# Integrating urban household solid waste management with WASH: implications from case studies of monitoring in Sub-Saharan Africa

Wright, Jim1\*, Dzodzomenyo, Mawuli2, Hill, Allan G.3, Okotto, Lorna G.4, Thomas-Possee, Mair L.H.3, 6, Shaw, Peter J.1, Okotto-Okotto, Joseph5

1 School of Geography and Environmental Science, University of Southampton, Building 44, Highfield, Southampton SO17 1BJ, UK. Emails: j.a.wright@soton.ac.uk, p.j.shaw@soton.ac.uk

2 School of Public Health, University of Ghana, P.O. Box LG 25, Legon, Accra, Ghana. Email: mdzodzomenyo@ug.edu.gh

3 Social Statistics and Demography, University of Southampton, Building 58, Highfield, Southampton SO17 1BJ, UK. Email: ah4e10@soton.ac.uk

4 School of Spatial Planning and Natural Resource Management, Jaramogi Oginga Odinga University of Science and Technology, P.O. Box 210-40601, Bondo, Kenya. Email: lgokotto@yahoo.com

5 Victoria Institute for Research on Environment and Development International, P.O. BOX 6423-40103, off Nairobi Road, Rabuor, Kenya. Email: jokotto@hotmail.com

\* Corresponding author.

6 Present Address: WaterAid, 6th Floor, 20 Canada Square, London E14 5NN.

**Author contributions**

Conceptualization: AGH, JAW, LO, JOO, PJS, MD. Formal analysis: JAW, MTP. Methodology: AGH, MD, MTP, JAW. Project administration: JAW, MD, JOO, LO. Writing – original draft: JAW. Visualization: JAW, MTP, JOO, LGO. Writing – review & editing: MD, AGH, LGO, MTP, PJS, JOO.

**Abstract**

Water, Sanitation and Hygiene (WASH) are commonly grouped for service delivery planning, monitoring and policy, reflecting their many interconnecting impacts, but few studies articulate household-level WASH-solid waste interactions. We aim to assess mismanaged solid waste interactions with WASH that affect urban households and whether integrated waste-WASH indicators can be constructed to monitor these interactions. Via literature review, we identify three trade-offs and seven synergies between WASH and waste management for urban households. Trade-offs arise from consumption of water packaged in bottles or bags and disposable diapers (DDs), whilst synergies include opportunities for households with water services to wash separated waste or cloth diapers. One trade-off (packaged water consumption) has grown rapidly in southeast Asia and West Africa. Household surveys for Ghana and Kenya demonstrate that the urban population lacking waste collection services overlaps strongly with those lacking WASH services. In Kenya, 3.3 million people simultaneously lacked waste collection, hygiene, and basic sanitation services. Finally, we construct indicators from household survey micro-data to measure DD and packaged water consumption in households lacking waste services. Case studies show that from 2012-13 to 2016-17, packaged water consumption grew among Ghanaian households burning or dumping waste, whilst most urban Nigerian households consuming DD lack waste collection services. We conclude that household survey micro-data can be used to construct trade-off measures to inform policy and target services towards populations simultaneously exposed to uncollected waste and lacking WASH services. However, such analyses require an institutional mechanism to coordinate cross-goal monitoring and greater survey data harmonisation. In countries where large populations lack both waste collection and WASH services or with growing DD or packaged water consumption, balanced evidence is needed on DD and packaged water’s impacts from both WASH and solid waste management perspectives.

**Keywords:**

Low and middle-income countries; Solid Waste; Sustainable Development Goals; Water, Sanitation and Hygiene; urban planning

## Introduction

It is common for Water, Sanitation and Hygiene (WASH) to be grouped together for service delivery, planning, monitoring and policy. This grouping reflects the many interconnecting impacts of the WASH components, first captured via the ‘F diagram’ (Wagner and Lanoix, 1958). This shows the inter-linkage of WASH-related disease transmission pathways and associated infection control barriers. Many service delivery programmes now combine two or all of the WASH components (Esteves Mills and Cumming, 2016), reflecting the ‘F diagram’. However, the ‘F diagram’ rarely captures how mismanaged solid waste (SW) interacts with WASH to affect urban households.

Analyses of Sustainable Development Goal (SDG) targets have generally found synergies between SDG6 (incorporating WASH targets) and other SDGs (Barbier and Burgess, 2019, Pradhan et al., 2017, Kroll et al., 2019), including with solid waste-related targets. SDG targets 6.1 and 6.2, both related to WASH, have many synergies with other SDGs (Fader et al., 2018). For example, the sanitation SDG target (6.2) shows extensive synergies with other SDGs (Parikh et al., 2021), including those relating to waste management. Conversely, (Rodić and Wilson, 2017) identified no explicit relationship between solid waste (SW) and SDG6. Empirical studies of SDG synergies and trade-offs have analysed pre-designed, national-level SDG indicators (Pradhan et al., 2017, Kroll et al., 2019, Lusseau and Mancini, 2019), but not constructed new indicators. In this study, we use currently available household survey micro-data to construct new indicators to capture SW-WASH SDG interactions.

It has been argued that solid waste management (SWM) should be integrated within WASH for service delivery, because of synergies between SWM, water, and sanitation (Narayan et al., 2021). Synergies include commonalities in the service delivery chains that provide water to remove excreta and waste from communities, and potential for sharing innovative emerging technologies and planning approaches (Narayan et al., 2021). We also argue for integration of SWM with WASH, but from the perspective of urban households as service users rather than service providers. We also draw on proposals for SWM planning in low- and middle-income countries (LMICs) to widen systems thinking boundaries beyond technical SWM to incorporate socio-economic aspects of urbanisation (Marshall and Farahbakhsh, 2013). We address the following questions:

* What inter-connections exist between SWM and WASH from the perspective of urban households?
* To what extent have these inter-connections changed over time?
* To what extent do the urban populations lacking basic WASH also lack SW collection services?
* How can existing household survey and census micro-data be used to monitor inter-connections between WASH and municipal SWM?

