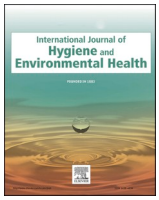
International Journal of Hygiene and Environmental Health 250 (2023) 114171

Contents lists available at ScienceDirect

International Journal of Hygiene and Environmental Health

journal homepage: www.elsevier.com/locate/ijheh



Open defaecation by proxy: Tackling the increase of disposable diapers in waste piles in informal settlements

Hannah L. White [a,*], Taonga Mwapasa [b], Madalitso Mphasa [c], Patrick Ken Kalonde [c,d], Nicholas Feasey [c,e,f], David M. Oliver [a], Michael J. Ormsby [a], Tracy Morse [g], Kondwani Chidziwisano [b,h], Richard S. Quilliam [a]

[a] Biological and Environmental Science, Faculty of Natural Sciences, University of Stirling, Stirling, FK9 4LA, UK
[b] Centre for Water, Sanitation, Health and Appropriate Technology Development (WASHTED), Malawi University of Business and Applied Sciences, Private Bag 303, Chichiri, Blantyre 3, Malawi
[c] Malawi-Liverpool Wellcome Research Programme, Blantyre, Malawi
[d] Department of Tropical Disease Biology, Liverpool School of Tropical Medicine, Liverpool, UK
[e] Department of Clinical Sciences, Liverpool School of Tropical Medicine, Liverpool, UK
[f] Kamuzu University of Health Sciences, Blantyre, Malawi
[g] Department of Civil and Environmental Engineering, University of Strathclyde, Glasgow, G1 1XQ, UK
[h] Department of Environmental Health, Malawi University of Business and Applied Sciences, Private Bag 303, Chichiri, Blantyre 3, Malawi

ARTICLE INFO

Keywords:
Child faeces
Environmental pollution
Faecal-oral diseases
Single use plastic
Sustainable waste management

ABSTRACT

Disposable diapers are becoming increasingly popular and present an emerging challenge for global waste management, particularly within LMICs. They offer a cheap and convenient way for caregivers to manage child excreta; however, insufficient understanding of safe disposal methods, combined with limited access to waste management services results in hazardous disposal. Used diapers are being increasingly found dumped in the open environment, including in water bodies and in open fields, leading to faecal contamination of the environment and an enhanced risk of transmission of faecal-oral diseases such as cholera and typhoid. United Nations SDG 6 aims to end open defaecation globally by 2030; however, improper disposal of used diapers will hamper progress towards reaching this goal. In this review, we identify current trends in use and subsequent disposal of single use disposable diapers in LMICs, and critically discuss the environmental and public health impacts of current practices, and potential solutions to address these challenges. Contemporary methods for managing the disposal of single use diapers for communities in LMICs tend to be cost prohibitive with few alternative options other than dumping in the environment. Modern cloth diapers offer a low waste alternative to disposable diapers but often carry an unaffordable high upfront cost. Here, in addition to advocating improved efforts by governments to upgrade access and quality of waste management services, we recommend the design and implementation of intervention schemes aimed to increase awareness of safe and hygienic disposal practices for disposable diapers.

1. Introduction

In 2020, it was estimated that 1.7 billion people lacked access to basic sanitation services, with 494 million people practicing open defaecation (WHO & UNICEF, 2021). Open defaecation is defined as the disposal of human faeces in the open environment, such as in fields, forests, water bodies, or with municipal solid waste (WHO & UNICEF, 2021). However, the concept of open defaecation also extends to the disposal of faeces contained within other materials, such as plastic bags or diapers, where there is potential for the faeces to become exposed to the open environment (WHO & UNICEF, 2021). Irrespective of the pathway, open defaecation poses a significant risk to public health and is widely associated with an increased prevalence of diarrhoeal diseases, particularly among children (Njuguna 2016; Ayalew et al., 2018; Anandan et al., 2021). In 2019, diarrhoeal disease was ranked as the fifth leading cause of disease worldwide, responsible for over 1.53 million deaths, with one third of these being children under 10 years of age (Abbafati et al., 2020; IHME 2020). In the last decade, there has

* Corresponding author.
E-mail address: hannah.white@stir.ac.uk (H.L. White).

https://doi.org/10.1016/j.ijheh.2023.114171
Received 15 February 2023; Received in revised form 6 April 2023; Accepted 17 April 2023
Available online 23 April 2023

been a marked increase in the global usage of disposable diapers, with sales in 2021 reaching 7.9 billion kilograms, a 36 % increase compared to 2013 (Brinckmann 2022). Growth is expected to continue to rise, increasing most rapidly in low- and middle-income countries (LMICs), with significant consequences for both environmental and human health (Tembo and Chazireni 2016; Ntekpe et al., 2020; Brinckmann 2022).

A concerted effort has been made towards improving global sanitation conditions, with the United Nations (UN) Sustainable Development Goal 6 (SDG 6) aiming to end open defaecation, and provide universal access to drinking water, sanitation, and hygiene by 2030 (WHO & UNICEF, 2021). There is a significant volume of data demonstrating that the elimination of open defaecation can have positive health effects, by reducing the prevalence of diarrhoeal disease and other associated morbidities such as active trachoma and childhood stunting (Njuguna 2016; Rahman et al., 2020; Delelegn et al., 2021). Moreover, the implementation of water, sanitation, and hygiene (WaSH) infrastructure and practices, such as piped water supplies, sewer connections, and regular hand washing with soap and water, can further reduce the impacts of open defaecation and reduce diarrhoea-related morbidity (Wolf et al., 2018). However, whilst it has been reported that the world is currently on track to end open defaecation by 2030 (WHO & UNICEF, 2021), this will require a fourfold increase in rates of progress to achieve universal access to basic sanitation services (WHO & UNICEF, 2021).

Research on open defaecation has mainly focused on direct excretion in the environment, and largely neglected the contribution of disposable diapers. Under the UNICEF and World Health Organisation (WHO) Joint Monitoring Program (JMP), a defining feature of improved sanitation is the hygienic separation of humans from their excreta (WHO & UNICEF, 2021). Although at the point of use disposable diapers readily achieve such a barrier, this is often transitory (Kubiak et al., 1993; Kamat and Malkani 2003), with improper disposal leading to barrier breakdown, and the increased likelihood of human contact with faecal material (Reese et al., 2015). Despite this risk, guidelines regarding the safe disposal of children's excreta and single use diapers are indistinct, with guidelines stating that children's faeces can only be safely disposed of in a toilet or latrine, or by burying; however, no mention is given to disposable diapers despite their increasing popularity (Brinckmann 2022).

Typically, diapers are disposed of in municipal solid waste (MSW) and sent to landfill, or directly dumped in the environment, particularly in LMICs where waste management options are often limited (Reese et al., 2015; Muia 2018). Diapers contain a mixture of materials, including organic compounds such as cellulose, and a range of plastic polymers such as polypropylene, polyethylene, and super absorbent polymers; consequently, once diapers are in the environment, they can take decades or even centuries to degrade (Shuker and Cadman 2018; Roman et al., 2020; Płotka-Wasylka et al., 2022). In many countries, it is common for dogs, pigs, birds, and other vermin to roam over landfill sites and open waste piles in search of food (Doron 2021). Faecal material in diaper waste is often targeted by dogs and pigs who tear open diapers and release the faeces into the environment (Fig. 1) (Remigios 2014; Mathe 2018; Ntekpe et al., 2020). Human faeces can potentially harbour a range of pathogenic viruses, bacteria, protozoa, and helminths (Jex et al., 2012); and without hygienic separation, can lead to the transmission of enteric diseases and helminthiasis (Anandan et al., 2021), which together are responsible for over 90 % of all diarrhoea-related deaths (Troeger et al., 2018).

