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Household water use and greywater management in Khulna city, Bangladesh

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ABSTRACT

While substantial progress has been made in improving water and sanitation services in low- and middle-income countries, aligned basic services such as greywater, stormwater, and solid waste management have progressed little in recent decades. Data was collected in Khulna city, Bangladesh via a household survey (n = 192) of low-income areas exploring domestic water use and greywater volumes, characteristics, and disposal practices. Most households (71%) use a piped water supply for domestic purposes, supplemented by seasonal rainwater harvesting (26%) and greywater use (13%). Of the total water used by households (mean: 594 L/household/day and equivalent to 116 L/person/day), approximately 58% becomes greywater through bathing, dishwashing, religious practices, handwashing, laundry, and mopping. Greywater produced ranges from 61-1274 L/household/day, with a mean of 345 L/household/day and equivalent to 78.4 L/person/day. Greywater characteristics vary depending on the activity, individual behaviours and any products used during cooking, bathing, or cleaning. After generation, households dispose greywater to open drains (67%), nearby waterbodies (17%) directly to the ground (9%), or decentralised wastewater treatment system (7%). Without services for greywater management, greywater disposal may have considerable public and environmental health implications, necessitating careful attention and oversight from service-providers and stakeholders beyond the household-level.

1. Introduction

"Greywater" refers to wastewater generated from domestic activities, such as cooking, cleaning, and bathing, and constitutes 65–100% of the total wastewater discharged by households (Siegrist et al., 1976; Morel and Diener, 2006). Studies in various countries report 14–225 L/person/day of greywater is produced (Siegrist et al., 1976; Butler and Davies, 2004; Morel and Diener, 2006; Carden et al.,2007a; Katukiza et al.,2012; Alexander and Godrej, 2015; Oteng-Peprah et al., 2018; Shaikh and Ahammed, 2020). According to the Joint Monitoring Programme (JMP), 1.8 billion additional people gained access to piped water between 2000 and 2022; and by 2022, 79% of the global population had an improved water source on their premises (UNICEF/WHO, 2023). Thus, actual greywater volumes in low and middle income countries (LMICs) are likely to increase, and display various characteristics due to the wide spectrum of domestic activities and customary/behavioural practices worldwide (Shaikh and Ahammed, 2020).

Water and waste management interventions in LMICs often fail to incorporate greywater management (Imhof and Muhulemann, 2005; Katukiza et al.,2015; Narayan et al.,2021). Consequently, in unsewered areas, residents dispose greywater into open drains, nearby watercourses or directly onto the ground creating unsightly peri-domestic conditions. Because of pathogens, salts, suspended solids, fats, oil, and chemicals in the greywater, it adversely affects public and environmental health by attracting disease vectors and reducing soil and water quality (WHO, 2006; Carden et al.,2007a; Alexander and Godrej, 2015; Shaikh and Ahammed, 2020).

Although greywater composition and volumes vary worldwide, greywater is often more concentrated in LMICs than in higher income countries due to lower water consumption (Morel and Diener, 2006; Carden et al.,2007b; Shaikh and Ahammed, 2020). Therefore, as the coverage, quality, and reliability of piped water networks increase, so will the volumes of greywater and overall domestic wastewater that must be safely managed (Howard et al.,2020). For these reasons, it is

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important that greywater is given greater attention by researchers, practitioners, and decision-makers - so these challenges can be greater explored, and any resultant implications understood.

While various studies exploring greywater volumes, characteristics and treatment options are available, the majority are conducted in Europe, North America, The Middle East, and Australasia (Birks and Hills, 2007; Christova-Boal et al., 1996; Eriksson et al., 2008; Faruqui and Al-Jayyousi, 2002; Fowdar et al., 2017; Friedler, 2004; Halalsheh et al., 2008; Jamrah et al., 2008; Ottoson and Stenström, 2003; Palmquist and Hanæus, 2005; Siggins et al., 2016).

