007), stillbirth (Cherry *et al.* 2008) and infant mortality (Rahman *et al.* 2010), and fluoride has been associated with low birthweight (Diouf *et al.* 2012) and skeletal fluorosis (Bo *et al.* 2003). It has been estimated that in the coastal areas of Bangladesh, increasing saline intrusion during the dry season results in people consuming 2.5–8 times the recommended salt intake, potentially leading to hypertensive disorders of pregnancy (HDP) (Khan *et al.* 2011).

Industrial contaminants, particularly metals, in drinking water raise concerns for pregnant women, with a systematic review showing adverse effects of metal exposure on placental function and foetal development (Caserta *et al.* 2013), as well as neurodevelopment and other effects in children (Pocock *et al.* 1994; Ferris *et al.* 2008). Exposure to mercury, potassium or lead, for example, is associated with spontaneous abortion (Aschengrau *et al.* 1989) and congenital malformations (Vahter *et al.* 2002; Bellinger 2005). Lead is nephrotoxic and can progressively lead to renal failure, gout and hypertension, all risk factors for HDP (Nolan & Shaikh 1992; Ekong *et al.* 2006). Prenatal exposure resulting in maternal blood lead levels of >10 μg/dl can adversely affect fertility, hypertension, infant neurodevelopment and foetal growth (Bellinger 2005).

Systematic reviews of exposure to agricultural pesticides and herbicides – that may be consumed via contaminated surface or groundwater – have shown that whilst there is inconclusive evidence for an association between residential proximity to agricultural pesticides and adverse pregnancy outcomes (Shirangi *et al.* 2011), systematic reviews of parental exposure to specific pesticides show these to be associated with specific cancers and other adverse outcomes among children (Lopez Duenas *et al.* 2012; Nicolle-Mir 2012). Some studies have shown that pregnant women and their foetuses are particularly susceptible to effects of nitrates (Calderon 2000), including spontaneous abortions, intrauterine growth

restriction, congenital malformations and methaemoglobinaemia (blue baby syndrome), although a systematic review suggests these links are inconclusive (Manassaram *et al.* 2006). Endocrine-disrupting compounds mimic and/or block effects of endogenous hormones and have been associated with earlier age at menarche in a systematic review (Yermachenko & Dvornyk 2013). Early age at menarche is associated with earlier age at first sex, and earlier pregnancy, which in turn, is associated with worse pregnancy outcomes. Endocrine disrupters have also been linked to altered ovarian function, impaired fertility and changed placental function (Balabanič *et al.* 2011; Buttke *et al.* 2012; Fowler *et al.* 2012) and to a higher risk of spontaneous abortions and low birthweight (Calderon 2000; Balabanič *et al.* 2011), although systematic review results of these are inconclusive (Peters *et al.* 2010; Caserta *et al.* 2011). It is generally agreed that disinfection by-products may potentially cause spontaneous abortions (Waller *et al.* 1998), stillbirths (King *et al.* 2000), birth defects (Cedergren *et al.* 2002) and small-for-gestational-age infants (Grellier *et al.* 2010). Some of these associations are supported by systematic reviews.

Water-system-related infections. The second subgroup within the 'in-water' dimension concerns infectious agents in the water, grouped in the additional 'water-systems' category and Bradley's 'water-based' and 'water-borne' categories (Categories C and D in Figure 1). Whilst water systems can spread infection via poorly maintained air-cooling systems and cause Legionnaires' disease, this is uncommon and affects the general population without posing particular risks to women (Heymann 2008), so are not considered here, although the category is included in Figure 1 for completeness.

Water-based infections. Water-based infections are transmitted via aquatic vectors, such as snails, fish or crustaceans, in which part of the life cycle of the infective agent occurs. Schistosomiasis is notable from a maternal/reproductive health perspective as genital schistosomiasis is associated with cervical cancer (Feldmeier *et al.* 1995; Moubayed *et al.* 1995), ectopic pregnancy and infertility (Swai *et al.* 2006); and in pregnant women, it is associated with anaemia (Abdelgadir *et al.* 2012), undernutrition (King *et al.* 2005) and inflammation (Kurtis *et al.* 2011). It can also affect foetal immune response (Seydel *et al.* 2012), leading to foetal inflammation (Kurtis *et al.* 2011) and low birthweight (Siegrist & Siegrist-Obimpeh 1992; Qunhua *et al.* 2000). However, there are no systematic reviews. Other water-based infections, such as dracunculiasis (guinea worm) or diphyllobothriasis (tapeworm), are not known to pose specific risks to women, although pregnant or lactating women may be excluded from treatments if drugs had not been tested in pregnant women and are thus contraindicated (Gyapong *et al.* 2003). Exclusion from treatment because of pregnancy or breastfeeding applies also to other WASH-related diseases and conditions (Maduka *et al.* 2004).