To date, there has been minimal research into understanding the trends in, and challenges behind, the use of disposable diapers in LMICs. Given the increasing global usage of disposable diapers and their potential to act as a reservoir for pathogenic microorganisms, there is a pressing need to raise awareness of the problems associated with diapers in the environment. Here, we critically discuss the challenges associated with the use of disposable diapers in LMICs, drawing particular attention to common disposal practices employed by caregivers, and the resultant impacts on environmental and human health.

Fig. 1. Stray dog rummaging through disposable diaper waste on an open dump site in Ndirande, Blantyre, Malawi.

2. Current trends in the use of disposable diapers

There has been a transition away from the use of traditional cloth diapers towards single-use disposables over the course of the last century (Krafchik 2016). In 2021, global sales of disposable diapers reached nearly 8 billion kilograms, generating US$47.9 billion in revenue, and are predicted to rise to 9.2 billion kilograms by 2026, an annual increase of 3.7 % since 2013 (Brinckmann 2022). Sales have grown most rapidly in Asia, Africa, and the Americas, and the largest future increases are likely to occur in LMICs; for example, Nigeria is expected to see a 117 % rise by 2026 (Brinckmann 2022). Disposable diapers are considered a premium product, with greater availability to those with higher household incomes and higher levels of education (Eke and Opara 2013; Muia 2018). Income is predicted to rise in LMICs (IMF 2022), and partially explains the expected rapid increases in sales of disposable diapers in these regions. However, higher birth rates in LMICs compared to high income countries are also likely to contribute to the growth in sales (The World Bank 2019b; Brinckmann 2022).

Shifts in consumer preference are also evident, with many caregivers in LMIC settings now choosing to use disposable diapers over traditional cloth diapers (Table 1). In some areas, such as in Nakuru, Kenya, almost 100 % of caregivers now choose disposable single-use diapers (Wambui et al., 2015). The primary reason given for this preference is that disposable diapers are more convenient, particularly when water for washing cloth diapers is scarce or limited, or when during the rainy season cloth diapers are more difficult to dry (Jesca and Junior 2015; Wambui et al., 2015; Muia 2018). They also provide better containment of child excreta, particularly through the night, and can reduce the incidence of diaper dermatitis (Kubiak et al., 1993; Counts et al., 2014; Wambui et al., 2015). Disposable diapers are also more convenient for working mothers and those with less time for washing cloth diapers (Mathe 2018). Although disposable diapers are becoming more affordable, their use is still associated with middle- and higher-income households (Jesca and Junior 2015; Agestika et al., 2022).

In a survey across 21 villages in the Kampong Speu and Battambang provinces of Cambodia, only 13 % of caregivers used disposable diapers, despite recognising that they were convenient, clean, and timesaving (Miller-Petrie et al., 2016). Most respondents reported that their child defaecated in a latrine, a potty, or in the yard (Miller-Petrie et al., 2016). Fifteen of these villages were in rural locations where low usage likely reflects limited accessibility of disposable diapers as rural communities often experience reduced connectivity to transport networks, combined with lower household incomes compared to urban areas (Population Reference Bureau, 2015; World Bank Group 2019). The average cost of a disposable diaper (US$0.43) was found to be nearly three times the price of a traditional cloth diaper (US$0.11) in these regions (Miller-Petrie

Table 1
Percentage of caregivers in some example LMICs that use disposable versus cloth diapers.

Country	Area	*n*	Child's age (years)	Disposable diaper (%)	Cloth diaper (%)	Both (%)	Reference
Zimbabwe	Urban	60	<2	78.0	18.0	4.0	(Jesca and Junior 2015)
Kenya	Urban	87	–	86.2	13.8		(Muia 2018)
Kenya	Urban	148	–	94.6	5.4		(Wambui et al., 2015)
Zimbabwe	Urban	380	–	60.7	24.6	12.9	(Nyamayedenga and Tsvere 2020)
Nigeria	Urban	141	<2	44.7	10.6	44.7	(Eke and Opara 2013)
Indonesia	Urban	184	<5	33.2	16.3		(Agestika et al., 2022)
Cambodia	Rural	129	<5	13.0	4.0		(Miller-Petrie et al., 2016)

et al., 2016). In contrast, the use of disposable diapers in urban areas can be high: in two densely populated suburbs of Nairobi, Kenya, over 86 % of caregivers used disposable diapers, with a significant positive association with both household income and level of education (Muia 2018).

As a single use product, sales are directly translated into waste, with billions of kilograms of diaper waste generated each year (Brinckmann 2022). Most diapers are disposed of indiscriminately, being either incinerated, or combined with municipal solid waste (MSW) and subsequently transferred into the open environment (Ellen MacArthur Foundation 2020; Ntekpe et al., 2020). Data collected from 19,000 sites across 82 countries between 2011 and 2018 identified disposable diapers as being among the top 25 most common items found on the sea floor and in the top 40 most common items found in terrestrial settings (Roman et al., 2020); diaperscan also comprise 21 % of waste found in waterways (e.g., in Indonesia; Shuker and Cadman 2018). Once in the environment, disposable diapers pose a risk to the environment, wildlife, and human health (Kordecki et al., 2022), as it can take centuries for the plastic components to decompose (Płotka-Wasylka et al., 2022).

3. Environmental hazards of disposable diapers

In many LMICs, there is often a lack of awareness of the appropriate methods for disposing of used diapers, and of the health and environmental implications of improper disposal (Remigios 2014; Mathe 2018; Muia 2018). Whilst product packaging encourages caregivers to dispose of diapers with MSW (Remigios 2014), they are also commonly discarded in latrines, or by burning or dumping in the environment (Fig. 2). Recommended practice also states that faecal material should be cleaned from diapers before disposal (UNICEF 2006; Remigios 2014); however, many caregivers believe this to be unnecessary or find it challenging without a reliable water supply or access to a working latrine.

The most common method of disposal is with household MSW, in compliance with manufacturer guidelines; however, this is only practiced by 35 % of caregivers (Fig. 2) and has limited relevance to those living within informal settlements where the provision of MSW services is minimal or absent (Kaza et al., 2018; Turpie et al., 2019). In LMICs the management of MSW is typically poor due to a lack of financial

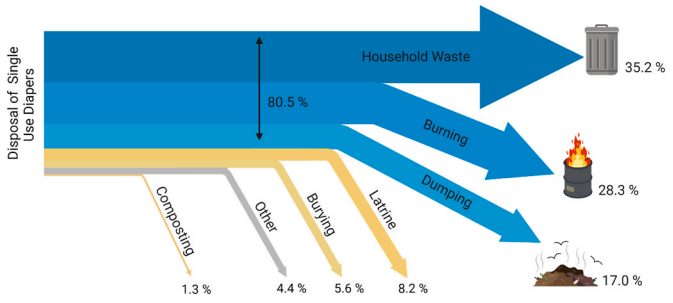


Fig. 2. Methods of discarding used disposable baby diapers by caregivers in LMICs. Values are weighted averages based on data collected from peer reviewed studies (Jesca and Junior 2015; Wambui et al., 2015; Miller-Petrie et al., 2016; Tembo and Chazireni 2016; Muia 2018; Nyamayedenga and Tsvere 2020; Agestika et al., 2022). Figure created with BioRender.com.

resources, infrastructure, and expertise (Muia 2018). The fraction of MSW that is mismanaged, i.e., unaccounted for, negatively correlates with GDP per capita (Lebreton and Andrady 2019). In sub–Saharan Africa and South Asia, only 44 % of MSW is collected, versus 100 % in North America, and 90 % in Europe and Central Asia (Kaza et al., 2018; Turpie et al., 2019). The mismanaged portion is most often dumped alongside roads, in waterways, or on open land; or burned in close proximity to communities, polluting the air, water, and soil. Even when collected, the majority of MSW in LMICs is disposed of in landfill, most of which operate as open dumpsites (Gutberlet and Uddin 2017; Kaza et al., 2018). Without proper management, hazardous leachates such as heavy metals and hydrocarbons can contaminate groundwater or be transported into surface waters (Akinola et al., 2018; Aralu et al., 2021). Harmful volatile and greenhouse gases are also generated from the decomposing waste (Chiemchaisri et al., 2019; Ngwabie et al., 2019) and the heat generated during biological and chemical decomposition of waste can lead to spontaneous fires (Chavan et al., 2022).