There are substantially fewer studies available from LMICs countries in Asia, Africa, Latin America, and the Caribbean (Imhof and Muhulemann, 2005; Morel and Diener, 2006). In low-income urban areas, greywater is the largest volumetric waste stream produced by households (Katukiza et al.,2012), yet greywater management remains understudied. Where studies are available in LMICs, the majority are from Africa including Ghana, Kenya, Uganda, South Africa, Botswana and Zimbabwe, and focus on either single or combined factors relating to household greywater quantities, quality, treatment or disposal in low-income areas. Factors include the location in the home greywater is produced (e.g., kitchens or bathrooms), the household fixtures used (basins, or taps), existing water and sanitation facilities and access (Alexander and Godrej, 2015; Armitage et al.,2009; Bakare et al.,2017; Carden et al.,2007b, 2007a; Dwumfour-Asare et al.,2017, 2018; Katukiza et al., 2014; Katukiza, Ronteltap, van der Steen, et al.,2014; Katukiza et al., 2014; Madungwe and Sakuringwa, 2007; Oteng-Peprah et al., 2018; Raude et al.,2009).

In this study, we explore greywater management practices in low-income areas of Khulna city, Bangladesh. By implementing a household survey in six purposively selected study sites, typical domestic activities, greywater volumes, characteristics, and disposal practices of 192 households were identified and examined. The findings of this study also contribute to wider debates on greywater management by highlighting gaps in current provisions and shedding light on the potential implications for public and environmental health.

2. Methods

2.1. Study location

The study was undertaken in Khulna City Corporation (Fig. 1) – herein referred to as Khulna – a low-lying coastal city in southwestern Bangladesh. It is the third largest city in Bangladesh after Dhaka and Chattogram, with 0.7 million residents (Bangladesh Bureau of Statistics, 2022) and 32,900 people/km^2 (SNV, 2017). The city comprises residential, industrial, and administrative areas (79%), and agricultural