Water-borne infections. Water-borne infections are directly transmitted by micro-organisms in water, the classic example being cholera. Here, we consider those that differentially affect women, such as Hepatitis E, with higher incidence, greater severity of symptoms and elevated mortality rates among pregnant women (Emerson & Purcell 2004; Heymann 2008; Aggarwal & Naik 2009). It is also associated with a greater risk of stillbirth (Rein *et al.* 2012).

Pathways linked to behaviour

Most water-borne infections are faecal–oral and overlap with the water-washed category and so are captured in the second dimension of 'behaviour'. This dimension concerns the health effects posed by behaviour relating to WASH. Cairncross and Feachem's redefinition of the water-washed category included infections spread by behaviours stemming from a lack of water or from poor hygiene, including personal and domestic hygiene, and hygiene in the public domain such as in educational establishments and workplaces, including health facilities (Cairncross *et al.* 1996).

Water-washed infections. There are many examples of water-washed infections. Evidence in this area can be dated at least as far back as the elegant work of Gordon (1795) and Semmelweis (1983) demonstrating the association between puerperal sepsis and poor hygiene of birth attendants, a theory later strengthened by the discovery that the causal agent was Streptococcus A, a water-washed infection. Sepsis in pregnancy or the puerperium is mainly caused by unhygienic practices and poor infection control, including lack of hand-washing, unclean surfaces and unhygienic vaginal examination or cord-cutting in health facilities or in the home (Ali *et al.* 2006; Darmstadt *et al.* 2009). Tetanus is another important contributor to mortality of mothers and newborns, and tetanus toxoid vaccination among pregnant women reduces neonatal death and morbidity (Fauveau *et al.* 1993; Demicheli *et al.* 2005; Roper *et al.* 2007; Kourtis *et al.* 2014). Staphylococcus can be another common cause of puerperal or newborn infection (Heymann 2008).

Some intestinal worm infections can also be classified as water-washed. An estimated 6.9 million pregnant women in sub-Saharan Africa are infected with hookworm, and systematic reviews show they are at risk of hookworm-related anaemia (Brooker *et al.* 2008). Hookworm infestation in pregnancy is associated with decreased infant birthweight and intrauterine growth retardation (Christian *et al.* 2004), and a systematic review indicated that maternal antihelminthic treatment reduced stillbirths (Menezes *et al.* 2009). Systematic reviews of ascariasis and trichuriasis showed them to be associated with maternal anaemia (Noronha *et al.* 2012) and with stunting and cognitive deficits, respectively (Ruma *et al.* 2008). Helminth infections are also associated with increased susceptibility to HIV/AIDS, malaria and tuberculosis (Fincham *et al.* 2003; Le Hesran *et al.* 2004; Elias *et al.* 2007).

Systematic reviews indicated that the most common non-malaria bloodstream infection among pregnant women admitted to hospital in reviews of studies from both Africa (Reddy *et al.* 2010) and Asia (Deen *et al.* 2012) is *Salmonella enterica*, to which pregnant women have greater susceptibility (Smith 1999). *Salmonella* can result in spontaneous abortion (Smith 1999). Listeria, another water-borne/water-washed infection, has an annual infection rate over 17 times higher among pregnant women (Southwick & Purich 1996), who account for 27% of all listerial infections (Janakiraman 2008). Exposure in pregnancy is associated with spontaneous abortion (Heymann 2008), stillbirth and preterm delivery (Goldenberg & Thompson 2003). The latter association is confirmed in systematic reviews (Lamont *et al.* 2011; Semedo Leite *et al.* 2012). A systematic review of neonatal melioidosis suggested that vertical transmission exists (Thatrimontrichai & Maneenil 2012), whilst a systematic review of Yersinia infection showed it to be associated with adverse pregnancy outcomes (Semedo Leite *et al.* 2012). The only study found by a systematic review of antenatal genital tract screening and treatment for lower genital tract infection (GTI) showed a reduced risk of preterm birth and preterm low birthweight (Xiong *et al.* 2006). Pregnant women face increased susceptibility to influenza, with increased severity of illness (Jamieson *et al.* 2006). A systematic review showed higher rates of hospitalisation, ICU admission and death among pregnant women during the 2009 A(H1N1) flu pandemic (Mosby *et al.* 2011).