Besides anecdotal evidence, there is limited data discerning the exact quantity of diaper waste among MSW. Small-scale studies are highly variable and indicate that diapers make up between 0.2 and 22.2 % of total MSW (Reese et al., 2015; Perez et al., 2021). Countries with higher fertility rates and a more youthful population tend to have a higher percentage of disposable diapers in MSW. For example, in Bolivia, where 11.3 % of the population is under the age of 5 years and the fertility rate is 2.8 (births per woman), 12.1 % of MSW is made up of disposable diapers. In contrast, in Japan, where 4.0 % of the population is under the age of five and the fertility rate is 1.4, only 2.8 % of MSW consists of diapers (The World Bank 2019a; Perez et al., 2021). However, sampling methods may explain some of this variability, depending on whether waste is characterised when it arrives at dump sites or whether waste is directly surveyed at the household level (Thanh et al., 2010; Taboada-González et al., 2014).

Unreliable, insufficient, or non-existent household waste collection by local councils drives many people to manage their waste independently, with little choice but to burn or dump waste in their local environment (Remigios 2014; Jesca and Junior 2015; Nyamayedenga and Tsvere 2020). Over 28 % of caregivers choose to burn used disposable diapers (Fig. 2), believing it to be a quick and easy way to reduce or eliminate waste (Velis and Cook 2021). However, diapers are not readily combustible and often require catalysts such as paraffin (Remigios 2014; Nyamayedenga and Tsvere 2020). Disposable diapers can also contain a cocktail of harmful chemicals including polycyclic aromatic hydrocarbons (PAHs), dioxins, furans, formaldehyde, and volatile organic compounds such as naphthalene and toluene (ANESES 2019). When openly burned, diapers and other MSW release noxious gases and small particulate matter ($PM_{2.5}$) into the environment, which can pose a serious risk to human health (Kumari et al., 2017; Velis and Cook 2021). Air pollution is a leading contributor towards the global burden of disease, particularly within LMICs. Globally, in 2019, air pollution was estimated to have been responsible for more than 6.6 million deaths and over 213 million disability-adjusted life years (DALYs) (Cohen et al., 2017; IHME 2020; Velis and Cook 2021). In particular, $PM_{2.5}$ is linked to infection of the lower respiratory tract, lung cancer, ischaemic heart disease, cerebrovascular disease (stroke), and chronic obstructive pulmonary disease (Cohen et al., 2017; IHME 2020).

Therefore, whilst burning used diapers is a quick and easy solution to waste management, it leaves unsightly residues, is damaging to human health, and is clearly not an environmentally sustainable strategy.

Open dumping is another popular and widespread form of independent waste management and is routinely practised by 93 % and 66 % of people on low and low-middle incomes respectively, compared to just 2 % of people in high income groups (Kaza et al., 2018). In the absence of adequate bins, 17 % of caregivers favour dumping used disposable diapers at illegal dumpsites (Fig. 2). These are typically small to medium sized open sites located within or at the periphery of communities (Remigios 2014; Kordecki et al., 2022); however, the use of smaller more discreet sites, recently coined "Jay-dumping", is becoming more common (Nyamayedenga and Tsvere 2020). Jay-dumping sites tend to be located further away from communities and are used by single households (Nyamayedenga and Tsvere 2020). Regardless, open dumping of disposable diaper waste is unsightly, attracts vermin, and enhances the risk of disease transmission (Remigios 2014; Jesca and Junior 2015; Mathe 2018).

In informal settlements, diapers are often disposed of in pit latrines; however, this reduces the fill time, requiring more frequent emptying which can be costly for low-income households, who often delay emptying and continue to use latrines when no longer hygienically safe (Jenkins et al., 2015; Gudda et al., 2019). Diapers and other solid waste, such as cloth and sanitary items, also make emptying pits more challenging as they need to be removed by hand, increasing workers' contact with faecal material (Chipeta et al., 2017; Portiolli et al., 2021). Conversely, in areas with modern sewerage systems, diapers are frequently disposed of in flushable latrines. Sewer systems are not designed to manage disposable diapers and when flushed, the absorbent cellulose fluff pulp and super absorbent polymer (SAP) components absorb water and swell leading to permanent blockages and sewerage overflows (Chinyama and Toma 2013; Remigios 2014).

Some caregivers in LMICs choose to bury disposable diapers (Fig. 2); and although deemed a safe and hygienic practice (UNICEF 2006), this only applies to the organic component. Plastics are not readily biodegradable and can persist in the environment for hundreds, if not thousands of years, depending on the plastic type and environmental conditions (Chamas et al., 2020). Furthermore, buried plastics can release leachates, such as plasticisers and flame retardants, which lead to environmental toxicity (Zimmermann et al., 2021). Disposal through composting is much the same as only the cellulose component and faecal material can be readily biodegraded, leaving the plastic components to persist (Ferronato et al., 2020).

4. Public health risks of unregulated diaper disposal

When improperly disposed of, human faeces pose a risk for the transmission of enteric diseases and helminthiasis via the faecal-oral route (Anandan et al., 2021). Globally, more than 1.6 million people die per annum from diarrhoeal-related diseases and approximately 1.5 billion people are infected with helminths (including hookworm, ascariasis and trichuriasis), with a disproportionately high burden in LMICs (Pullan et al., 2014; Troeger et al., 2018). Cholera (caused by *Vibrio cholerae*) is endemic in many LMICs and widely associated with faecal contamination of the environment (Oguttu et al., 2017; Muzembo et al., 2022; WHO 2022). Outbreaks lead to the loss of approximately 95,000 lives each year and have been intensifying in recent years, with a rise in reported case numbers and the geographical range of outbreaks (WHO 2022). Furthermore, there is evidence that faecal contamination in the environment can contribute towards the emergence and spread of antimicrobial resistance (Thongsamer et al., 2021).

In LMICs, the recycling industry is largely run by the informal sector (Kaza et al., 2018). Informal waste pickers (IWPs) often operate at dumpsites (formal and informal), scavenging for materials of worth, such as plastic or metal, which can be sold on to the recycling industry. Most operate with minimal PPE, using their bare hands to rummage through waste, and exposing themselves to physical, chemical, and biological hazards (Kasinja and Tilley 2018; Zolnikov et al., 2021). Cuts from broken glass, cans, and needles are common, as well as exposure to chemical solvents and pesticides (Cruvinel et al., 2019; Zolnikov et al., 2021). Working conditions lead to poor health, with many IWPs suffering from episodic diarrhoea, bronchitis, eye infections, and osteo-muscular disorders (Chokhandre et al., 2017; Cruvinel et al., 2019). The presence of disposable diapers amongst MSW presents an increasingly common biological hazard, exposing IWPs to human faecal material and increasing the risk of contracting communicable diarrhoeal diseases such as cholera and typhoid (Remigios 2014).