## The WASH-SWM nexus: inter-connections affecting urban health.

A nexus is where feedback loops between system components lead to trade-offs and synergies that are not apparent from studying each component in isolation (Zhang et al., 2018). Improper SWM has multiple health impacts, including pulmonary diseases linked to pollutants from waste burning, diarrhoeal and vector-borne diseases such as hanta virus transmission via rats, and injury to waste collectors (Vinti et al., 2021). Among these diverse health impacts, we examine SWM-WASH interactions affecting household diarrhoeal disease risk as a persistent top five cause of global child morbidity and mortality since 1990 (Troeger et al., 2018). The F-diagram has long been used to understand the transmission pathways by which WASH relates to health outcomes, particularly diarrhoeal disease (Wagner and Lanoix, 1958). It originally emphasised faeces, flies, fingers, food, fluids and fields (soil), as transmission pathways and control points for bacterial pathogens. Later versions added fomites and livestock (Penakalapati et al., 2017). The diagram has recently been modified to capture mismanaged SW as a risk factor attracting the fly vector for trachoma, *Musca sorbens* (Greenland et al., 2019); otherwise, F-diagram depictions exclude SW. To address this omission, via structured discussion, we identified potential SW-WASH connections affecting urban households, drawing on literature to substantiate each connection (Table 1). Figure 1 illustrates the synergies [S] and trade-offs [T] between SW collection and WASH service access affecting urban households and their immediate environments.

|  |  |
| --- | --- |
| **Trade-off [T] or Synergy [S] ID** | **Description and supporting literature** |
| T1 | Consumption of packaged water (sold in plastic bottles or bags) often reduces population exposure to faecally contaminated water (Williams et al., 2015), but generates plastic waste (Wardrop et al., 2017). This misaligns with waste management hierarchy principles, which prioritises waste reduction above reuse, recycling, recovery and landfill (Gharfalkar et al., 2015).  |
| T2 | Single-use disposable diapers provide a convenient means of child faeces disposal, but can be mismanaged or dumped (Mbiba, 2014); (Velasco Perez et al., 2020). Their consumption again misaligns with waste management hierarchy principles.  |
| T3 | Personal Protective Equipment (PPE) and hand hygiene protect against communicable diseases (Lio et al., 2021). The Covid-19 pandemic highlighted substantial mismanaged waste generation from discarded PPE and hand hygiene products (Tripathi et al., 2020). An estimated 0.15 to 0.39 million tonnes of plastic debris from mismanaged face masks entered the oceans annually at the pandemic’s height (Chowdhury et al., 2021). Similar waste disposal issues arise from widening access to menstrual hygiene products (Elledge et al., 2018). |
| S4 | Basic or safely managed sanitation provision should reduce household faeces disposal in plastic bags via ‘flying toilets’ (Tumwebaze et al., 2013) and mixing human with SW, thereby lowering occupational health risks for waste collectors (Ziraba et al., 2016). |
| S5 | SW collection service provision should reduce households disposing of SW via sanitation facilities (e.g., pit latrines), impairing their intended function (Narayan et al., 2021). |
| S6 | Reducing mismanaged SW, particularly organic waste and faeces, should discourage flies, other pests, and defecation by livestock near the home, in turn lessening recontamination risks for household stored water (Das et al., 2018). |
| S7 | Waste service provision should reduce mismanaged SW blocking urban storm-drains and other water courses (Armitage, 2007). Where water tables are shallow, this increases flood risk and pit latrine overspill, exacerbating faecal contamination of shallow wells (Katukiza et al., 2010). |
| S8 | Greater waste collection service coverage would reduce mismanaged plastics from domestic waste entering the environment, then breaking down into micro-plastics, and thereby ultimately reduce future water treatment costs associated with micro-plastics removal (Shen et al., 2020). |
| S9 | Since washing increases waste value for recycling or reuse (Asim et al., 2012), sufficient water access could promote greater domestic waste separation and thereby recycling or reuse. |
| S10 | Use of reusable cloth diapers requires sufficient water and soap for washing (Kuhl et al., 2021). |

Table 1: Synergies [S] and trade-offs [T] between uncollected solid waste and Water, Sanitation and Hygiene (WASH) affecting urban households.

Figure 1 depicts household-level mechanisms (S4 to S10) that account for the synergies between SDG6 and uncollected SW identified via national-level SDG indicators (Kroll et al., 2019, Barbier and Burgess, 2019). Access to sufficient water is a necessary precondition for some household behaviours positively linked to waste management hierarchy principles (S9; S10). However, it also highlights WASH-SW collection service delivery trade-offs arising from the consumption of DDs, packaged water, and hygiene products as urban lifestyles change (T1 to T3).

**

*Figure 1: Synergies and trade-offs between solid waste management and Water, Sanitation, and Hygiene (WASH) for urban households and their immediate neighbourhoods.*

There are thus mechanisms (S4 to S7, possibly S8) that could result in synergistic diarrhoeal disease risks for households simultaneously exposed to uncollected waste and lacking WASH services. A synergistic risk is where a combined hazard is riskier than each of its constituent hazards in isolation (Hampson et al., 2003). However, it remains unclear whether multiple exposure to uncollected waste and lack of WASH services translate into synergistic diarrhoeal disease risk. Systematic reviews examining health impacts of SWM currently focus on occupational health risks to waste collectors (Ncube et al., 2016, Poole and Basu, 2017, Zolnikov et al., 2021), domestic waste burning (Velis and Cook, 2021), or from proximity to waste disposal sites (Porta et al., 2009, Vinti et al., 2021, Ncube et al., 2016, Mattiello et al., 2013, Tait et al., 2020) but do not consider diarrhoeal disease impacts of uncollected waste in the home. Diarrhoeal disease risks from waste disposal behaviours can increase due to unsafe child faeces disposal, including disposal via garbage (Bawankule et al., 2017). Simultaneous lack of sanitation, hygiene, and water services also exposes households to the synergistic diarrhoeal disease risk pathways identified via the F-diagram. Evidence for such synergistic health risks is mixed, finding no synergistic effect of sanitation and water on diarrhoeal disease risk or child growth in some studies (Bekele et al., 2020, Jee Hyun et al., 2015, Merchant et al., 2003, Rah et al., 2020), and synergistic effects of hygiene and sanitation on child growth in others (Jee Hyun et al., 2015, Bekele et al., 2020). It is thus unclear from analogous literature examining synergistic health effects of WASH whether the mechanisms in Figure 1 will necessarily generate synergistic health risks. Furthermore, evidence is lacking on the synergistic health effects of simultaneous exposure to uncollected waste and lack of WASH services.

