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Disposable diaper waste accumulation at the human-livestock-wildlife interface: A one health approach

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ABSTRACT

Improper management of disposable diaper waste is becoming a priority global health issue because it has resulted in environmental accumulation of fecal pathogens and non-biodegradable material. Concerns include drinking water safety, as well as chemical and physical contaminants that may harm human, animal (domestic and wildlife), and environmental health. In rural areas, especially those in low- and middle-income countries where municipal waste management infrastructure may be lacking, this issue is particularly challenging. Using a One Health approach, this study used spatial statistics to describe the location and proximity of disposable diaper waste sites to livestock grazing areas, human dwellings, rivers, and conservation areas in agro-pastoralist communities in South Africa. A total of 627 unique diaper waste sites were identified and plotted between May 2019 and March 2020. The mean distance of waste sites to rivers was 2,196 m (SD=1,799) and 5,523 m (SD=2,642) to protected areas. Most diaper waste sites were located along the perimeter of villages and dwellings, where livestock grazing areas are common. This description of waste sites is an important step in strategizing efficient and effective waste management programs and policies that prioritize those areas with greatest potential impact on human, animal, and environmental health for remediation.

1. Introduction

Sanitation interventions remain a crucial part of public health initiatives, yet at least 785 million people worldwide lack access to safe, clean, and reliable drinking water, and 673 million people do not have access to sanitation infrastructure (United Nations, 2019a). In low- and middle-income countries, diarrheal diseases are the sixth leading cause of death (WHO, 2020); however, research shows that reliable access to sanitation and hygiene interventions such as safe disposal of human excreta decreases diarrhea-related morbidity (Wolf et al., 2018). The lack of access to basic sanitation and hygiene infrastructure also has negative social impacts on communities, and women are disproportionately affected (FAO, 2012).

The United Nations Sustainable Development Goals (SDGs) address 17 universal health and development issues, including access to clean water and sanitation (Goal 6) and responsible consumption and production (Goal 12) (United Nations, 2019a). Amidst a growing population, these goals aim to build a more sustainable and resilient future for all. The widespread usage and environmental management of disposable diapers is a priority global health issue that is related to these SDGs. In comparison to their reusable cloth counterparts, disposable diapers consume more than 20 times the raw materials, produce 60 times the solid waste, and utilize 2.3 times more water (Ajmeri, 2016). Additionally, disposable diapers are comprised largely of superabsorbent polymers (SAPs), plastics, and wood pulps that contribute to microplastic pollution (Hasegawa et al., 2021; Niaounakis et al., 2017). The gels and polymers that enhance a diaper's absorbency can take 250–500 years to degrade (Khoo et al., 2019) and can enhance the water retention properties of soil (Zekry et al., 2020). Improper waste management can lead to multiple public and environmental health impacts. While research is lacking on the long-term health effects associated with exposure to microplastics, preliminary evidence suggests concern for neurodegenerative and autoimmune disorders, cancers, and inflammatory lesions (Prata et al., 2020; Rhaman et al., 2021).

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Human feces are a significant carrier of pathogens and parasites that are responsible for numerous infectious diseases, including campylobacteriosis, typhoid fever, hepatitis E, cryptosporidiosis, and schistosomiasis (Huber et al., 1994; Sclar et al., 2016). Many of these pathogens can contaminate food and water and are considered zoonotic, capable of being transmitted between humans and animals. Disposable diapers can harbor enteric pathogens that can cause diarrheal diseases (Holaday et al., 1995; Huber et al., 1994). Amongst children, these diarrheal diseases are a major contributor to early childhood death, malnutrition, and impaired growth (George et al., 2016). In addition to shared infectious threats, disposable diapers can also pose a physical hazard for domestic and wild animals as the polymer materials may damage gastrointestinal villi and reduce feed intake (Stock et al., 2020). Ingestion of foreign material can also cause intestinal obstructions in animals that can be fatal (Ström et al., 2018).