Used diapers also create obnoxious odours, attracting flies and animals such as dogs and rodents (Remigios 2014; Jesca and Junior 2015; Mathe 2018). Flies are notorious mechanical vectors of disease, able to transport bacteria and viruses from faeces to food via surface contact (Pace et al., 2017; Thomson et al., 2021; Asada et al., 2022). Furthermore, human faeces provide a preferential medium for oviposition by *Musca sorbens* (the eye-seeking fly), a vector for the bacterium *Chlamydia trachomatis* (Emerson et al., 2001). Infection with *C. trachomatis* is a predominant cause of the eye disease active trachoma, a major cause of child blindness worldwide (Bourne et al., 2013; MacLeod et al., 2019; Delelegn et al., 2021). Dogs are also a particular nuisance, frequently documented to scatter and tear open used diapers (Fig. 1); even when disposed of with MSW, dogs are known to break into bins and seek out diapers (Remigios 2014; Mathe 2018). Such scavenging behaviour can re-expose faecal material to the environment and increase the risk of enteric disease spread.

The attraction of animals to diapers at dumpsites also presents an additional risk of zoonotic disease transmission (Krystosik et al., 2020; Doron 2021). Dogs, chickens, and birds are well known to feed on human faeces, and it can constitute one fifth of the diet (by mass) of free roaming dogs and provides a valuable dietary resource (Butler et al., 2018). However, these coprophagic habits create a pathway for human-animal disease transmission. Whilst the consumption of contaminated faeces may not lead to infection, animals can become a reservoir, transmitting disease via their faeces (Finley et al., 2007; Nijsse et al., 2014). Animal faeces have been identified as a significant reservoir for viruses and enteric pathogens including *Campylobacter*, non-typhoidal *Salmonella*, and *Cryptosporidium* (Delahoy et al., 2018).

5. Design and implementation of intervention schemes

Despite heavy criticism of current methods of disposal, very few alternatives have been offered. The mismanagement of disposable diaper waste in LMICs is multifaceted and influenced by factors at numerous levels, including the caregiver, the local council, and the national government. As such, solutions need to be targeted at different scales. In LMICs, governments typically lack the financial resources to improve waste management systems and struggle to cover operational costs, leading to lapses in services (Kaza et al., 2018; Muia 2018). Thus, initial efforts may be better focussed at the level of the caregiver, identifying feasible alternatives to disposable diapers and promoting behavioural change regarding waste disposal.

5.1. Diaper recycling systems

Recycling of disposable diapers is complex and expensive; and consequently, predominantly only available in high income countries (HIC) (Khoo et al., 2019). In LMICs, initial thought has gone into the introduction of community level diaper collection schemes, whereby households separate disposable diapers from general MSW and deliver them to a collection point for specialist disposal. However, these schemes rely on the willingness of caregivers to participate. In a survey of caregivers in Nairobi, Kenya, only 19.6 % ($n = 148$) would be openly willing to take their used diapers to a collection point, while others would only consider it if given a financial incentive. Willingness was

positively correlated with caregivers' level of education, indicating that implementation of educational campaigns alongside collection schemes may help boost participation and increase their viability (Wambui et al., 2015). If the challenge of separating out the plastic components of diapers can be overcome, low-cost composting methods that breakdown the organic fractions of disposable diapers, i.e., human excreta and cellulose, into compost suitable for use as agricultural fertiliser may offer a solution and add value to this challenging waste stream (Ferronato et al., 2020).

5.2. Modern reusable cloth diapers

Arguments are regularly made for reversion to cloth reusable diapers (Tembo and Chazireni 2016). In Indonesia, Agestika et al. (2022) found that disposable diaper usage increased unhygienic practices regarding the disposal of child's faeces, irrespective of the household sanitation level; indicating that with the current level of waste management, together with the environmental awareness of caregivers, cloth diapers can be more hygienic. Cloth diapers increase the likelihood of safe disposal of child's faeces since the faeces must be removed before washing (Miller-Petrie et al., 2016), e.g., through disposal in a latrine or by burying (Agestika et al., 2022). Cloth diapers can be cheaper and have a lower environmental impact compared to disposable diapers, although this is often context dependent (Miller-Petrie et al., 2016; UNEP 2021). It is estimated that for a single child over a two- and half-year diapering period, the manufacture and use of reusable cloth diapers requires between 1221 and 1854 m^3 of water, which is up to 14-fold higher than for disposable diapers (Aumônier et al., 2008). Modern reusable cloth diapers also carry a higher upfront cost (Tumulango et al., 2021). Life cycle assessments for cloth diapers have revealed that their primary environmental impacts stem from the energy requirements of laundering whereas for disposable diapers, this arises from their manufacture (Aumônier et al., 2008; UNEP, 2021). When washed and dried in a water and energy-efficient manner, such as on a cold cycle in a fully loaded modern washing machine followed by air drying, cloth diapers have a lower environmental impact than disposable diapers (UNEP 2021). However, this has less relevance in LMICs where access to electric washing facilities can be limited.

Hand washing laundry is laborious, time consuming, and water intensive, with respondents spending an average of 9.5 h per week carrying out routine washing duties and using 59 L of water per 7.5 kg wash (The Washing Machine Project 2022). Furthermore, a high proportion of households in LMICs must travel off-premises to collect water (WHO & UNICEF, 2021), transporting it using buckets and exposing themselves to risks of physical injury from carrying heavy loads and navigating treacherous routes; a burden that falls disproportionately on women (Adams et al., 2022). In addition, the availability of soap for washing is often limited, which combined with a lack of water and drying facilities, is a major obstacle to the uptake of reusable cloth menstrual products, which share similar laundry requirements to those of reusable diapers (Kambala et al., 2020; Rossouw and Ross 2021; Roxburgh et al., 2022). There is also the associated cost and environmental footprint of fuel if heating water for washing, which typically arises from non-renewable sources. In Sub-Saharan Africa, oil and natural gas are becoming the primary fuels used for this purpose; however, charcoal is still dominant in some areas as it is cheap, readily available and has a high energy content (Makonese et al., 2016; IEA 2019). Switching from disposable diapers to modern cloth diapers would likely exacerbate these challenges.

There have been some positive results in trials investigating the feasibility of introducing modern reusable diapers to communities in LMICs that are struggling to manage their disposable diaper waste. In the Pacific island nation of Vanuatu, 96 % of trial participants ($n = 59$) across three rural communities expressed positive views on modern reusable diapers. However, there were concerns regarding the associated extra labour, access to water for washing, and their size and comfort (Tumulango et al., 2021). Furthermore, a starter pack of modern reusable diapers carries a high purchase price, retailing at US$166 in the current trial. Whilst these costs can be offset by the reuse of diapers over the duration of a child's diapering period, many caregivers cannot afford this initial outlay (Aumônier et al., 2008; Tumulango et al., 2021). Financial literacy was also identified as a barrier to uptake as not all caregivers had a complete understanding of the long-term cost-benefit of reusable diapers. Conclusions of the trial recommended that governments and reusable diaper manufacturers explore arrangements for structural financial support schemes (Tumulango et al., 2021), as unless costs can be reduced or spread over time, it is unlikely that modern reusable diapers will be an accessible solution to the escalating challenge of disposable diaper waste.

5.3. Raising awareness and behavioural change

Irrespective of the alternatives, disposable diaper usage within LMICs remains high (Fig. 2) and raising awareness of the implications of current practices surrounding their use is key. Many caregivers do not understand the risks associated with improper disposal and lack the knowledge to make informed choices about alternative practices (Remigios 2014; Mathe 2018; Muia 2018). Although dissemination of information in LMICs can be challenging, there have been many successful WaSH interventions that serve as good models for encouraging behavioural change in LMIC communities (Malolo et al., 2021; Panulo et al., 2022; Simiyu et al., 2022).