## Nexus trends affecting urban SWM and WASH: the example of packaged water.

Household surveys suggest some trade-offs are growing rapidly in low- and middle-income country (LMIC) cities, particularly in relation to WASH-related product consumption (T1; Figure 1). The World Health Organisation and UNICEF have noted increasing proportions of urban households reporting packaged water as their main drinking-water source, particularly in West Africa and Southeast Asia (World Health Organization and UNICEF, 2017). Drawing on databases underpinning SDG6 (UNICEF/WHO Joint Monitoring Program, 2023), we therefore constructed time series of indicators for selected countries in these two regions (Figure 2). In Nigeria, Performance Monitoring for Action (PMA) surveys from 2016 to 2018 consistently identified over 43% of urban households (ca. 48.4 million people in 2021) using packaged water as their main drinking-water source. In Ghana, surveys including the Malaria Indicator Survey, PMA surveys, and Multiple Indicator Cluster Survey from 2017-21 all estimated packaged water as the main drinking-water source for at least 41% of urban households (7.8 million people in 2021). In Indonesia, national Socio-economic Surveys (SUS) from 2018-20 indicate over 50% of urban households (ca. 82.2 million people in 2020) using packaged water as their main source, though census, Demographic and Health Surveys and PMA surveys suggest lower proportions of 12.9% to 18.6% since 2016. Southeast Asia appears a packaged water consumption hotspot, with high reported consumption in Lao, the Philippines and Vietnam.

Proliferation of packaged water consumption (Figure 2) does not reflect a conscious service delivery strategy by national governments. For example, the Ghanaian government considered banning sachet water because of its consequences for plastic waste management (Stoler et al., 2012). Studies in Indonesia and Ghana have attributed consumer preference for packaged water to convenience relative to boiling, low coverage of continuous piped water supplies, water utility mistrust, and its perceived safety (Prasetiawan et al., 2017, Puspita et al., 2023, Abrokwah et al., 2022).



*Figure 2: Percentage of urban households reporting packaged water as their main drinking-water source in selected Southeast Asian and West African countries (source:(UNICEF/WHO Joint Monitoring Program, 2023); data points represent national household surveys or censuses).*

## Overlap in urban populations lacking WASH and solid waste collection services.

(UN-Habitat, 2016) defines a slum as where most residents either lack secure tenure, have non-durable housing, lack improved sanitation, lack improved drinking-water sources, or live in overcrowded housing. This definition thus includes water and sanitation, but not waste collection services. The lack of an indicator integrating WASH with SWM means it is unclear how far populations that lack WASH also lack SW collection services and are thereby exposed to the interactions in Fig. 1.

We examined this question, choosing Ghana and Kenya as case studies with household survey capturing SW collection and WASH services. We calculated the population lacking basic WASH and waste collection services, both for each service and as different combinations of these four services. WASH and SW service data from the 2016-2017 Ghana Living Standards Survey (GLSS7) and 2015-2016 Kenyan Integrated Household Budget Survey (KHBS) were used. The GLSS7 (October 2016 to October 2017) employed a two-stage stratified sampling design, with 1000 enumeration areas (EAs) selected as primary sampling units (PSU) (Ghana Statistical Services, 2018). Fifteen households were selected per PSU, generating a sample of 15,000 households. The response rate was 93.9% giving a final sample of 14,009 households, with 6,018 urban households. The KHBS (September 2015 to August 2016) also used a two-stage stratified sampling design. Ten households were selected from each of 2,400 clusters, resulting in 24,000 selected households (Kenya National Bureau of Statistics, 2018). 90.7% responded, giving a final sample of 21,773 households with 8,681 being urban.

For both countries, we applied SDG6 indicator definitions (Table S1) to survey micro-data. Since the Kenyan and Ghanaian surveys lacked data on safely managed water and sanitation services respectively we identified households lacking basic WASH services (UNICEF and WHO, 2023). The Kenyan survey had no question about water or soap availability, so for Kenya we defined lacking hygiene as having no handwashing facility at home. We classified households burning or dumping waste as lacking waste collection services. We then calculated the number of urban households nationally lacking different sets of the four services (i.e. water, sanitation, hygiene, and SW collection services), using the *svy* commands in Stata V16.1 (StataCorp, 2019) to account for the multi-stage survey design. Visualising intersections for more than three sets is challenging using Venn or Euler diagrams, thus we used the UpSetR package in RStudio (R Core Team, 2020) to visualise the population sets lacking access to these four services (Conway et al., 2017). To assess how definitions affected the estimated populations lacking different service combinations, we repeated this workflow classifying limited sanitation or water services as adequate, thus following a lower service tier in the SDG6 indicator framework (Table S1).



(a)



(b)

*Figure 3: UpsetR visualisation of urban population sub-groups lacking different combinations of basic water (W), solid waste collection (R), basic sanitation (S), and hygiene services (H) for: (a) Ghana, 2016-17; (b) Kenya, 2015-6. Horizontal bar charts a(i) and b(ii) show the size of population lacking basic WASH or solid waste collection services (“Set Size”). Vertical bar charts a(ii) and b(ii) show the size of population (“Intersection Size”) lacking specific combinations of the services indicated by the joined black circles below each bar. Population figures are shown in thousands of people.*

In urban Ghana, a larger population lacked basic sanitation and hygiene than lacked other services (Figure 3a(i)). In urban Kenya, the populations lacking basic water, sanitation and waste collection services were similar in size (Figure 3b(i)). In Ghana, the two most frequent combinations of the four services that urban populations lack are firstly hygiene and sanitation and secondly waste collection, hygiene, and sanitation (Figure 3a(ii)). In urban Kenya the two most frequent service sets that populations lack in combination are waste collection, hygiene, and sanitation, and then hygiene and sanitation (Figure 3b(ii)). Similar patterns emerged when using limited services to define inadequate water and sanitation (Supplemental Figure 1).

In Ghana and Kenya, there is a high degree of overlap between neighbourhoods and populations lacking hygiene or sanitation services and those lacking SW collection services. Many disadvantaged neighbourhoods should be a priority for both WASH and SWM service delivery. These populations are simultaneously exposed to mismanaged waste and faecal contamination via lack of WASH services, presenting synergistic diarrhoeal disease risks (Figure 1). These patterns (Figure 3) could be repeated elsewhere, since the same barriers often impede both WASH and waste collection service delivery. Affordability and cost recovery inhibit both WASH (UNICEF and WHO, 2021) and waste collection service delivery (Rodić and Wilson, 2017) to low-income communities, along with lack of tenure and unplanned urbanisation in small towns and peripheral peri-urban areas (Dos Santos et al., 2017).