Water-related insect vector-borne infections. Numerous water-related insect vector infections are transmitted via mosquitoes (malaria, dengue, lymphatic filariasis and yellow fever), tsetse flies (trypanosomiasis) and black flies (onchocerciasis) that live or bite near water. Some of these, namely malaria and dengue, pose specific risks related to women. Pregnant and post-partum women, particularly primi- and secundi-gravidae, are more susceptible to malaria (Boel *et al.* 2012; Chico *et al.* 2012), whereas more subclinical presentation obscures detection and treatment (Desai *et al.* 2007). Malaria in pregnant women is associated with an increased risk of anaemia and severe anaemia (Shulman *et al.* 2002). An estimated 0.5–23.0% of maternal deaths in high transmission areas and 0.6–12.5% in low transmission areas are caused by malaria (Brabin & Verhoeff 2002). Infection with malaria also increases risk of spontaneous abortion (McGready *et al.* 2012), stillbirth (Goldenberg & Thompson 2003) and intrauterine growth retardation (Steketee *et al.* 2001) and leads to anaemia in newborns (van Eijk *et al.* 2002). Systematic reviews of malaria prevention show significant reductions in severe maternal anaemia, low birthweight, perinatal mortality (Desai *et al.* 2007) and stillbirth (Menezes *et al.* 2009; Barros *et al.* 2010; Ishaque *et al.* 2011). Mosquitoes that transmit dengue breed in water-storage containers. General symptoms include internal bleeding, shock and death, but in pregnant women, dengue has been associated with higher maternal mortality (Mota *et al.* 2012) and spontaneous abortion (Tan *et al.* 2012). A systematic review showed conclusive evidence of dengue vertical transmission but inconclusive evidence on adverse pregnancy outcomes (Pouliot *et al.* 2010). Another systematic review showed evidence of vertical transmission of trypanosomiasis, although the absolute risk is unknown (Lindner & Priotto 2010).

Distant water sources or lack of water when needed. The 'behaviour' dimension also includes WASH-related behaviours that lead to non-infectious diseases or conditions. These include physical aspects of carrying heavy water loads or disposing of faeces, time or money spent on these activities, risks associated with the location of water or sanitation points, and behaviours related to the actual or perceived availability of WASH or to the real or perceived risk of stigma/disgust around the biological processes of defecation, urination or menstruation.

Data from households in 45 countries show two-thirds of drinking water is collected by women (UNICEF, WHO 2011). Carrying heavy loads is associated with spinal compression, injuries to the spinal column and increased risks of degenerative rheumatism (Dufaut 1988). It can also cause hernia and genital prolapse (Jorgensen *et al.* 1994) and may increase the risk of spontaneous abortion (Florack *et al.* 1993; Figà-Talamanca

2006). Sub-Saharan African studies estimated that an average of 10% of the carrier's daily calorie intake was spent carrying water (Rosen & Vincent 1999). Handling child faeces and socialising children into using sanitation facilities can also expose individuals to risk; women and girls are much more likely to perform these roles (Hannan & Andersson 2002; Gil *et al.* 2004).

The financial and opportunity costs of obtaining and treating water, doing laundry, managing menstruation and treating WASH-related illnesses can consume a significant share of poor families' resources. In Africa, it is estimated that water collection accounts for 40 billion hours a year, and the potential reduction in time-lost, poverty and drudgery through better access to water is substantial (Bardasi & Wodon 2006; Lawson 2007). In Pakistan, greater distances from water sources led to reduced participation in income-generating activities for women (Ilahi & Grimard 2000). Households often pay unofficial suppliers of water (often of substandard quality) (Semba *et al.* 2009), and prices charged are typically >10 times the formal water supply tariff (Cairncross & Kinnear 1992). Studies show that reduction in time spent on water-related chores translates into improved school attendance among girls (Koolwal & van de Walle 2010; Nauges & Strand 2011).