The 'Hygienic Family' intervention in rural Malawi used a combination of group meetings, workshops, and household visits, alongside rewards and messaging campaigns, to successfully implement behavioural change surrounding household WaSH practices and food hygiene (Morse et al., 2019; Panulo et al., 2022). The study resulted in health and social benefits for both study participants and the local community, with a 13 % reduction in reported cases of diarrhoea (Morse et al., 2020; Malolo et al., 2021). Meetings, workshops, and household visits acted as points of contact for learning and provided participants with ongoing support, whilst messaging solidified the learning, with posters, leaflets, and other prompts acting as visual reminders of key points (Garofano and Webster 2019; Malolo et al., 2021). Rewards included high-value household items, such as plastic buckets or soap, and provided participants with the means and motivation to progress. Participants also became role models to non-participating community members, inspiring other households to implement the new hygiene practices and increasing dissemination of the desired behavioural change within the community (Malolo et al., 2021).

Similarly, positive results have been achieved using artistic and participatory based approaches to encourage improved hand hygiene in Latin American communities (Zisa et al., 2022). The Lazos de Agua programme targeted 1680 households across Colombia, Mexico, Nicaragua, and Paraguay using short films, theatre productions, songs, murals, and puppet shows to convey messages in a culturally relevant context, resulting in a 15 % increase in the proportion of the population practising proper hand hygiene after a 22-month intervention period (Zisa et al., 2022). If translated well, similar frameworks could be effective in implementing behavioural change regarding the management of disposable diaper waste in LMIC communities. Interventions could be designed around promoting safer disposal habits and to encourage the use of cloth diapers instead of disposables, and by rewarding improved practice with free hygiene consumables as in the Hygienic Family intervention (Malolo et al., 2021).

Manufacturers also have a responsibility to provide information on best practice for the disposal of used diapers; typically, this information is printed on external packaging. However, in LMICs, many everyday household items are sold singularly or in small volumes, which makes them more accessible to those with low purchasing power, such as those living in informal settlements and piece-rate workers; consequently, consumers will not have access to the external packaging and so may not

receive this information (Remigios 2014; Donovan and Park 2022). Printing disposal instructions on individual diapers or on posters and leaflets situated around communities may help overcome this packaging limitation and disseminate this important information to those consumers who are only able to make small affordable daily purchases (Donovan and Park 2022).

Any scheme directed at changing the behaviour of caregivers must also be complemented by infrastructural development. In LMICs, an increase in waste management services is often recognised as an important factor in reducing open dumping and littering; for example, the provision of more bins and more frequent waste collections (Kaza et al., 2018; Garofano and Webster 2019). However, this can be challenging to implement as governments are often financially restricted and waste management is often regarded as low priority (Kaza et al., 2018). Furthermore, formal or informal waste collection in informal settlements can be impaired by road inaccessibility, potential violence and crime, social stigma, and difficulties associated with collecting payment (Kaza et al., 2018). Local bylaws may assist in discouraging open dumping, but these would require significant enforcement which is also limited by resources and capacity (Garofano and Webster 2019).

6. Conclusions and future perspectives

Disposable diapers present an important resource for caregivers in LMICs, providing a convenient and affordable method for managing child excreta. Yet, the current lack of infrastructure and guidance on the disposal of used diapers, together with a general lack of community awareness of the environmental and human health consequences of improper disposal, is having considerable negative impacts on LMIC communities and could hamper progress towards achieving SDG6. Current indicators as defined by the UNICEF and WHO JMP ladder for sanitation, do not account for the contribution of disposable diapers towards open defaecation. Under these criteria, countries could feasibly conclude that they have eliminated open defaecation without ensuring the safe and hygienic disposal of diapers, leading to the misconception that this aspect of SDG6 has been met. Given the predicted rise in usage of disposable diapers, particularly within LMICs, it is imperative that their contribution is formally acknowledged.

Little progress has been made on the development of feasible, low-cost solutions for the disposal of single-use diapers in LMICs; and moving forward this must become a priority for manufacturers and the research community. Behavioural change is also key, and intervention schemes aimed to educate caregivers on safe disposal practices for disposable diapers will be invaluable in achieving this. Higher priority must be given to the waste management sector with more funding allocated towards waste collection services and the development of sanitary waste disposal. Moreover, manufacturers of disposable diapers must take greater responsibility for the disposal of their products, putting more resources into educating consumers of best practice. However, these changes will be limited in effectiveness if not supported by the appropriate infrastructure. Governments hold ultimate responsibility for national waste management strategies, and integrated top-down changes will be essential for addressing the emerging challenge of disposable diaper waste.

CRediT authorship contribution statement

HW, RQ: Conceptualization. **RQ:** Funding acquisition, Supervision. **HW:** Investigation, Visualization, Writing - original draft. **HW, TM, MM, PK, NF, DO, MJ, TM, KC, RQ:** Writing - review & editing.

Acknowledgements

This work was supported by the UKRI Natural Environment Research Council (NERC) as part of the GCRF SPACES project [grant number NE/V005847/1].

References

Abbafati, C., et al., 2020. Global burden of 369 diseases and injuries in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. Lancet 396 (10258), 1204–1222.

Adams, E.A., Byrns, S., Kumwenda, S., Quilliam, R., Mkandawire, T., Price, H., 2022. Water journeys: household water insecurity, health risks, and embodiment in slums and informal settlements. Soc. Sci. Med. 313, 115394 https://doi.org/10.1016/J.SOCSCIMED.2022.115394.

Agestika, L., Sintawardani, N., Hamidah, U., Nyambe, S., Yamauchi, T., 2022. Pattern of child faeces management and disposable diaper usage among under-fives in an Urban Slum of Bandung, Indonesia. J. Water, Sanit. Hyg. Dev. 12 (1), 32–40.

Akinola, B.S., Awoyemi, M.O., Matthew, O.J., Adebayo, A.S., 2018. Geophysical and hydro-chemical investigation of contamination plume in a basement complex formation around Sunmoye dumpsite in Ikire, Southwestern Nigeria. Model. Earth Syst. Environ. 4 (2), 753–764.

Anandan, M., Vs, S., Rubeshkumar, P., Ponnaiah, M., Jesudoss, P., Karumanagounder, K., Murhekar, M., 2021. Outbreak of acute diarrhoeal disease attributed to consumption of faecal contaminated water supplied through damaged pipelines in Thiruper, Tiruvallur district, Tamil Nadu, India, 2016. Clin. Epidemiol. Glob. Health 10, 100701. https://doi.org/10.1016/J.CEGH.2021.100701.

ANESES, 2019. Revised OPINION of the French Agency for Food, Environmental and Occupational Health & Safety on the Safety of Baby Diapers 2017-SA-0019 [Patent].

Aralu, C.C., Okoye, P.A.C., Akpomie, K.G., Eboagu, N.C., 2021. Levels of polycyclic aromatic hydrocarbons in leachates from unlined dumpsite of Agu-Awka Anambra state. https://doi.org/10.1080/03067319.2021.1993842.

Asada, Y., Chua, M., Tsurumi, M., Nyambe, I., Narada, H., 2022. Detection of Escherichia coli, rotavirus, and Cryptosporidium spp. from drinking water, kitchenware, and flies in a periurban community of Lusaka, Zambia. J. Water Health 20 (7), 1027–1037. https://doi.org/10.2166/wh.2022.276.

Aumônier, S., Collins, M., Garrett, P., 2008. An Updated Lifecycle Assessment Study for Disposable and Reusable Nappies. Science Report – SC010018/SR2, Bristol.

Ayalew, A.M., Mekonnen, W.T., Abaya, S.W., Mekonnen, Z.A., 2018. Assessment of diarrhea and its associated factors in under-five children among open defecation and open defecation-free rural settings of Dangla District, Northwest Ethiopia. J. Environ. Publ. Health 2018. https://doi.org/10.1155/2018/4271915.