## Enhanced monitoring: Integrating SWM into WASH indicators.

International monitoring of WASH versus SWM is currently rather disjointed, with different custodial agencies responsible for underpinning indicators (van Driel et al., 2022). UNICEF and the World Health Organization manage the WASH indicators: the proportions of population using safely managed drinking-water services (SDG Indicator 6.1.1), safely managed sanitation services and a hand-washing facility with soap and water (SDG Indicator 6.2.1) (UNICEF and WHO, 2023) . SDG Target 6.3 aims to reduce dumping and thereby improve water quality (Rodić and Wilson, 2017), but does not have an associated SW indicator. Otherwise, among 12 SDGs linked to SW, relevant indicators are the proportion of municipal SW collected and managed in controlled facilities (SDG Indicator 11.6.1 managed by UN-Habitat) and the national recycling rate (SDG 12.5.1 managed by the UN Environment Programme, UNEP), which both link to marine plastic debris density (SDG 14.1.1 managed by UNEP). WASH monitoring indicators are under SDG6, but SW indicators are under SDGs 11 and 12. Organisational responsibility for international monitoring of WASH and SWM is also split. The World Bank also collates international statistics on SW (Kaza et al., 2018). Within SDG6, constructing indicators for households whose WASH behaviours affect SWM has proved challenging, e.g., classifying households using packaged water (Stoler, 2012). Currently, packaged water is considered an improved drinking-water source subject to having sufficient microbiological quality (UNICEF and WHO, 2019). Similarly, DDs are challenging to classify for monitoring. Disposal of child faeces (including diapers) as SW is classified as unsafe (Bain and Luyendijk, 2015), but household surveys do not capture onward SW flows and some waste may subsequently be safely disposed of (Mugel et al., 2022). Over-estimates of unsafe child faeces disposal may ensue.



Figure 4: Percentage of urban households in Ghana reporting packaged water purchases in the preceding 6 weeks by main method of waste disposal, 2012-13 compared with 2016-17 ((waste disposal modes: 1. Collected. 2. Uncollected).

By drawing on micro-data from existing household expenditure surveys with suitable expenditure coding and service access questions, we developed indicators that quantify DD and packaged water consumption in households lacking waste collection services. Many household expenditure surveys record household purchases and main waste disposal method, enabling both monitoring and inter-country comparisons. In West Africa, almost all packaged water is sold as ‘sachets’ in 500mL plastic bags (Stoler, 2017). For example, two successive GLSS surveys show that packaged water consumers who dumped or burnt their waste grew from 13.2% of urban Ghanaian households in 2012-13 to 17.0% in 2016-17 (Figure 4), despite waste collection service coverage expanding over this period. Likewise, an inter-country comparison using the GLSS7 and 2018-2019 Nigerian Living Standards Survey (NLSS) (Nigeria National Bureau of Statistics, 2019), showed that of the 6.3% of Ghanaian households who reported diaper purchases, most had their waste collected or used public dump facilities. Of the 16.1% of Nigerian households reporting diaper purchases, most either dumped their waste indiscriminately, burnt or buried it. This approach can only be applied to a subset of African countries, given current household survey data availability and content. Barriers to more widespread, robust indicator construction include a lack of suitable commodity codes to record packaged water or DD purchases, data quality issues relating to respondent recall, and limited data on household waste disposal, particularly concerning waste separation and subsequent disposal of plastics or DDs separately from other household waste (Wright et al., 2022, Thomas-Possee et al., 2024).



Figure 5: Percentage of urban households reporting disposable diaper purchases by main method of waste disposal for Ghana in 2016-17 and Nigeria in 2018-19 (waste disposal modes: 1. Collected. 2. Uncollected).

## Opportunities and barriers to maximising SWM-WASH synergies and optimising trade-offs.

In countries where large populations lack both WASH and SW collection services or with rapidly growing DD or packaged water consumption, building on previous recommendations (Marshall and Farahbakhsh, 2013), systems thinking boundaries should be widened beyond SWM to incorporate WASH. Given widespread international household survey availability, monitoring analyses (Figs 2-5) could be expanded and extended to other LMICs to support policy and planning. Systematic global analysis of packaged water consumption trends (Fig 2) could provide policy-relevant insights into potential underlying drivers such as safely managed water service coverage. Mapping and visualising populations simultaneously lacking WASH and SW collection services (Fig 3) would enable their prioritisation for service upgrade, given the adverse interactions between uncollected SW and WASH (Fig 1). Finally, DD or packaged water consumption (Figs 4-5) among households lacking SW collection services could be estimated in other LMICs to identify likely mismanaged waste hotspots. In all three cases, however, lack of harmonised household survey content inhibits generalisability (Thomas-Possee et al., 2024, Wright et al., 2022). For example, survey questionnaires for some earlier years and countries lack response categories for packaged water, whilst many lack SW collection service questions. Additionally, as household surveys are conducted on approximately 5-yearly cycles, derived indicators may be outdated.

Furthermore, governance fragmentation across UN custodial agencies inhibits monitoring coordination across targets between and within some SDGs (van Driel et al., 2022), forming a significant institutional barrier to coordinating monitoring spanning SDG6 and 11. One proposed solution is appointing and resourcing a chief statistician(Ulrich, 2017) or equivalent UN agency (van Driel et al., 2022) to coordinate cross-SDG activity. Alternatively, non-UN research organisations could address this monitoring agenda, as with SDG trade-off analysis (Zhou et al., 2021).

Extended Producer Responsibility (EPR) has been advocated as a policy response to both DDs (Płotka-Wasylka et al., 2022) and packaged water (Quartey et al., 2015), wherein manufacturers take responsibility for their products’ post-consumption environmental impacts. However, its uptake in LMICs is hampered by their large informal manufacturing sectors and lack of regulation, which means producers can evade EPR costs (Gupt and Sahay, 2015, Kojima et al., 2009). Although Ghana’s sachet water industry includes a significant informal sector (Dzodzomenyo et al., 2018), evidence is limited concerning packaged water manufacturing elsewhere and DD manufacturing. Hence, there is a need to understand the scale of informal manufacturing to assess EPR’s viability.