Despite the potential harms of disposable diaper waste accumulation in the environment, there remains a significant knowledge gap in usage and disposal practices, as well as their environmental fate (Cordella et al., 2015; Martin et al., 1996; Mathe et al., 2018; Meseldzija et al., 2013; Reese et al., 2015). As the global population grows, understanding the impact of these materials becomes increasingly important to safeguard the food and water supply and protect human and animal health. Waste products generated by human activities are major causes of environmental and health challenges (Ziraba et al., 2016). Those most vulnerable to these challenges are those who lack municipal infrastructure and reliable access to water, sanitation and hygiene (WASH) resources (Ikeme et al., 2003). Solid waste management practices vary greatly across regions and even countries and can entail reduced waste generation, re-use, recycling, composting, and safe disposal through landfill. In low- and middle-income countries, however, these are often not practiced due to lack of laws and policies governing waste management enforcement and available funding. In low-income countries, solid waste collection is less than 50% compared to about 98% in high-income countries (Ziraba et al., 2016).

In South African communities within the Kruger to Canyons (K2C) Biosphere Region, identified as a Presidential Poverty Node due to lack of access to basic water, sanitation, hygiene, and refuse removal services (Bushbuckridge Local Municipality, 2021), environmental accumulation of disposable diapers has been identified as a priority issue (Berrian et al., 2016). Prior studies indicate that 80% of households with young children utilize disposable diapers and disposal practices are variable (e.g., burning, burying, throwing in bush/rivers) (Berrian et al., 2016). Due to the ecologically sensitive location of this community at the interface of private and provincial conservation areas, this study aims to quantify and describe the location and proximity of disposable diaper waste sites to livestock grazing areas, human dwellings, rivers, and protected areas. Results may be used to identify priority areas for environmental remediation and inform community waste management policies and infrastructure.

2. Materials and methods

2.1. Study site

The study was performed within the Kruger to Canyons (K2C) Biosphere Region in northeastern South Africa, which straddles Limpopo and Mpumalanga Provinces. The biosphere covers over 2.5 million hectares, encompassing Kruger National Park and other national and provincial conservation areas. Three Southern African biomes are incorporated: grasslands, Afro-montane forests, and the savannah of the lowveld. This area is also considered a Strategic Water Source Area, generating a disproportionate amount of water for the lower-lying regions (UNESCO, 2021a). There are multiple major towns in the Region (Tzaneen, Phalaborwa, Bushbuckridge, Hoedspruit, and Graskop) as well as rural villages, which largely consist of agro-pastoralist communities that raise cattle, goats, and chickens predominantly (Berrian et al., 2016).

Table 1
Average distance of diaper waste sites from areas of interest within the Kruger to Canyons Biosphere Region, Republic of South Africa.

Area of Interest	Mean (meters)	SD[1] (meters)
Protected Areas	5523	2642
Rivers	2196	1799

[1] SD = standard deviation.

2.2. Data collection

To coordinate and implement K2C sustainable development activities in accordance with the UNESCO Man and the Biosphere strategy (UNESCO, 2021b), the K2C Biosphere Region non-profit organization was established in 2011. The organization employs residents from communities within the Sehlare Tribal Authority through the Environmental Monitors (EM) Programme. The EM program is funded through the national Department of Forestry, Fisheries and the Environment, employing youth to support environmental organizations. From May 2019 to March 2020, EMs collected the GPS location of disposable diaper waste sites within selected villages. GPS locations were recorded in a Microsoft Excel spreadsheet. Open-source GIS data from the Department of Forest, Fisheries and the Environment (Department of Forestry, Fisheries and the Environment, 2021), the 2011 Republic of South Africa National Census (Code for Africa, 2011), and Google Earth™ provided additional vector data to describe the relationship of waste sites to human dwellings, rivers, and protected conservation areas. Protected areas were defined as nature reserves, national parks, and protected environments under the National Management Protected Areas Act 2003 (Department of Forestry, Fisheries and the Environmnent, 2021). The decision to utilize nationally recognized protected areas and rivers is rooted in the rich dichotomy of terrestrial and aquatic ecosystems. While vastly different, both of these ecological models provide valuable insights to the types of acute and chronic One Health issues that may result from improper management of disposable diapers.