Bourne, R., Stevens, G., White, R., Smith, J., Flaxman, S., Price, H., Jonas, J., Keeffe, J., Leasher, J., Naidoo, K., Pesudovs, K., Resnikoff, S., Taylor, H., 2013. Causes of vision loss worldwide, 1990–2010: a systematic analysis. The Lancet Global Health 1 (6), e339–e349. https://doi.org/10.1016/S2214-109X(13)70113-X.

Brinckmann, M., 2022. Baby Diapers Report 2022: Statista Consumer Market Outlook - Segment Report. Article No: did-48854-1.

Butler, J.R.A., Brown, W.Y., du Toit, J.T., 2018. Anthropogenic food subsidy to a commensal carnivore: the value and supply of human faeces in the diet of free-ranging dogs. Animals 2018 8, 67, 67 8(5).

Chamas, A., et al., 2020. Degradation rates of plastics in the environment. ACS Sustain. Chem. Eng. 8 (9), 3494–3511.

Chavan, D., Manjunatha, G.S., Singh, D., Periyaswami, L., Kumar, S., Kumar, R., 2022. Estimation of spontaneous waste ignition time for prevention and control of landfill fire. Waste Manag. 139, 258–268. https://doi.org/10.1016/J.WASMAN.2021.11.044.

Chiemchaisri, C., Chiemchaisri, W., Boocha, M., 2019. Emissions of volatile organic compounds from solid wastes and leachate at a municipal solid waste dumpsite in Thailand. Energy, Environ. Sustain. 357–367.

Chinyama, A., Toma, T., 2013. Understanding the poor performance of urban sewerage systems: a case of coldstream high density suburbs, chinhoyi, Zimbabwe. Urban Plan. Des. Res. 1 (3).

Chipeta, W.C., Holm, R.H., Kamanula, J.F., Mtonga, W.E., de los Reyes, F.L., 2017. Designing local solutions for emptying pit latrines in low-income urban settlements (Malawi). Phys. Chem. Earth 336–342. https://doi.org/10.1016/J.PCE.2017.02.012. Parts A/B/C 100.

Chokhandre, P., Singh, S., Kashyap, G.C., 2017. Prevalence, predictors and economic burden of morbidities among waste-pickers of Mumbai, India: a cross-sectional study. J. Occup. Med. Toxicol. 12 (1), 1–8.

Cohen, A.J., et al., 2017. Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015. Lancet 389 (10082), 1907–1918.

Counts, J.L., Helmes, C.T., Kenneally, D., Otts, D.R., 2014. Modern disposable diaper construction: innovations in performance help maintain healthy diapered skin. Clin. Pediatr. 53 (9 Suppl. l), 10S–13S.

Cruvinel, V.R.N., et al., 2019. Health conditions and occupational risks in a novel group: waste pickers in the largest open garbage dump in Latin America. BMC Publ. Health 19 (1), 1–15.

Delahoy, M.J., Wodnik, B., McAliley, L., Penakalapati, G., Swarthout, J., Freeman, M.C., Levy, K., 2018. Pathogens transmitted in animal feces in low- and middle-income countries. Int. J. Hyg Environ. Health 221 (4), 661–676. https://doi.org/10.1016/J.IJHEH.2018.03.005.

Delelegn, D., Tolcha, A., Beyene, H., Tsegaye, B., 2021. Status of active trachoma infection among school children who live in villages of open field defecation: a comparative cross-sectional study. BMC Publ. Health 21 (1), 1–10.

Donovan, K.P., Park, E., 2022. Knowledge/seizure: debt and data in Kenya's zero balance economy. Antipode 54 (4), 1063–1085.

Doron, A., 2021. Stench and sensibilities: on living with waste, animals and microbes in India. Aust. J. Anthropol. 32 (S1), 23–41.

Eke, G.K., Opara, P. lbo, 2013. Mothers knowledge and home management of nappy rash in port harcourt, Nigeria. Nigerian Health J. 13 (4), 152–157.

Ellen MacArthur Foundation, 2020. A circular economy for nappies and how to implement it locally. Isle of Wight, United Kingdom. https://bbia.org.uk/wp-content/uploads/2020/11/A-Circular-Economy-for-Nappies-final-oct-2020.pdf. (Accessed 11 August 2022). Available at:

Emerson, P., Bailey, R., Walraven, G., Lindsay, S., 2001. Human and other faeces as breeding media of the trachoma vector Musca sorbens. Med. Vet. Entomol. 15 (3), 314–320. https://doi.org/10.1046/J.0269-283X.2001.00318.X.

Ferronato, N., Pinedo, M.L.N., Torretta, V., 2020. Assessment of used baby diapers composting in Bolivia. Sustainability 12 (12), 5055.

Finley, R., Ribble, C., Aramini, J., Vandermeer, M., Popa, M., Litman, M., Reid-Smith, R., 2007. The risk of salmonellae shedding by dogs fed Salmonella-contaminated commercial raw food diets. Can. Vet. J. 48 (1), 69.

Garofano, N.T., Webster, M., 2019. The Commonwealth Litter Programme: Final Report – Best Practices for Vanuatu (Suffolk).

Gudda, F.O., Moturi, W.N., Oduor, O.S., Muchiri, E.W., Ensink, J., 2019. Pit latrine fill-up rates: variation determinants and public health implications in informal settlements, Nakuru-Kenya. BMC Publ. Health 19 (1), 1–13.

Gutberlet, J., Uddin, S.M.N., 2017. Household waste and health risks affecting waste pickers and the environment in low- and middle-income countries. Int. J. Occup. Environ. Health 23 (4), 299–310. https://doi.org/10.1080/10773525.2018.1484996.

IEA, 2019. Africa energy outlook 2019. https://www.iea.org/reports/africa-energy-outlook-2019. (Accessed 6 December 2022). Available at:

IHME, 2020. Global burden of disease study 2019 (GBD 2019). https://vizhub.healthdata.org/gbd-results/. (Accessed 9 August 2022). Seattle. Available at:

IMF (2022). International Monetary Fund, 2022. World economic outlook: countering the cost-of-living crisis. https://www.imf.org/en/Publications/WEO/Issues/2022/10/11/world-economic-outlook-october-2022#Projections. (Accessed 29 November 2022). Washington, DC. Available at:

Jenkins, M.W., Cumming, O., Cairncross, S., 2015. Pit latrine emptying behavior and demand for sanitation services in dar Es salaam, Tanzania. Int. J. Environ. Res. Publ. Health 2015 12, 2588–2611, 12(3), pp. 2588–2611.

Jesca, M., Junior, M., 2015. Practices regarding disposal of soiled diapers among women of child bearing age in poor resource urban setting. J. Nurs. Health Sci. 4 (4), 63–67.

Jex, A.R., et al., 2012. Detection of diarrhoeal pathogens in human faeces using an automated, robotic platform. Mol. Cell. Probes 26 (1), 11–15. https://doi.org/10.1016/J.MCP.2011.10.004.

Kamat, M., Malkani, R., 2003. Disposable diapers : a hygienic alternative. Indian J. Pediatr. 70 (11), 879–881.

Kambala, C., Chinangwa, A., Chipeta, E., Torondel, B., Morse, T., 2020. Acceptability of menstrual products interventions for menstrual hygiene management among women and girls in Malawi. Reprod. Health 17 (1), 1–12.

Kasinja, C., Tilley, E., 2018. Formalization of informal waste pickers' cooperatives in Blantyre, Malawi: a feasibility assessment. Sustain. 2018 10 (4), 1149, 1149 10.