Trade-offs (Section 2) highlight a need for balanced evidence from dialogue between WASH and SWM professionals to inform explicit policy on DD and packaged water. Proposed DD or packaged water bans (Malindi Kenya, 2019) risk undermining the likely time-saving benefits for mothers from DD (Massengale et al., 2017) or reduced faecal contamination exposure from packaged water consumption (Williams et al., 2015), whilst subsidised (Kathambi, 2022) or unplanned growth in their consumption runs counter to waste hierarchy principles. Greater understanding is also needed of health risks to urban households from mismanaged SW via fieldwork and systematic review, including synergistic effects with WASH.

## Conclusion

Separate organisations are often responsible for SWM and WASH service delivery, policy, and monitoring, so indicator fragmentation means the population lacking both SW collection and WASH services lacks visibility. We highlight numerous inter-connections between urban WASH and mismanaged SW, thereby adversely affecting this population (Section 2), whose size is not readily apparent. We show that increased packaged water consumption constitutes a growing trade-off between SWM and water service delivery, particularly in West Africa and Southeast Asia (Section 3). Through two case studies, we illustrate how survey micro-data can be used to visualise populations lacking different service combinations (Section 4). In Ghana and Kenya, there is significant overlap between urban populations lacking SW collection services and WASH services. We argue that underlying service delivery barriers will lead to similar overlap elsewhere. We also illustrate how indicators can be constructed from existing household survey micro-data to measure packaged water or DD consumption in populations lacking SW collection services, reflecting trade-offs between WASH and SW goals (Section 5). Thus, micro-data analysis could be used more widely to generate additional policy insights into SDG synergies and trade-offs and to prioritise populations exposed to mismanaged SW and lacking WASH access for service delivery. However, this would require an institutional coordination mechanism, such as a UN Chief Statistician, to deliver cross-SDG analyses. Furthermore, construction of SW-WASH monitoring indicators is only currently possible in countries that have the necessary existing household survey data resources. In future, relatively modest modifications to household survey questionnaire content would enable more widespread country coverage of these indicators.

Urban service delivery will therefore require engagement with community groups and structures in the same communities for both WASH and waste collection services. Alongside commonalities in service delivery chains and provision models between water, sanitation and SW (Narayan et al., 2021), our community perspective suggests a need for balanced evidence from both WASH and SWM communities to inform policy on DD and packaged water. Where large urban populations are simultaneously exposed to mismanaged waste and lack WASH services, we also highlight a need for research into the synergistic health impacts of these multiple exposures. Thus, particularly in emerging economies with rapidly urbanising populations, there is a need for systems thinking that encompasses both WASH and SWM.

## Funding

This research was undertaken through the 'Expanding safe water and waste management service access to off-grid populations in Africa’ project funded through a UKRI Collective Fund award via the Global Challenges Research Fund (ref: ES/T008121/1). The support of the UK Economic and Social Research Council (ESRC) is gratefully acknowledged. The funder had no role in data collection, analysis and interpretation, reporting writing, or the decision to submit the article for publication.

## Data statement

This study was a re-analysis of existing data that are publicly available from Ghana Statistical Services at <https://www2.statsghana.gov.gh/nada/index.php/catalog/72/study-description> and <https://www2.statsghana.gov.gh/nada/index.php/catalog/97>, the Nigerian National Bureau of Statistics <https://www.nigerianstat.gov.ng/nada/index.php/catalog/68/study-description> , the Kenya National Bureau of Statistics at <https://statistics.knbs.or.ke/nada/index.php/catalog/13/study-description>, and the UNICEF/WHO Joint Monitoring Program at <https://washdata.org/>.

## Ethical approval

This secondary data analysis was approved by the ethics committee of the Faculty of Environmental and Life Sciences, University of Southampton, UK (Ref: 56 807; approval date: 10 May 2020). All procedures performed in studies analysing data on human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments.

## References

ABROKWAH, S., EKUMAH, B., ADADE, R. & AKUOKO, I. S. G. 2022. Drivers of single-use plastic waste generation: lessons from packaged water consumers in Ghana. *GeoJournal,* 87**,** 2611-2623.

ARMITAGE, N. 2007. The reduction of urban litter in the stormwater drains of South Africa. *Urban Water Journal,* 4**,** 151-172.

ASIM, M., BATOOL, S. A. & CHAUDHRY, M. N. 2012. Scavengers and their role in the recycling of waste in Southwestern Lahore. *Resources, Conservation and Recycling,* 58**,** 152-162.

BAIN, R. O. B. & LUYENDIJK, R. 2015. Are burial or disposal with garbage safe forms of child faeces disposal? An expert consultation. *Waterlines,* 34**,** 241-254.

BARBIER, E. B. & BURGESS, J. C. 2019. Sustainable development goal indicators: Analyzing trade-offs and complementarities. *World Development,* 122**,** 295-305.

BAWANKULE, R., SINGH, A., KUMAR, K. & PEDGAONKAR, S. 2017. Disposal of children’s stools and its association with childhood diarrhea in India. *BMC Public Health,* 17**,** 12.

BEKELE, T., RAHMAN, B. & RAWSTORNE, P. 2020. The effect of access to water, sanitation and handwashing facilities on child growth indicators: Evidence from the Ethiopia Demographic and Health Survey 2016. *PLOS ONE,* 15**,** e0239313.

CHOWDHURY, H., CHOWDHURY, T. & SAIT, S. M. 2021. Estimating marine plastic pollution from COVID-19 face masks in coastal regions. *Marine Pollution Bulletin,* 168**,** 112419.

CONWAY, J. R., LEX, A. & GEHLENBORG, N. 2017. UpSetR: an R package for the visualization of intersecting sets and their properties. *Bioinformatics,* 33**,** 2938-2940.

DAS, J. K., HADI, Y. B., SALAM, R. A., HODA, M., LASSI, Z. S. & BHUTTA, Z. A. 2018. Fly control to prevent diarrhoea in children. *Cochrane Database of Systematic Reviews*.

DOS SANTOS, S., ADAMS, E. A., NEVILLE, G., WADA, Y., DE SHERBININ, A., MULLIN BERNHARDT, E. & ADAMO, S. B. 2017. Urban growth and water access in sub-Saharan Africa: Progress, challenges, and emerging research directions. *Science of The Total Environment,* 607-608**,** 497-508.

DZODZOMENYO, M., FINK, G., DOTSE-GBORGBORTSI, W., WARDROP, N., ARYEETEY, G., COLEMAN, N., HILL, A. & WRIGHT, J. 2018. Sachet water quality and product registration: a cross-sectional study in Accra, Ghana. *Journal of Water and Health,* 16**,** 646-656.