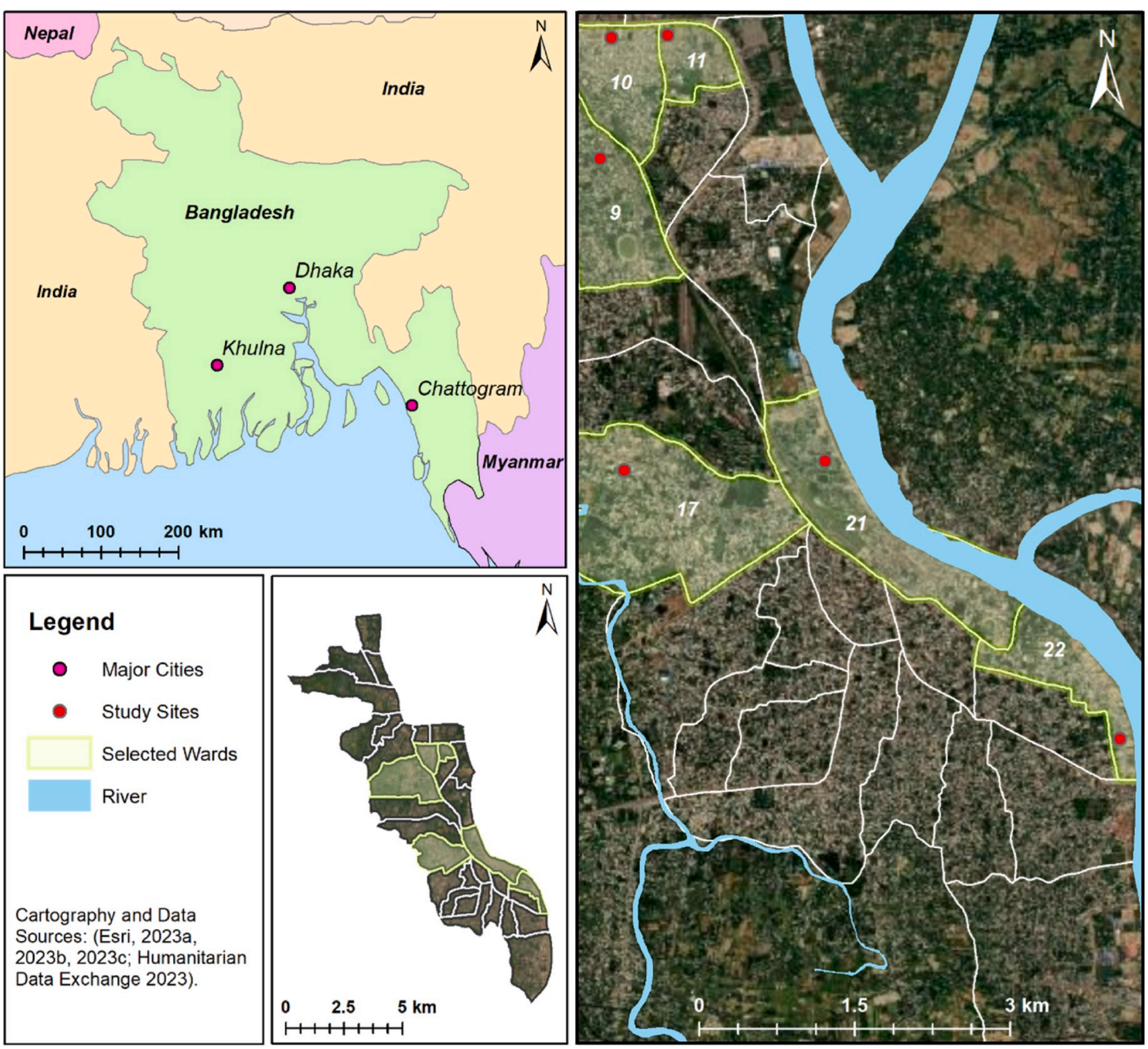

Fig. 1. Maps showing the location of Khulna (top), the Khulna City Corporation area (bottom) and selected study sites (right) (ESRI, 2023a, 2023b, 2023c; Humanitarian Data Exchange, 2023).

land (21%) (JICA, 2011).

Khulna is a suitable study location as it has many aspects that are representative of other City Corporations in Bangladesh, such as population density, land use, administrative structure, environmental and climate vulnerabilities, while also demonstrating typical urban water and sanitation conditions found elsewhere in Bangladesh.

Khulna encompasses 31 wards administered by Khulna City Corporation (KCC). 8.4% of households are low-income or informal. With a total area of 46 km^2 (Gunawan et al., 2015), access to basic services in Khulna varies considerably. Three organizations currently manage the city's water, waste, and urban planning: (1) KCC is responsible for basic urban services, which include faecal sludge management, drainage, and solid waste management; (2) Khulna Water Supply and Sewerage Authority (KWASA) is responsible for piped water supply and development of a sewer network; and (3) Khulna Development Authority (KDA) is responsible for re-development planning and approval of new building designs, in accordance with the national building codes (SNV, 2020).

Although KWASA is expanding the existing water supply network, in 2015, they were only able to meet 47.5% of the city's total demand through piped water services (Fahmida et al.,2013; Gunawan et al., 2015). Most residents use onsite sanitation, either a septic tank (66%) or a pit latrine (23%). However, poor construction of pits and tanks, and incorrect discharge of septic tank effluent limits safe containment and disposal of faecal sludge. Those who do not have a septic tank, or pit latrine (11%) use unimproved toilets that cannot safely contain excreta. This results in faecal sludge entering covered/uncovered drains (96%), nearby water bodies (3%) or open ground (1%) (SNV, 2020).

The city's 1200 km drainage network was originally intended to convey and discharge stormwater. However, in practice it also receives discarded solid waste, greywater, faecal sludge from on-site sanitation systems and high volumes of sand, soil, and tree/plant matter (Roy et al., 2018; Haldar et al.,2020, 2021, 2022). A 2021 study by Haldar et al., suggests that 50,000 m^3 of untreated greywater a day is transported via the city's drainage network, before being discharged untreated into the Mayur River. Likewise, Zaman and Islam (2016) project total combined wastewater (blackwater and greywater) generation in the city rising from 201,000 m^3 in 2020, to 262,000 m^3 and 388,000 m^3 in 2030 and 2050, respectively.