Water and sanitation in isolated locations. Distant locations of water and sanitation pose other risks, such as snakebites associated with open defecation in fields (Singh *et al.* 2008), and it is known that flies, mosquitoes and cockroaches are common in humid and dark latrines, posing a nuisance, and an occasional risk of harm to health (Curtis & Minjas 1985). Because women take longer to use sanitation points and pregnant women urinate more frequently, they may be exposed to these risks for longer. Other dangers are men taking advantage of the isolated location of latrines to harass, or sexually assault women (Cairncross 2003) – rape and violence against women on the way to or from public toilets and open defecation sites have been widely reported (Amnesty International 2010; Lennon 2011; Massey 2011).

Perception of water and sanitation availability. The actual or perceived absence of WASH can lead individuals to adopt harmful behaviours, such as reductions in water use and food consumption (Cairncross & Cliff 1987; Gadgil 1998) and substitution with alcohol (Mamman *et al.* 2002; Potukuchi & Rao 2010). Optimal hydration is necessary for health and cognitive functioning; fluid restriction and inadequate personal hygiene may lead to GTI or urinary tract infections (UTI) (Bledsoe *et al.* 1994; Nygaard & Linder 1997; Amiri *et al.* 2009), which in turn are associated with preterm birth, low birthweight, pre-eclampsia and anaemia (Lettieri *et al.* 1993; Schieve *et al.* 1994; Conde-Agudelo *et al.* 2008; Mazor-Dray *et al.* 2009; Minassian *et al.* 2013).

Defecation, menstruation and urination can be associated with stigma and consequently damage self-esteem. These biological processes are considered private, if not shameful, in most societies, and a lack of WASH facilities may result in individuals experiencing fear and significant psychological distress. Inadequate toilet provision, especially in low-income urban areas, leads to women's concerns that they cannot maintain their self-respect and social reputation, poses physical safety risks to themselves and their children, increases financial costs and leads to social stigma for living without adequate services (Amnesty International 2010). Women report feeling pressure to use sanitation facilities only at certain times (Massey 2011). The principal benefits from completed water supply projects were identified as less tension/conflict, improved self-esteem, women's empowerment, women's hygiene (e.g. menstrual), improved school attendance and teachers accepting village postings (Cairncross & Valdmanis 2006).

Menstrual hygiene and hygiene after delivery to manage lochia require water and clean, private toilets and either reusing cloths that have been adequately cleaned and dried, menstrual cups or using single-use pads. Women feel a strong pressure to hide signs of menstruation and resort to reuse of unhygienic moist menstrual rags. Studies link poor menstrual hygiene to urinary or reproductive tract infections and other illnesses (Wasserheit *et al.* 1989; Younis *et al.* 1993), including toxic shock (Heymann 2008), subsequent pelvis inflammatory disease, infertility and pelvic pain (Ahmed & Yesmin 2008).

Lastly, the availability of WASH is also important in making education establishments and health facilities acceptable to both employees and users. Improvements in water supply were associated with increased uptake of teaching posts in Ghana (Adugna *et al.* 2001). Many have posited that a lack of sanitation and hygiene contribute to truancy, failing classes, absenteeism and drop out, particularly in the transition from primary to secondary schools (Fakeye & Adegoke 1994; Abioye-Kuteyi 2000; Jones & Finlay 2001), although a systematic review of the evidence on the benefits of same-sex toilets in schools for retention of adolescent girls is inconclusive (Birdthistle *et al.* 2011). Healthcare providers ranked lack of water and sanitation points as important reasons for refusing to accept rural postings (Henderson & Tulloch 2008).

Life course

The final lens, that of the life course, examines impacts at these different time points, seeking to understand how effects at one age impact across the lifespan, including via intergenerational influences on foetal development and growth (Ben-Shlomo & Kuh 2002). Adopting the life course approach and adding it to the modified WASH framework and to the lens of gender inequality helps identify whether WASH impacts health beyond its immediate effects and presents longer-term consequences, perhaps at a later life stage or intergenerationally.