ELLEDGE, M. F., MURALIDHARAN, A., PARKER, A., RAVNDAL, K. T., SIDDIQUI, M., TOOLARAM, A. P. & WOODWARD, K. P. 2018. Menstrual Hygiene Management and Waste Disposal in Low and Middle Income Countries—A Review of the Literature. *International Journal of Environmental Research and Public Health* [Online], 15.

ESTEVES MILLS, J. & CUMMING, O. 2016. The impact of water, sanitation and hygiene on key health and social outcomes: review of evidence. London.

FADER, M., CRANMER, C., LAWFORD, R. & ENGEL-COX, J. 2018. Toward an Understanding of Synergies and Trade-Offs Between Water, Energy, and Food SDG Targets. *Frontiers in Environmental Science,* 6.

GHANA STATISTICAL SERVICES 2018. Ghana Living Standards Survey Round 7: Poverty Trends in Ghana, 2005-2017. Accra.

GHARFALKAR, M., COURT, R., CAMPBELL, C., ALI, Z. & HILLIER, G. 2015. Analysis of waste hierarchy in the European waste directive 2008/98/EC. *Waste Management,* 39**,** 305-313.

GREENLAND, K., WHITE, S., SOMMERS, K., BIRAN, A., BURTON, M. J., SARAH, V. & ALEMAYEHU, W. 2019. Selecting behaviour change priorities for trachoma ‘F’ and ‘E’ interventions: A formative research study in Oromia, Ethiopia. *PLOS Neglected Tropical Diseases,* 13**,** e0007784.

GUPT, Y. & SAHAY, S. 2015. Review of extended producer responsibility: A case study approach. *Waste Management & Research,* 33**,** 595-611.

HAMPSON, S. E., ANDREWS, J. A., BARCKLEY, M., LEE, M. E. & LICHTENSTEIN, E. 2003. Assessing Perceptions of Synergistic Health Risk: A Comparison of Two Scales. *Risk Analysis,* 23**,** 1021-1029.

JEE HYUN, R., AIDAN, A. C., BHUPENDRA, B., VICTOR, M. A., SUZANNE, C. & SARAH, A. 2015. Household sanitation and personal hygiene practices are associated with child stunting in rural India: a cross-sectional analysis of surveys. *BMJ Open,* 5**,** e005180.

KATHAMBI, J. 2022. Ruto Promises 3-month diaper supply for new mothers. *Capital News*.

KATUKIZA, A. Y., RONTELTAP, M., OLEJA, A., NIWAGABA, C. B., KANSIIME, F. & LENS, P. N. L. 2010. Selection of sustainable sanitation technologies for urban slums — A case of Bwaise III in Kampala, Uganda. *Science of The Total Environment,* 409**,** 52-62.

KAZA, S., YAO, L., BHADA-TATA, P. & VAN WOERDEN, F. 2018. What a waste 2.0: a global snapshot of solid waste management to 2050. Washington D.C.

KENYA NATIONAL BUREAU OF STATISTICS 2018. Basic report: 2015/16 Kenya Integrated Household Budget Survey (KIHBS). Nairobi.

KOJIMA, M., YOSHIDA, A. & SASAKI, S. 2009. Difficulties in applying extended producer responsibility policies in developing countries: case studies in e-waste recycling in China and Thailand. *Journal of Material Cycles and Waste Management,* 11**,** 263-269.

KROLL, C., WARCHOLD, A. & PRADHAN, P. 2019. Sustainable Development Goals (SDGs): Are we successful in turning trade-offs into synergies? *Palgrave Communications,* 5**,** 140.

KUHL, J., BISIMWA, L., THOMAS, E. D., WILLIAMS, C., NTAKIRUTIMANA, J., COGLIANESE, N., BAULER, S., FRANÇOIS, R., SANVURA, P., BISIMWA, J. C., MIRINDI, P. & GEORGE, C. M. 2021. Formative research for the development of baby water, sanitation, and hygiene interventions for young children in the Democratic Republic of the Congo (REDUCE program). *BMC Public Health,* 21**,** 427.

LIO, C. F., CHEONG, H. H., LEI, C. I., LO, I. L., YAO, L., LAM, C. & LEONG, I. H. 2021. Effectiveness of personal protective health behaviour against COVID-19. *BMC Public Health,* 21**,** 827.

LUSSEAU, D. & MANCINI, F. 2019. Income-based variation in Sustainable Development Goal interaction networks. *Nature Sustainability,* 2**,** 242-247.

MALINDI KENYA. 2019. *Kilifi: County want to ban baby diapers* [Online]. Malindi Kenya. Available: <https://www.malindikenya.net/en/articles/news/last-news/kilifi--county-want-to-ban-baby-diapers.html> [Accessed 30/01/2024 2024].

MARSHALL, R. E. & FARAHBAKHSH, K. 2013. Systems approaches to integrated solid waste management in developing countries. *Waste Management,* 33**,** 988-1003.

MASSENGALE, K. E. C., ERAUSQUIN, J. T. & OLD, M. 2017. Health, Social, and Economic Outcomes Experienced by Families as a Result of Receiving Assistance from a Community-Based Diaper Bank. *Maternal and Child Health Journal,* 21**,** 1985-1994.

MATTIELLO, A., CHIODINI, P., BIANCO, E., FORGIONE, N., FLAMMIA, I., GALLO, C., PIZZUTI, R. & PANICO, S. 2013. Health effects associated with the disposal of solid waste in landfills and incinerators in populations living in surrounding areas: a systematic review. *International Journal of Public Health,* 58**,** 725-735.

MBIBA, B. 2014. Urban solid waste characteristics and household appetite for separation at source in Eastern and Southern Africa. *Habitat International,* 43**,** 152-162.

MERCHANT, A. T., JONES, C., KIURE, A., KUPKA, R., FITZMAURICE, G., HERRERA, M. G. & FAWZI, W. W. 2003. Water and sanitation associated with improved child growth. *European Journal of Clinical Nutrition,* 57**,** 1562-1568.

MUGEL, S. G., CLASEN, T. F. & BAUZA, V. 2022. Global practices, geographic variation, and determinants of child feces disposal in 42 low- and middle-income countries: An analysis of standardized cross-sectional national surveys from 2016 – 2020. *International Journal of Hygiene and Environmental Health,* 245**,** 114024.