Khulna's precarious sanitation and drainage situation is especially concerning as local farmers rely on the Mayur River for irrigation in the dry season (Roy et al.,2018; Haldar et al.,2021). During this time, water quality deteriorates and exceeds the FAO irrigation standards, affecting soil properties, crop yields and food safety (Haldar et al.,2020, 2022). Furthermore, the main aquifer in Khulna is at risk from pollution because of the underlying sandy clay soil, high groundwater levels of less than 1 m, and sanitation facilities nearby to tubewells and other groundwater sources (Adhikari et al.,2006; Gunawan et al., 2015; SNV, 2020). This results in an increased prevalence of diarrhoeal disease, skin diseases and urinary tract infections associated with inadequate water and sanitation provisions (Hoque et al.,2022). Hence unless water and waste management in the city – including greywater – are improved, the consequences for both public and environmental health will continue to be far-reaching.

2.2. Study design

2.2.1. Sampling

A cross-sectional survey design was adopted. Six study sites were purposively chosen from different Wards, either a single road or a clustered block of houses, based on pre-determined criteria and in discussion with local partners (WaterAid Bangladesh, Nabolok, and SNV Netherlands Development Organisation). Chosen study sites should: (1) represent low-income, unplanned or slum communities as per KDA definition (SNV, 2019, p. 17); (2) have varying household water, sanitation, and hygiene (WASH) infrastructure and service conditions; (3) be in proximity to other study sites and have similar peri-domestic conditions; and (4) have ongoing or proposed investment in water, sanitation, or drainage infrastructure and services by KCC or KWASA, or with funds directed via non-governmental organizations (NGOs) operating in Khulna.

Given the time and resources available, households were selected by combining convenience and quota-based sampling. Quotas of households to be targeted were determined to correspond to the ratios of varying water and sanitation facilities for Khulna, as previously reported (Kabir and Salahuddin, 2014, p. 10; Gunawan et al., 2015, p. 33; WSUP Advisory, 2016, p. 21; SNV, 2019, p. 17, 2020, p. 71). The number of households to target at each site were determined with the guidance of local partners and based on the various types of water and sanitation facilities present. At each site, door-to-door surveys were carried out until the target quota of water and sanitation facilities was reached.

Household data were collected from an adult household representative, preferably women. Women were chosen as they are generally more knowledgeable about household water use and domestic practices due to traditional gender roles.

2.2.2. Questionnaire

The first section of the questionnaire (see supplementary material) includes demographic and housing-related questions adapted from the Bangladesh Census (Bangladesh Bureau of Statistics, 2022). Section two focuses on domestic water use, greywater volumes, characteristics, and disposal practices. Household data concerning domestic activities, their frequency (e.g., daily, weekly etc.) location (e.g., inside the home or plot, off-plot, or other) and the water source used were captured. Domestic practices and activities included basic needs (e.g., cooking/food preparation); personal hygiene (e.g., bathing, handwashing, flushing the toilet and anal cleansing); cleaning (e.g., dishwashing, laundry, mopping and cleaning the toilet). Households could also report any additional practices or activities that were missed. Water usage estimates for personal hygiene and cleaning practices were obtained via self-reporting the volume of, and number of buckets required to complete each domestic activity. Due to limited water metering in the study area, as well as the fact that domestic activities are completed in different locations and using different water sources, recording volume measurements using flow meters or via utility-supplied water meters was not possible within the timeframe of the study. For each greywater producing activity, the household products used (e.g., soaps, detergents, etc.) and the location of greywater disposal according to pre-determined responses based on the JMP liquid waste disposal question were also captured (UNICEF and WHO, 2018, p. 22). Sections three to five are based on the JMP core questions for drinking water, sanitation, and hygiene (UNICEF and WHO, 2018). To validate self-reported variables, prompted and unprompted observations of both the peri-domestic environment, and household water and sanitation facilities were also incorporated.

The questionnaire does not capture water usage for drinking (water consumed directly or indirectly through food or beverages), cooking or food preparation (e.g., for boiling or rinsing vegetables) because of the widely recognised inaccuracy and variability in individual estimates (Tamason et al.,2016; Cassivi et al.,2019, 2021; Howard et al.,2020); figures for the frequency of handwashing and toilet use were taken from wider literature (Howard and Bartram, 2003, p. 14; DeOreo et al.,2016; UNICEF, 2020; Sayeed et al.,2021).