2.3. Data analysis

GPS data were imported into and processed using ArcGIS Pro-Version 2.7.0. Data input errors were identified and corrected manually. The “XY Table to Point” data management tool was used to create a vector point feature from the coordinates in the dataset. Additional shapefiles from open-source data were added as map layers and results visualized. To determine the distance (in meters) between diaper waste sites to specified areas of interest (e.g., rivers, protected areas), the “Generate Near Table” analysis tool was used for calculations. Summary statistics were performed to determine the mean and standard deviation associated with calculated distances between features. The “Multiple Ring Buffer” analysis tool was used to describe the density of diaper waste sites around dwellings and grazing areas at 400, 2200 and 4000 m. Density of sites was used instead of distance from individual dwellings because there was not publicly available vector data containing coordinates of individual dwellings within villages. Distances (in meters) of specified buffer zones were extrapolated from a voluntary community survey that asked respondents to report how far they walked to discard diapers.

3. Results

A total of 627 unique diaper waste sites were identified and plotted in relation to rivers (Fig. 1a) and protected areas (Fig. 1b) within the study site. Each waste site location is represented by a single point on the map. Average distances of waste sites to areas of interest, including protected areas and rivers, are summarized in Table 1. Additionally, three distinct buffer zones were established to determine proportion of waste sites

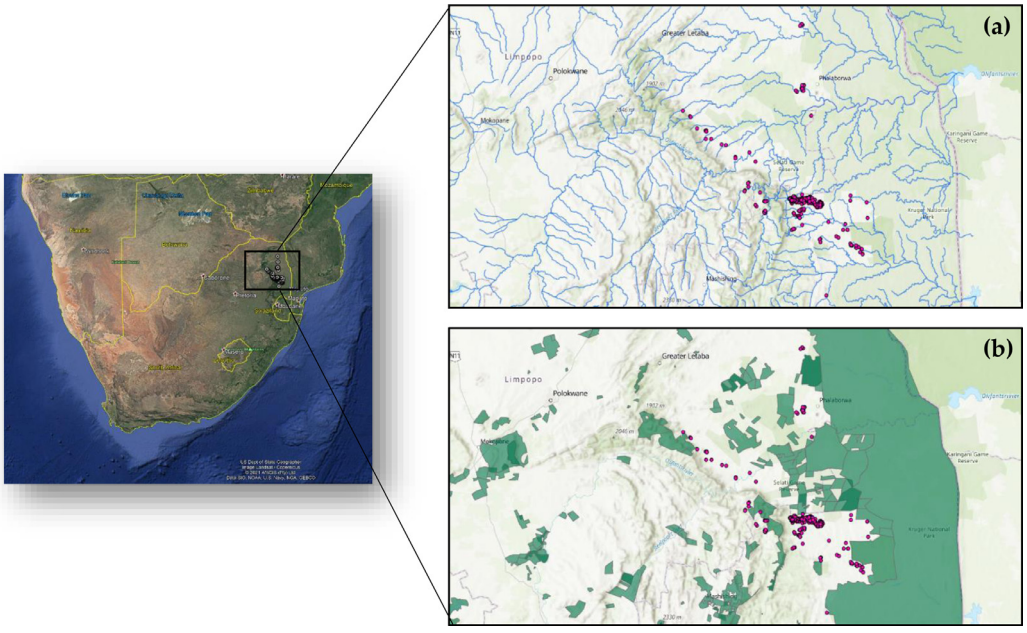

Fig. 1. Location of diaper waste sites relative to **(a)**, rivers (blue) and **(b)**, protected areas (green) in the Kruger to Canyons Biosphere Region, Republic of South Africa.

Table 2
Proportion of diaper waste sites within a specified buffer zone within the Kruger to Canyons Biosphere Region, Republic of South Africa.