In its simplest form, life course theory allows for an effect at one age to act at a later age. For example, infection with *Escherichia coli* has been associated with pregnancy-related hypertension 5 years after infection (Moist *et al.* 2009). Many WASH-related hazards have intergenerational effects; either because contaminants or infectious agents pass through the placenta and affect the foetus, or because they have systemic effects on the mother, such as fever, an altered immune response including inflammation, low weight gain, absorption into bone or anaemia. The consequences for the foetus include spontaneous abortion and stillbirth, but also malformations, infections, anaemia, preterm birth or low birthweight in the newborn. For example, hookworm infection in young women may lead to anaemia, including in pregnancy, which is associated with low birthweight. Low birthweight in turn is associated with cognitive impairment, learning disability and behavioural problems among children; poor anthropometric status in childhood; higher risk of delivering a low birthweight baby in reproductive age; higher arterial blood pressure, chronic kidney disease, ischaemic cardiomyopathy, stroke, diabetes and respiratory disease in adulthood (Rich-Edwards *et al.* 1997; Barker *et al.* 2002; Whincup *et al.* 2008).

Many risks resulting from disadvantage or poor WASH accumulate. Gender discrimination against girls and women, in terms of access to food, care, education and work, begins in infancy and can determine later life outcomes. Chronic and recurring hookworm infection throughout childbearing age, when women are menstruating, can have a chronic effect on women's iron levels, with iron-deficiency anaemia being especially common in adolescent girls and women of childbearing age (Brooker *et al.* 2008). Hookworm and schistosoma infections are associated with increased incidence of malaria (Adegnika & Kremsner 2012), and malaria itself can also cause severe anaemia. WASH-related pathogens (especially those causing diarrhoea) lead to reduced food intake and the malabsorption of nutrients causing undernutrition, which makes repeat infections more likely (Brown 2003), by increasing the susceptibility to diarrhoea and severity of diarrhoeal episodes (Lima *et al.* 2000; Checkley *et al.* 2008).

The critical window within the life course approach is illustrated by the 0–2-year age group. Repeated infection with excreta-related pathogens, including worms, in early life leads to growth faltering and stunting (Guerrant *et al.* 2012). Stunted children have little opportunity to catch up later and grow to be short adults. Short women face an increased risk of cephalo-pelvic disproportion, obstructed labour and death and are more likely to have a Caesarean section and low birthweight infant (Song *et al.* 2009; Tsvieli *et al.* 2012). Repeated Caesarean section increases the likelihood of ruptured uterus and placenta praevia, both of which are risk factors for death (Rossi & D'Addario 2008; Main *et al.* 2012).

Discussion

The conceptual approach taken here brings together three requisite components for understanding the potential linkages between WASH and maternal and perinatal health: gendered health effects, WASH-related disease transmission and the longer-run life course risks. The framework suggests that WASH affects the risk of adverse maternal health outcomes but that these exposures are multiple and overlapping and may be distant from the immediate health outcome. Our conceptual framework reflects this by taking a life course approach, allowing for risk accumulation and intergenerational effects combined with an equity or gender lens, then linked to the more traditional classification of diseases by transmission.

Much of the evidence underpinning this framework is surprisingly weak, based on biological plausibility, observational studies and in some cases anecdotal or circumstantial evidence. We found relatively few systematic reviews addressing these topics. For example, despite numerous advocacy claims, the evidence that lack of school sanitation leads girls to dropout or that poor menstrual hygiene causes reproductive tract infections is almost non-existent. However, where direct evidence exists, it confirms the view that adequate WASH may confer substantial benefits to maternal health. Further strengthening of this evidence base is critical and the conceptual framework presented here offers a basis for identifying major research gaps. In particular, systematic reviews are required to more rigorously assess the current quality of evidence for the various exposure/outcome relationships included. Primary research is required to investigate the nature and magnitude of effects for particular WASH exposures (such as improved hygiene practice

in birth settings, sustained and heavy water collection and unsanitary menstrual cloths) on specific maternal and reproductive as well as neonatal and child health outcomes.