Prior to data collection, the questionnaire was validated by local partners before being piloted with local staff and several households to ensure proper translation and clarity of the final version. The surveying team was then trained on the questionnaire, the local context, and ethical protocols. Throughout surveying enumerators maintained two-way translation between Bangla and English to ensure the quality and completeness of the data being recorded.

2.3. Data collection

Household data were collected in both April and November 2022 prior to and after the rainy season. Surveying was completed by a single team, comprising, postgraduate students from Khulna University, the first author, and local staff from NABOLOK and SNV.

2.4. Data analysis

Data were captured in hardcopy and transcribed into Microsoft Excel 365 for data cleaning and processing. Activities reported by fewer than 10% of households, including where greywater is either produced in negligible volumes, or not produced at all from a reported activity are not reported. Data on activity frequency were transformed into daily averages, factoring in the number of household members. These averages were then combined with reported water use for each activity to calculate the total water use per activity. Overall household water usage was determined by consolidating estimates from all domestic activities. Activity locations were then grouped based on the reported locations.

To estimate handwashing and toilet usage, reference values were employed alongside self-reported variables and include: a daily handwashing frequency of 7.35 times per person Sayeed et al. (2021); water use per handwash being either 2 L per person if using an on-plot water supply (Howard and Bartram, 2003, p.14), or 0.45 L if using a mobile object or jug (UNICEF, 2020). Daily toilet use was assumed five times per person per day (DeOreo et al.,2016).

Greywater volumes were calculated by activity and as household totals based on water use estimates and assuming a 100% return rate - i.e., accounting for no wastage or water loss during or after each activity. Greywater characteristics of concern were assumed based on the reported household practices and products used, in combination with wider literature, as shown in Table 3. Greywater disposal locations were grouped based on the responses obtained. This study intends to draw attention to the need for water and waste management policy and decision-making to include greywater in future spatial and service planning. As such, water use and greywater volumes generated are reported by household rather than per person.

Exploratory data analysis using descriptive statistics, e.g., frequencies, measurements of central tendency (median, mean and mode) and dispersion was undertaken.

2.5. Ethical approval

Ethical approval was granted by Loughborough University (Project ID: 7962, March 17, 2022). All respondents were briefed about the study before providing written consent to participate. Additionally, all data has been anonymised to maintain confidentiality and prevent respondents from being identified.

3. Results

3.1. Household characteristics

Questionnaires were completed with both women and men respondents from 192 households. Most residents live in two-roomed properties, all rooms serve multiple purposes (sleeping, cooking, bathing, etc.). The mean family size is 4.4, consistent with national and regional data (Bangladesh Bureau of Statistics, 2022). Additional household characteristics are given in Table 1.

Table 1
Characteristics of households surveyed in Khulna.

Variable	Frequency (N)	Percentage (%)
Gender of respondents		
Men	21	11
Women	171	89
Tenure status		
Owner	52	27
Renter	62	32
No tenure	75	39
No data	3	2
Dwelling type		
Separate	56	29
Apartment	17	9
Joint	116	60
No data	3	2
Construction type		
Pucca[a]	24	13
Semi-Pucca[b]	90	47
Kucha[c]	69	36
Mixed	9	5

Notes.
[a] Pucca: A housing structure in Bangladesh with a concrete floor, walls, and roof.
[b] Semi-pucca: A housing structure in Bangladesh with a concrete floor, corrugated tin partition and corrugated tin roof.
[c] Kucha: A housing structure in Bangladesh that has a mud-dried earthen floor with a bamboo, straw, or grass-based roof (SNV, 2020, p. xii).

3.2. WASH facilities

A variety of WASH facilities were reported (Fig. 2).

3.2.1. Drinking water

Most households (86%) reported using off-plot water sources including tubewells (55%), public taps (28%) or delivered water (3%) for drinking, cooking, and food preparation. Only 13% use an on-plot tubewell (8%) or tap (5%). Drinking water data from two households (1%) was not recorded.