Buffer Zone (meters)	Protected Areas, n (%)	Rivers, n (%)
<400	13 (2.1)	132 (21.1)
<2200	43 (6.9)	343 (54.7)
<4000	200 (31.2)	476 (75.9)

within each (Table 2). On average, diaper waste sites were found in closer proximity (and in greater proportion) to rivers than protected areas.

Google Earth™ allowed for the visualization of diaper waste sites in relation to human dwellings and roadways (Fig. 2a). With regard to human-dominated landscapes, most diaper waste sites were located on the perimeter of rural villages where dirt roadways and animal grazing areas were common. Most clusters of diaper waste sites in relation to dwellings and grazing areas were located within the 400-meter buffer zone (Fig. 2b). The village of Ga-Boelang had the highest concentration of diaper waste sites in the study area.

4. Discussion

The mapping of diaper waste sites in this K2C region allowed for the characterization of disposal practices and the identification of high-density clusters that can be prioritized for remediation. Waste sites were aggregated in human-dominated landscapes, particularly adjacent to dwellings and roadways where access by residents and domestic animals would be greater. With regard to ecologically-sensitive areas, diaper waste sites were more concentrated near rivers than protected areas. Prior survey work in this region suggests that residents perceive rivers as "washing away" waste and even a potentially environmentally-friendly disposal option due to the lack of visible accumulation (Kordecki, 2021). A study in Zimbabwe reported that women preferred burning, burying, flushing in the toilet, or dumping disposable diapers in open spaces Remigios (2014). While less visible to residents, indiscriminate dumping and burying of disposable diapers has the undesirable consequence of mixing with groundwater and contaminating drinking water with pathogenic bacteria and viruses. When disposed of near drainage, diapers can block water runoff, causing flooding. Water accumulation, due to improper drainage or diaper absorption, can also create breeding habitats for insects that transmit disease as biological or mechanical vectors (Ntekpe et al., 2020). As an environmental consequence, a study in Bangladesh demonstrated severe water pollution can significantly diminish a river's ability to sustain life by altering vital factors such as dissolved oxygen content and pH (Halder and Islam, 2015). While there is a growing body of literature investigating the health and environmental impact of water pollution, including but not limited to that caused by disposable diapers, many of these studies focus on higher density cities and suburbs with more organized waste management infrastructure (e.g., landfills, sewer systems). In comparison, the health effects and ecological impacts related to water pollution for more rural communities that lack waste and water management systems are not as well documented. Moreover, the specific topography, climate, and land use in the K2C Region add a layer of complexity to this issue.

Given the proximity of diaper waste sites to rivers and the significance of surface waters in the K2C to downstream ecosystems, future research should focus on water quality, particularly targeting high-density waste site locations (e.g., Ga-Boelang). Fecal bacteria, such as total coliforms or *Escherichia coli*, may be useful indicators of water quality associated with diaper waste. Given the clustering of waste sites on the perimeter of rural villages (along roadways and animal grazing paths), waste management programs, such as the placement of municipal collection bins, may target these priority areas. Currently, there is no organized or regulated municipal waste management infrastructure in the study area; hence, one of the reasons this region was selected as a Presidential Poverty Node.

A pilot survey of caretakers in this region revealed that women are largely responsible for the purchase and disposal of diapers (Kordecki, 2021), suggesting an ideal target audience for future education and interventions. Despite the increased cost, all surveyed individuals utilized disposable diapers to some degree. Reasons behind this are not thoroughly understood but could be related to convenience, as well as lack of reliable water accessibility for cleaning reusable diapers. In the future, this issue could become exacerbated as climate change threatens freshwater availability throughout the world (UNESCO World Water Assessment Programme, 2020), driving increased use of disposable diapers.