Kaza, S., Yao, L.C., Bhada-Tata, P., van Woerden, F., 2018. What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. World Bank, Washington, DC. © World Bank. License: CC BY 3.0 IGO. Available at: https://openknowledge.worldbank.org/handle/10986/30317. (Accessed 11 August 2022). Accessed.

Khoo, S.C., Phang, X.Y., Ng, C.M., Lim, K.L., Lam, S.S., Ma, N.L., 2019. Recent technologies for treatment and recycling of used disposable baby diapers. Process Saf. Environ. Protect. 123, 116–129. https://doi.org/10.1016/J.PSEP.2018.12.016.

Kordecki, H., Antrobus-Wuth, R., Uys, M.-T., van Wyk, I., Root, E.D., Berrian, A.M., 2022. Disposable diaper waste accumulation at the human-livestock-wildlife interface: a one health approach. Environ. Challen. 8, 100589.

Krafchik, B., 2016. History of diapers and diapering. Int. J. Dermatol. 55, 4–6.

Krystosik, A., Njoroge, G., Odhiambo, L., Forsyth, J.E., Mutuku, F., LaBeaud, A.D., 2020. Solid wastes provide breeding sites, burrows, and food for biological disease vectors, and urban zoonotic reservoirs: a call to action for solutions-based research. Front. Public Health 7, 405. https://doi.org/10.3389/FPUBH.2019.00405/BIBTEX.

Kubiak, M., Kressner, B., Raynor, W., Davis, J., Syverson, R.E., Laabs, J., 1993. Comparison of stool containment in cloth and single-use diapers using a simulated infant feces. Pediatrics 91 (3), 632–636.

Kumari, K., Kumar, S., Rajagopal, V., Khare, A., Kumar, R., 2017. Emission from open burning of municipal solid waste in India. Environ. Technol. 40 (17), 2201–2214. https://doi.org/10.1080/09593330.2017.1351489.

Lebreton, L., Andrady, A., 2019. Future scenarios of global plastic waste generation and disposal. Palgrave Communications 5 (1), 1–11.

MacLeod, C., Binnawi, K., Elshafie, B., Sadig, H., Hassan, A., Cocks, N., Willis, R., Chu, B., Solomon, A., 2019. Unimproved water sources and open defecation are associated with active trachoma in children in internally displaced persons camps in the Darfur States of Sudan. Trans. Royal Soc. Trop. Med. Hygiene 113 (10), 599–609. https://doi.org/10.1093/TRSTMH/TRZ042.

Makonese, T., Masekameni, D.M., Annegarn, H.J., 2016. Energy use scenarios in an informal urban settlement in Johannesburg, South Africa. In: Proceedings of the 24th Conference on the Domestic Use of Energy. DUE 2016. https://doi.org/10.1109/DUE.2016.7466703.

Malolo, R., Kumwenda, S., Chidziwisano, K., Kambala, C., Morse, T., 2021. Social outcomes of a community-based water, sanitation and hygiene intervention. J. Water, Sanit. Hyg. Dev. 11 (3), 483–493.

Mathe, M., 2018. Environmental pollution-perceptions and views on usage and disposal of diapers: a case study of gwanda urban. Int. J. Innov. Sci. Res. Technol. 3 (5).

Miller-Petrie, M.K., Voigt, L., McLennan, L., Cairncross, S., Jenkins, M.W., 2016. Infant and young child feces management and enabling products for their hygienic collection, transport, and disposal in Cambodia. Am. J. Trop. Med. Hyg. 94 (2), 456–465.

Morse, T., Chidziwisano, K., Tilley, E., Malolo, R., Kumwenda, S., Musaya, J., Cairncross, S., 2019. Developing a contextually appropriate integrated hygiene intervention to achieve sustained reductions in diarrheal diseases. Sustainability 11 (17), 4656, 4656 11.

Morse, T., Tilley, E., Chidziwisano, K., Malolo, R., Musaya, J., 2020. Health outcomes of an integrated behaviour-centred water, sanitation, hygiene and food safety intervention–A randomised before and after trial. Int. J. Environ. Res. Publ. Health 17 (8), 2648, 2648 17.

Muia, V.K., 2018. Disposal methods of soiled diapers in low-income households of Nairobi county in Kenya. IJRDO - J. Appl. Sci. 4 (7), 11–20.

Muzembo, B.A., Kitahara, K., Debnath, A., Ohno, A., Okamoto, K., Miyoshi, S.I., 2022. Cholera outbreaks in India, 2011–2020: a systematic review. Int. J. Environ. Res. Publ. Health 19 (9), 5738.

Ngwabie, N.M., Wirlen, Y.L., Yinda, G.S., VanderZaag, A.C., 2019. Quantifying greenhouse gas emissions from municipal solid waste dumpsites in Cameroon. Waste Manag. 87, 947–953. https://doi.org/10.1016/J.WASMAN.2018.02.048.

Nijsse, R., Mughini-Gras, L., Wagenaar, J.A., Ploeger, H.W., 2014. Coprophagy in dogs interferes in the diagnosis of parasitic infections by faecal examination. Vet. Parasitol. 204 (3–4), 304–309. https://doi.org/10.1016/J.VETPAR.2014.05.019.

Njuguna, J., 2016. Effect of eliminating open defecation on diarrhoeal morbidity: an ecological study of Nyando and Nambale sub-counties, Kenya. BMC Publ. Health 16 (1), 1–6.

Ntekpe, M., Mbong, E., Edem, E., Hussain, S., 2020. Disposable diapers: impact of disposal methods on public health and the environment. Am. J. Med. Publ. Health 1 (2), 1009.

Nyamayedenga, V.K., Tsvere, P.M., 2020. Real time data capture: a response to unsustainable dumping of disposable diapers and sanitary pads in gweru city, Zimbabwe. East Afr. J. Educ. Soc. Sci. 1 (2), 54–64.

Oguttu, D.W., Okullo, A., Bwire, G., Nsubuga, P., Ario, A.R., 2017. Cholera outbreak caused by drinking lake water contaminated with human faeces in Kaiso Village, Hoima District, Western Uganda. October 2015 Infect. Dis. Poverty 6 (1), 1–7.

Pace, R.C., Talley, J.L., Crippen, T.L., Wayadande, A.C., 2017. Filth fly transmission of Escherichia coli O157:H7 and Salmonella enterica to lettuce, Lactuca sativa. Ann. Entomol. Soc. Am. 110 (1), 83–89.

Panulo, M., Chidziwisano, K., Beattie, T.K., Tilley, E., Kambala, C., Morse, T., 2022. Process evaluation of the hygienic family intervention: a community-based water, sanitation, and hygiene project in rural Malawi. Int. J. Environ. Res. Publ. Health 2022 19 (11), 6771. Page 6771 19.

Perez, M., Navarro, P., Morillas, A., Valdemar, R., Araiza, J., 2021. Waste management and environmental impact of absorbent hygiene products: a review. Waste Manag. Res. 39 (6), 767–783.

Płotka-Wasylka, J., Makoś-Chełstowska, P., Kurowska-Susdorf, A., Treviño, M.J.S., Guzmán, S.Z., Mostafa, H., Cordella, M., 2022. End-of-life management of single-use baby diapers: analysis of technical, health and environment aspects. Sci. Total Environ. 836, 155339 https://doi.org/10.1016/J.SCITOTENV.2022.155339.

Portiolli, G.F., Rogers, T.W., Beckwith, W., Tsai, J., Ole-Moiyoi, P., Wilson, N., de Los Reyes, F.L., 2021. Development of trash exclusion for mechanized pit latrine emptying. Environ. Sci. J. Integr. Environ. Res.: Water Research & Technology 7 (10), 1714–1722.