Respondents stated that they do not drink from on-plot taps and tubewells due to the salty taste, a red rust-like discoloration, and occasionally foul-smelling water with a muddy colour. Nevertheless, all respondents deemed their drinking water acceptable, with most (92%) consuming this water without any additional treatment. A few households (8%) use a single or combined treatment method, including settling/sedimentation (50%), filtration (38%), boiling (25%), chlorination (19%) or straining (13%), before drinking.

3.2.2. Domestic water

Over half reported using an on-plot private tap (51%) or tubewell (11%) for non-consumptive domestic activities e.g., bathing, handwashing, dishwashing, and laundry. A further 36% use an off-plot water source, either a public tap (20%) or shared tubewell (16%). Three households (2%) reported using a tubewell, but the location was not recorded.

Seasonal fluctuation in groundwater levels – particularly in the pre-monsoon season (March–May) - affecting tubewell supply was reported by almost half (47%) of those surveyed. As a result, residents use alternative tubewells (26%) or public taps (10%). In the monsoon season (June–October), a quarter of households (26%) reported using rainwater in addition to the water collected from their usual water source for domestic activities. Despite these seasonal changes, most (69%) expressed having enough water for domestic activities.

3.2.3. Handwashing

Households reported using an on-plot sink or tap (40%), or mobile object, such as a bucket or jug (46%) for handwashing. Those without on-plot facilities (14%), either wash their hands at a shared tubewell (1%) or communal bathroom/toilet block (13%). One household (1%) reported no handwashing facility.

3.2.4. Toilets

Most households (87%) have a pour-flush toilet, connected to either a septic tank (65%) or a pit (22%). Of those connected to a septic tank,