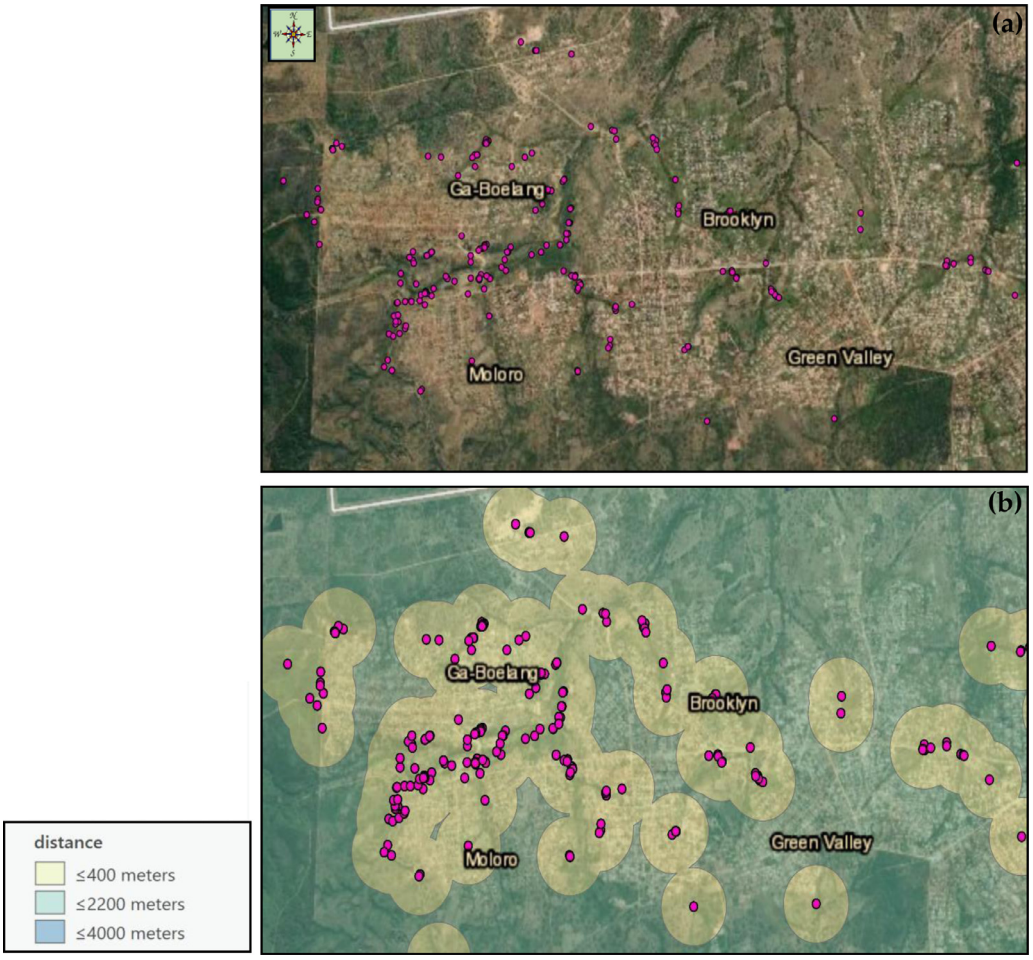

Fig. 2. Location of **(a)**, diaper waste sites relative to human-dominated landscapes (dwellings, roadways, animal grazing areas) and (**b**), buffer zones relative to human-dominated landscapes in the Kruger to Canyons Biosphere Region, Republic of South Africa.

Using demographic data (e.g., number of children per household currently using diapers) and estimated number of diapers used per child, the pilot survey also estimated an average of 3.31 (SD=1.66) disposable diapers used per household per day (Kordecki, 2021). An enhanced understanding of purchasing and disposal practices and priorities, including economic, socio-behavioral and cultural factors, may help to guide interventions that seek to curb use and/or promote more sustainable disposable practices. Additional research that evaluates these factors in the K2C Region is currently planned. To further improve the current study design, future research should also seek to estimate and incorporate the size/scale of diaper waste sites as well as the disposal methods (e.g., bury, burn) as these factors can affect environmental contamination levels and downstream effects. Additional factors, including terrain slope and seasonal influence (e.g., rainfall), may further affect the contamination pathway and should be considered in future work.