NARAYAN, A. S., MARKS, S. J., MEIERHOFER, R., STRANDE, L., TILLEY, E., ZURBRÜGG, C. & LÜTHI, C. 2021. Advancements in and Integration of Water, Sanitation, and Solid Waste for Low- and Middle-Income Countries. *Annual Review of Environment and Resources,* 46**,** 193-219.

NCUBE, F., NCUBE, E. J. & VOYI, K. 2016. A systematic critical review of epidemiological studies on public health concerns of municipal solid waste handling. *Perspectives in Public Health,* 137**,** 102-108.

NIGERIA NATIONAL BUREAU OF STATISTICS 2019. Nigeria Living Standards Survey 2018-2019 Report. Lagos.

PARIKH, P., DIEP, L., HOFMANN, P., CAMPOS, L., TEH, T., MULUGETTA, Y., MILLIGAN, B. & LAKHANPAUL, M. 2021. Synergies and trade-offs between sanitation and the sustainable development goals. *UCL Open Environment,* 2.

PENAKALAPATI, G., SWARTHOUT, J., DELAHOY, M. J., MCALILEY, L., WODNIK, B., LEVY, K. & FREEMAN, M. C. 2017. Exposure to Animal Feces and Human Health: A Systematic Review and Proposed Research Priorities. *Environmental Science & Technology,* 51**,** 11537-11552.

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. *Science of The Total Environment,* 836**,** 155339.

POOLE, C. J. M. & BASU, S. 2017. Systematic Review: Occupational illness in the waste and recycling sector. *Occupational Medicine,* 67**,** 626-636.

PORTA, D., MILANI, S., LAZZARINO, A. I., PERUCCI, C. A. & FORASTIERE, F. 2009. Systematic review of epidemiological studies on health effects associated with management of solid waste. *Environmental Health,* 8**,** 60.

PRADHAN, P., COSTA, L., RYBSKI, D., LUCHT, W. & KROPP, J. P. 2017. A Systematic Study of Sustainable Development Goal (SDG) Interactions. *Earth's Future,* 5**,** 1169-1179.

PRASETIAWAN, T., NASTITI, A. & MUNTALIF, B. S. 2017. ‘Bad’ piped water and other perceptual drivers of bottled water consumption in Indonesia. *WIREs Water,* 4**,** e1219.

PUSPITA, T., DHARMAYANTI, I., TJANDRARINI, D. H., ZAHRA, Z., ANWAR, A., IRIANTO, J., RACHMAT, B. & YUNIANTO, A. 2023. Packaged drinking water in Indonesia: The determinants of household in the selection and management process. *Journal of Water, Sanitation and Hygiene for Development,* 13**,** 508-519.

QUARTEY, E. T., TOSEFA, H., DANQUAH, K. A. & OBRSALOVA, I. 2015. Theoretical Framework for Plastic Waste Management in Ghana through Extended Producer Responsibility: Case of Sachet Water Waste. *International Journal of Environmental Research and Public Health* [Online], 12.

R CORE TEAM 2020. R: a language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing.

RAH, J. H., SUKOTJO, S., BADGAIYAN, N., CRONIN, A. A. & TORLESSE, H. 2020. Improved sanitation is associated with reduced child stunting amongst Indonesian children under 3 years of age. *Maternal & Child Nutrition,* 16**,** e12741.

RODIĆ, L. & WILSON, D. C. 2017. Resolving Governance Issues to Achieve Priority Sustainable Development Goals Related to Solid Waste Management in Developing Countries. *Sustainability* [Online], 9.

SHEN, M., SONG, B., ZHU, Y., ZENG, G., ZHANG, Y., YANG, Y., WEN, X., CHEN, M. & YI, H. 2020. Removal of microplastics via drinking water treatment: Current knowledge and future directions. *Chemosphere,* 251**,** 126612.

STATACORP 2019. Stata Statistical Software. 16 ed. College Station, Texas: Statacorp LLC.

STOLER, J. 2012. Improved but unsustainable: accounting for sachet water in post-2015 goals for global safe water. *Tropical Medicine & International Health,* 17**,** 1506-1508.

STOLER, J. 2017. From curiosity to commodity: a review of the evolution of sachet drinking water in West Africa. *WIREs Water,* 4**,** e1206.

STOLER, J., WEEKS, J. R. & FINK, G. 2012. Sachet drinking water in Ghana's Accra-Tema metropolitan area: past, present, and future. *Journal of Water, Sanitation and Hygiene for Development,* 2**,** 223-240.

TAIT, P. W., BREW, J., CHE, A., COSTANZO, A., DANYLUK, A., DAVIS, M., KHALAF, A., MCMAHON, K., WATSON, A., ROWCLIFF, K. & BOWLES, D. 2020. The health impacts of waste incineration: a systematic review. *Australian and New Zealand Journal of Public Health,* 44**,** 40-48.

THOMAS-POSSEE, M. L. H., SHAW, P., BAIN, R. E. S., HILL, A., OKOTTO-OKOTTO, J., OKOTTO, L. G., DZODZOMENYO, M. & WRIGHT, J. 2024. Disposable diaper consumption in Sub-Saharan Africa: estimating the risks of associated unsafe waste. *PLOS Sustainability and Transformation,* 3.

TRIPATHI, A., TYAGI, V. K., VIVEKANAND, V., BOSE, P. & SUTHAR, S. 2020. Challenges, opportunities and progress in solid waste management during COVID-19 pandemic. *Case Studies in Chemical and Environmental Engineering,* 2**,** 100060.