Pullan, R.L., Smith, J.L., Jasrasaria, R., Brooker, S.J., 2014. Global numbers of infection and disease burden of soil transmitted helminth infections in 2010. Parasites Vectors 7 (1), 1–19.

Rahman, M.H.U., Malik, M.A., Chauhan, S., Patel, R., Singh, A., Mittal, A., 2020. Examining the linkage between open defecation and child malnutrition in India. Child. Youth Serv. Rev. 117, 105345 https://doi.org/10.1016/J.CHILDYOUTH.2020.105345.

Reese, H., Alman, B., Null, C., 2015. Disposing of children's diapers with solid waste: a global concern? Waterlines 34 (3), 255–268. https://doi.org/10.3362/1756-3488.2015.024.

Reference Bureau, Population, 2015. The urban-rural divide in health and development data sheet. Washington, DC. Available at: https://www.prb.org/wp-content/uploads/2015/05/urban-rural-datasheet.pdf. (Accessed 11 October 2022). Accessed.

Remigios, M., 2014. The environmental health implications of the use and disposal of disposable child diapers in senga/nehosho suburb in Gweru city, Zimbabwe. Glob. J. Biol. Aquacult. Health Sci. 3 (2), 122–127.

Roman, L., Hardesty, B.D., Leonard, G.H., Pragnell-Raasch, H., Mallos, N., Campbell, I., Wilcox, C., 2020. A global assessment of the relationship between anthropogenic debris on land and the seafloor. Environ. Pollut. 264, 114663 https://doi.org/10.1016/J.ENVPOL.2020.114663.

Rossouw, L., Ross, H., 2021. Understanding Period poverty: socio-economic inequalities in menstrual hygiene management in eight low- and middle-income countries. Int. J. Environ. Res. Publ. Health 18 (5), 2571, 2571 18.

Roxburgh, H., Magombo, C., Kaliwo, T., Tilley, E.A., Hampshire, K., Oliver, D.M., Quilliam, R.S., 2022. Blood flows: mapping journeys of menstrual waste in Blantyre, Malawi. Cities and Health 6 (4), 738–751.

Shuker, I.G., Cadman, C.A., 2018. Indonesia - Marine Debris Hotspot: Rapid Assessment. Report No. 126686 Synthesis Report. Washington, D.C. Available at: https://documents.worldbank.org/en/publication/documents-reports/documentdetail/983771527663689822/indonesia-marine-debris-hotspot-rapid-assessment-synthesis-report. (Accessed 16 August 2022).

Simiyu, S., Aseyo, E., Anderson, J., Cumming, O., Baker, K.K., Dreibelbis, R., Mumma, J. A.O., 2022. A mixed methods process evaluation of a food hygiene intervention in low-income informal neighbourhoods of kisumu, Kenya. Matern. Child Health J. 1–13.

Taboada-González, P., Armijo-de-Vega, C., Aguilar-Virgen, Q., Ojeda-Benítez, S., 2014. Household solid waste characteristics and management in rural communities. Open Waste Manag. J. 3 (1), 167–173. https://doi.org/10.2174/1875934301003010167.

Tembo, E., Chazireni, E., 2016. The negative environmental impact of disposable diapers: the case of mberengwa district, Zimbabwe. Int. J. Health Sci. 4 (2), 2158–2161.

Thanh, N.P., Matsui, Y., Fujiwara, T., 2010. Household solid waste generation and characteristic in a Mekong Delta city, Vietnam. J. Environ. Manag. 91 (11), 2307–2321. https://doi.org/10.1016/J.JENVMAN.2010.06.016.

The Washing Machine Project, 2022. Investigating the feasibility of distributing the divya 1.5 manual washing machine in Kenya. A study on laundry habits and preferences in homa-bay county, Kenya. https://www.thewashingmachineproject.org/publications. (Accessed 5 December 2022). Available at:

The World Bank, 2019a. DataBank. Health nutrition and population statistics. https://databank.worldbank.org/source/health-nutrition-and-population-statistics. (Accessed 13 September 2022). Available at:

The World Bank, 2019b. World Development Indicators [Fertility rate, total (births per woman)]. https://data.worldbank.org/indicator/SP.DYN.TFRT. (Accessed 16 August 2022). Available at:

Thomson, J.L., Cernicchiaro, N., Zurek, L., Nayduch, D., 2021. Cantaloupe facilitates Salmonella typhimurium survival within and transmission among adult house flies (Musca domestica L.). Foodbor. Pathogens and Dis. 18 (1), 49–55.

Thongsamer, T., et al., 2021. Environmental antimicrobial resistance is associated with faecal pollution in Central Thailand's coastal aquaculture region. J. Hazard Mater. 416, 125718 https://doi.org/10.1016/J.JHAZMAT.2021.125718.

Troeger, C., et al., 2018. Estimates of the global, regional, and national morbidity, mortality, and aetiologies of diarrhoea in 195 countries: a systematic analysis for the Global Burden of Disease Study 2016. Lancet Infect. Dis. 18 (11), 1211–1228.

Tumulango, F., Macalister, L., Whitebread, E., 2021. Introducing modern reusable nappies into Vanuatu – a trial study. https://www.mammaslaef.com/wp content/uploads/sites/105/2021/02/FINAL-PilotStudy-FullReport.pdf. (Accessed 7 December 2022). Available at:

Turpie, J., Letley, G., Ng'oma, Y., Moore, K., 2019. The case for banning single-use plastics in Malawi. https://www.lilongwewildlife.org/reports/. (Accessed 11 August 2022). Available at:

UNEP, 2021. Single-use Nappies and Their Alternatives: Recommendations from Life Cycle Assessments.

UNICEF, 2006. Core questions on drinking-water and sanitation for household surveys. https://apps.who.int/iris/handle/10665/43489. (Accessed 20 October 2022). Available at:

Velis, C.A., Cook, E., 2021. Mismanagement of plastic waste through open burning with emphasis on the global South: a systematic review of risks to occupational and public health. Environ. Sci. Technol. 55 (11), 7186–7207.

Wambui, K.E., Joseph, M., Makindi, S., 2015. Soiled diapers disposal practices among caregivers in poor and middle income urban settings. Int. J. Sci. Res. Publ. 5 (10).

WHO & UNICEF, 2021. Progress on Household Drinking Water, Sanitation and Hygiene 2000-2020: Five Years into the SDGs (Geneva).

WHO, 2022. Disease outbreak news; cholera – global situation. https://www.who.int/emergencies/disease-outbreak-news/item/2022-DON426. (Accessed 24 January 2023). Available at: Available at:

Wolf, J., et al., 2018. Impact of drinking water, sanitation and handwashing with soap on childhood diarrhoeal disease: updated meta-analysis and meta-regression. Trop. Med. Int. Health 23 (5), 508–525.

World Bank Group, 2019. World - measuring rural access: update 2017/18. http://documents.worldbank.org/curated/en/543621569435525309/World-Measuring-Rural-Access-Update-2017-18. (Accessed 7 October 2022). Washington, D.C. Available at:

Zimmermann, L., Bartosova, Z., Braun, K., Oehlmann, J., Völker, C., Wagner, M., 2021. Plastic products leach chemicals that induce in vitro toxicity under realistic use conditions. Environ. Sci. Technol. 55 (17), 11814–11823.

Zisa, A., Nilsson, K., Mirza, R., Vachon, T., 2022. Achieving handwashing with social art for behaviour change: the experience of the lazos de Agua programme in Latin America. H2Open J. 5 (2), 323–332.

Zolnikov, T.R., Furio, F., Cruvinel, V., Richards, J., 2021. A systematic review on informal waste picking: occupational hazards and health outcomes. Waste Manag. 126, 291–308. https://doi.org/10.1016/J.WASMAN.2021.03.006.