Additional work is also required to quantify the population-level impact (population attributable fraction) in relation to maternal and reproductive health outcomes across different settings to assess where WASH may have greater or lesser importance. Finally, in the light of the recent publication of the Global Burden of Disease 2010 estimates (Murray *et al.* 2012), risk factor analyses for WASH may need to be expanded for the outcomes, such as and maternal morbidity, not currently included in these reference models which tend to focus primarily on childhood diseases (Ezzati *et al.* 2005). Once these WASH and maternal and reproductive health relationships are quantified, the scope needs to be widened to include these elements in the disease burden and take account of the complex ways in which factors interact and produce a range of direct and indirect risks (Watts & Cairncross 2012).

Whilst major gaps exist, the evidence is strongly suggestive of poor WASH influencing maternal and perinatal health outcomes to the extent that it should be considered in global strategies and national policy (Benova *et al.* 2014a; Gon *et al.* 2014). Current evidence precludes reliable estimates of the magnitude and potential of any impact, so that the degree of priority against other critical interventions or services – for example births with skilled attendance, emergency obstetric care, female education – is not clear. However, improved WASH is a human right, and a health and development priority in its own right, irrespective of its role in improving maternal and reproductive health. As a cost-effective and proven public health intervention, WASH services should be scaled up as a matter of urgency and the evidence for links to maternal and reproductive health only reinforces this case (Bartram & Cairncross 2010).

More pertinent here is whether either sector – maternal and reproductive health or WASH – should adjust its approach to harness the potential synergies suggested by the framework. In this area, we feel justified in suggesting options for consideration and discussion by governments, technical experts and civil society. To simplify these recommendations, we consider two domains: home births and facility births. In the case of domestic births, which account for 54% of births in sub-Saharan Africa (UNICEF 2012), joint planning in providing and targeting services would enable better coordination of resources towards reaching those most at risk. Within a broader strategy to have all births taking place in adequately equipped facilities, improving the environmental conditions for pregnancy, delivery and neonatal care for populations with poor access to health facilities is critical, even if this is an interim measure as part of longer-term strategy. Targeting these high-risk populations for improved WASH should also generate other gains for women and girls, via avoidance of all the other potential WASH-related harms. Sufficient routine surveillance and household survey data are available in almost all countries to characterise WASH-related risk of domestic births but this evidence is not jointly owned, used or tracked by the two sectors. Bringing existing data together and creating incentives for coordination will help target efforts towards the areas of greatest need, thereby addressing disparities or inequities (Benova *et al.* 2014b).

The second domain of WASH in facility birth settings is critical but less well documented. Data, such as the Service Provision Assessment surveys (SPA), World Health Organization Service Availability and Readiness Assessments (SARA) and Averting Maternal Death and Disability EmONC Needs Assessments, are collected in many settings – albeit with variable quality – but are under-utilised by the WASH sector. Although the most recent WHO Global Annual Assessment of Sanitation and Drinking Water (GLAAS) exercise included questions for governments on access to WASH in health facilities, few responded and the findings were not cross-validated with other available survey data (World Health Organization 2012). The Joint Monitoring Programme of the UN which tracks progress on the MDG water and sanitation target does not report data for WASH in health facilities because the MDG target did not include healthcare facilities and because such data are not routinely captured in the surveys and censuses that it uses to develop its reports (UNICEF, WHO 2012). Better collection and use of this data by the WASH sector, incentivised with national and global targets, may enhance efforts to improve WASH in facility birth settings (Velleman *et al.* 2014).

Conclusion

There is a body of evidence, supported by biological plausibility, that poor WASH negatively influences maternal and reproductive health outcomes, and foetal and neonatal outcomes, in a multitude of ways. This study presents a framework that builds on and combines existing approaches to identify gender inequalities in health, to classify WASH-related diseases and to delineate a life course approach. We identified a number of systematic reviews reporting associations between WASH and these outcomes that confirm that these

linkages are complex and long term, but nonetheless important. Within the conceptual framework presented here, we also elucidate that there are many gaps requiring both primary research to investigate specific exposure–outcome relationships, and additional systematic reviews of existing evidence. Whilst more evidence is needed, this work suggests there is sufficient evidence for greater consideration of WASH in closing the gap on maternal and perinatal health.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Webtable S1. Overview of identified mechanisms linking reproductive and maternal health to WASH exposures and types of evidence identified.

Webtable S2. WASH mechanisms linked with reproductive and maternal health for which we identified systematic or other evidence.

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