TROEGER, C., BLACKER, B. F., KHALIL, I. A., RAO, P. C., CAO, S., ZIMSEN, S. R. M., ALBERTSON, S. B., STANAWAY, J. D., DESHPANDE, A., ABEBE, Z., ALVIS-GUZMAN, N., AMARE, A. T., ASGEDOM, S. W., ANTENEH, Z. A., ANTONIO, C. A. T., AREMU, O., ASFAW, E. T., ATEY, T. M., ATIQUE, S., AVOKPAHO, E. F. G. A., AWASTHI, A., AYELE, H. T., BARAC, A., BARRETO, M. L., BASSAT, Q., BELAY, S. A., BENSENOR, I. M., BHUTTA, Z. A., BIJANI, A., BIZUNEH, H., CASTAÑEDA-ORJUELA, C. A., DADI, A. F., DANDONA, L., DANDONA, R., DO, H. P., DUBEY, M., DUBLJANIN, E., EDESSA, D., ENDRIES, A. Y., ESHRATI, B., FARAG, T., FEYISSA, G. T., FOREMAN, K. J., FOROUZANFAR, M. H., FULLMAN, N., GETHING, P. W., GISHU, M. D., GODWIN, W. W., GUGNANI, H. C., GUPTA, R., HAILU, G. B., HASSEN, H. Y., HIBSTU, D. T., ILESANMI, O. S., JONAS, J. B., KAHSAY, A., KANG, G., KASAEIAN, A., KHADER, Y. S., KHALIL, I. A., KHAN, E. A., KHAN, M. A., KHANG, Y.-H., KISSOON, N., KOCHHAR, S., KOTLOFF, K. L., KOYANAGI, A., KUMAR, G. A., MAGDY ABD EL RAZEK, H., MALEKZADEH, R., MALTA, D. C., MEHATA, S., MENDOZA, W., MENGISTU, D. T., MENOTA, B. G., MEZGEBE, H. B., MLASHU, F. W., MURTHY, S., NAIK, G. A., NGUYEN, C. T., NGUYEN, T. H., NINGRUM, D. N. A., OGBO, F. A., OLAGUNJU, A. T., PAUDEL, D., PLATTS-MILLS, J. A., QORBANI, M., RAFAY, A., RAI, R. K., RANA, S. M., RANABHAT, C. L., RASELLA, D., RAY, S. E., REIS, C., RENZAHO, A. M. N., REZAI, M. S., RUHAGO, G. M., SAFIRI, S., SALOMON, J. A., SANABRIA, J. R., 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. *The Lancet Infectious Diseases,* 18**,** 1211-1228.

TUMWEBAZE, I. K., ORACH, C. G., NIWAGABA, C., LUTHI, C. & MOSLER, H.-J. 2013. Sanitation facilities in Kampala slums, Uganda: users' satisfaction and determinant factors. *International Journal of Environmental Health Research,* 23**,** 191-204.

ULRICH, G. 2017. Does the United Nations need a Chief Statistician? *High-level Group for Partnership, Coordination and Capacity-Building for Statistics: 49th session of the United Nations Statistical Commission.* Ramallah, Palestine: UN Dept of Economic and Social Affairs.

UN-HABITAT 2016. Slum almanac 2015-16 tracking improvement in the lives of slum dwellers. Nairobi: UN-Habitat.

UNICEF & WHO 2019. Progress on household drinking-water, sanitation and hygiene 2000-2017: special focus on inequalities. New York.

UNICEF & WHO 2021. The measurement and monitoring of water supply, sanitation and hygiene (WASH) affordability: a missing element of Sustainable Development Goal (SDG) Targets 6.1 and 6.2. New York.

UNICEF & WHO 2023. Progress on household drinking water, sanitation and hygiene 2000-2022: special focus on gender. New York.

UNICEF/WHO JOINT MONITORING PROGRAM. 2023. *Household Data on Water Sanitation and Hygiene (WASH)* [Online]. New York: UNICEF. Available: <https://washdata.org/data/household> [Accessed 1/07/2023 2023].

VAN DRIEL, M., BIERMANN, F., KIM, R. E. & VIJGE, M. J. 2022. International organisations as ‘custodians’ of the sustainable development goals? Fragmentation and coordination in sustainability governance. *Global Policy,* 13**,** 669-682.

VELASCO PEREZ, M., SOTELO NAVARRO, P. X., VAZQUEZ MORILLAS, A., ESPINOSA VALDEMAR, R. M. & HERMOSO LOPEZ ARAIZA, J. P. 2020. Waste management and environmental impact of absorbent hygiene products: A review. *Waste Management & Research,* 39**,** 767-783.

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. *Environmental Science & Technology,* 55**,** 7186-7207.

VINTI, G., BAUZA, V., CLASEN, T., MEDLICOTT, K., TUDOR, T., ZURBRÜGG, C. & VACCARI, M. 2021. Municipal Solid Waste Management and Adverse Health Outcomes: A Systematic Review. *International Journal of Environmental Research and Public Health* [Online], 18.

WAGNER, E. G. & LANOIX, J. N. 1958. Excreta disposal for rural areas and small communities. *Monograph Series of the World Health Organization,* 39**,** 1-182.

WARDROP, N. A., DZODZOMENYO, M., ARYEETEY, G., HILL, A. G., BAIN, R. E. S. & WRIGHT, J. 2017. Estimation of packaged water consumption and associated plastic waste production from household budget surveys. *Environmental Research Letters,* 12.

WILLIAMS, A. R., BAIN, R. E. S., FISHER, M. B., CRONK, R., KELLY, E. R. & BARTRAM, J. 2015. A Systematic Review and Meta-Analysis of Fecal Contamination and Inadequate Treatment of Packaged Water. *PLOS ONE,* 10**,** e0140899.

WORLD HEALTH ORGANIZATION & UNICEF 2017. Safely managed drinking-water: thematic report on drinking-water 2017. Geneva.

WRIGHT, J. A., DAMKJAER, S., VAISANEN, H., ADAMA-TETTEY, Q., DZODZOMENYO, M., HILL, A. G., OKOTTO, L. G., OKOTTO-OKOTTO, J. & SHAW, P. 2022. On the use of household expenditure surveys to monitor mismanaged plastic waste from food packaging in low- and middle-income countries. *Environmental Research Letters,* 17**,** 124029.

ZHANG, C., CHEN, X., LI, Y., DING, W. & FU, G. 2018. Water-energy-food nexus: Concepts, questions and methodologies. *Journal of Cleaner Production,* 195**,** 625-639.

ZHOU, X., MOINUDDIN, M. & LI, Y. 2021. *SDG interlinkages analysis and visualisation tool (v4.0)* [Online]. Kanagawa, Japan: Institute for Global Environmental Strategies. Available: <https://sdginterlinkages.iges.jp/visualisationtool.html> [Accessed].

ZIRABA, A. K., HAREGU, T. N. & MBERU, B. 2016. A review and framework for understanding the potential impact of poor solid waste management on health in developing countries. *Archives of Public Health,* 74**,** 55.

ZOLNIKOV, T. R., FURIO, F., CRUVINEL, V. & RICHARDS, J. 2021. A systematic review on informal waste picking: Occupational hazards and health outcomes. *Waste Management,* 126**,** 291-308.