A limitation of this study was the use of a voluntary community survey (self-report) to determine the distance (in meters) that respondents walked to discard diapers; this measurement was then used to extrapolate buffer zones in relation to rivers and protected areas. Measurements were subject to under-/over-estimation as well as inconsistent units of measure that then had to be standardized. Future studies that evaluate diaper waste site locations should consider incorporating verifiable measurements, such as GPS waypoints from one location of interest to another.

One Health issues that may arise from improper management of disposable diaper waste include fecal contamination and subsequent diarrheal diseases related to drinking water safety, in addition to the bioaccumulation and long-term health effects of chronic microplastic exposure for both people and animals (domestic and wildlife) that share this landscape. Human feces are well-known carriers of infectious and zoonotic pathogens; however, fecal pollution may not only pose direct health concerns but also drive longer-term risks such as environmental antimicrobial resistance (AMR) (Thongsamer et al., 2021). Antimicrobial resistance in *E. coli* isolates from both people and animals (especially food-producing livestock) has shown strong correlation, suggesting transmission across the human-animal interface (Vieira et al., 2011). Excessive environmental accumulation of human waste may provide opportunities for AMR genes to multiply and introduce novel pathogens to threatened and endangered wildlife species. Moreover, immunosuppressed or malnourished individuals are especially vulnerable to diarrheal diseases. Thus, a One Health approach to research and implementation science is particularly valuable in landscapes such as the K2C Biosphere Region where human communities regularly interact with livestock and wildlife.

While improving access to water, sanitation, hygiene, and waste management services is an important step in mitigating these One Health risks, this research also highlights the knowledge gap pertaining to the long-term health impacts associated with accumulation of disposable diapers on a global scale. The global population is expected to rise an additional one billion people by 2030, and sub-Saharan Africa, where public health infrastructure and municipal services often lag, may account for more than half of this growth (United Nations, 2019b). As a result, disposable diaper use will likely increase, resulting in the accumulation of environmental waste and pathogen pollution. Future work

may prove useful in developing effective and sustainable solutions both at the community level as well as through manufacturers that may be persuaded to provide more environmentally-friendly materials and disposal options that are widely accessible, affordable, and address the realities of the consumer.

5. Conclusions

The study sought to provide a spatial description of disposable diaper waste sites, particularly in relation to sensitive ecological areas (e.g., rivers, protected areas) and human- and livestock-dominated environments. The average distance of diaper waste sites to rivers was 2196 m, in comparison to 5523 m for protected areas. The village of Ga-Boelang was identified as a priority location for remediation due to its high concentration of waste sites. This research is an important step in determining priority locations for remediation and sustainable waste management solutions. At the community level, this study demonstrates that diaper waste sites are spatially aggregated adjacent to rural villages, roadways, animal grazing areas, and rivers. While the location and proximity of diapers can serve as a useful proxy for environmental contamination and related health effects, future research must prioritize the direct links between waste sites, water quality, and human/animal morbidity. Diaper waste in the environment is a neglected but important global health issue with implications for human, animal, plant, and ecosystem health. A One Health approach that considers each of these components is recommended for future research and community-focused interventions.

Author contributions

Conceptualization, I.V.W., R.A.-W. and M.-T.U.; methodology, A.M.B., H.K., and E.D.R; software, H.K. and E.D.R; formal analysis, H.K.; resources, A.M.B., M.-T.U.; data curation, M-T.U. and R.A.-W; writing – original draft preparation, H.K. A.M.B.; writing – reviewing and editing, A.M.B., I.V.W., R.A.-W., M.-T.U., and E.D.R; supervision – A.M.B.; visualization – A.M.B. and H.K.; project administration – M.-T.U. and A.M.B. All authors have read and agreed to the published version of the manuscript.

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Institutional review board statement

Not applicable.

Informed consent statement

Not applicable.

Declaration of Competing Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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