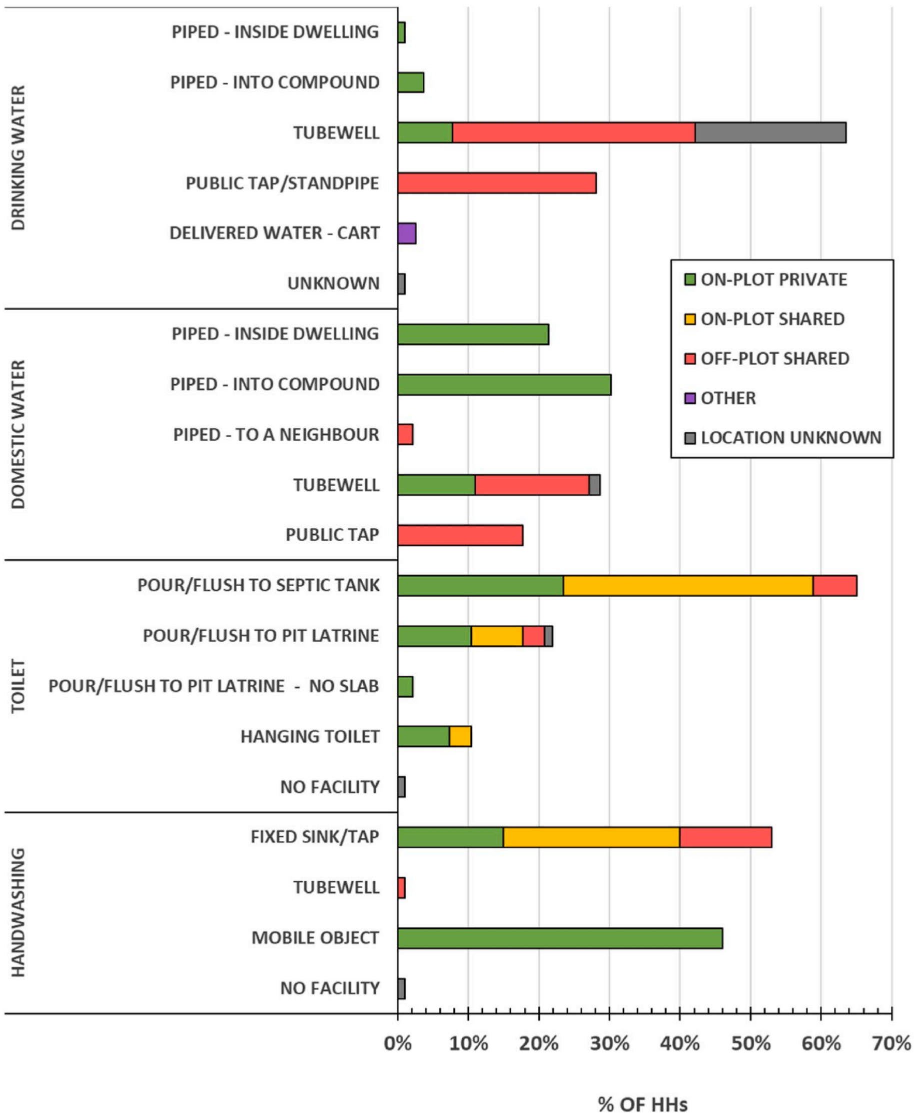

Fig. 2. Locations and types of water, toilet and handwashing facilities reported by 192 households (HHs) in Khulna.

most (58%) discharge into a decentralised wastewater treatment system (DEWATS), leach field/soak pit (26%), or an open drain (13%). Four households (3%) did not know where their septic tank discharged. A few households (12%) use either a hanging toilet (10%) or a pit latrine with no slab (2%). One household (1%) reported having no toilet facility. Compared to those with private toilet facilities (43%), over half share a toilet with other households (58%). The number of families sharing a toilet ranged from 2-40, with a mode of four families per toilet.

Table 2
Reported household (HH) activities and water use in Khulna.

		Activities	Water Use (Median litres/HH[a]/day)	Frequency of Activity (Mean occurrence/HH[a]/day)	Greywater Produced?
Practices	**Basic Needs**	Cooking and Food preparation	N/A	1.7	YES
	Personal Hygiene	Bathing	150	5.2	YES
		Handwashing	29	32.34[b]	YES
		Flushing the Toilet and Anal cleansing	200	22[b]	NO
	Religious	Wudu[c]	36	17.6	YES
	Cleaning	Dishwashing	44	2.6	YES
		Laundry	30	1.0	YES
		Mopping	10	1.1	YES
		Cleaning Toilet	9	0.4	NO

Notes.
[a] Based on a household with 4.4 members.
[b] Calculated using reference values.
[c] Wudu is an Islamic practice of washing/ablution before prayer or worship.

3.3. Household water use and practices

A variety of universal practices and activities were reported (Table 2). A few households mentioned other activities such as watering plants (8%), caring for pets/livestock (1%), children playing (1%) and house repairs (1%), however as greywater was either not produced (e.g. watering plants and animals), or was minimal (0.3–3 L/household day) these are excluded from further discussion.

Water usage from combined personal hygiene, cleaning, and religious practices for a typical family with 4.4 members is estimated as ranging between 99 and 2725 L/household/day, with a mean of 594 L/household/day (median 508 L/day, IQR: 361,721). This equates to 116 L/person/day (median), of water used for toilet flushing (46 L/person/day), bathing (34 L/person/day), dishwashing (10 L/person/day), Wudu (8 L/person/day), handwashing (7 L/person/day), laundry (7 L/person/day), mopping (2 L/person/day) and toilet cleaning (2 L/person/day).

3.3.1. Cooking and food preparation

Households prepare meals 1–2 times per day. Most cook within their household plot (84%), either indoors (32%), under a veranda (51%), or in a standalone outbuilding (2%). A few households use an open area (6%) or communal kitchen (5%).

3.3.2. Personal hygiene

Bathing was reported at least once per person per day, increasing during the hot dry season to 2–3 times per person per day. The reported water volumes ranged from 15 to 620 L/household/day, with a median of 150 L/household/day (Interquartile range (IQR): 90,200). Bathing usually occurs within the home (43%), or at an off-plot community facility (18%), shared tubewell (4%), or open area (28%). One household (1%) bathe in the nearby river. The bathing location was not captured for 13 households (7%).

All households (99%) reported regular handwashing activities using an on-plot sink or tap (40%) or mobile object (46%). Households without on-plot facilities reported using taps at communal facilities (13%) or shared tubewells (1%). Based on the reported handwashing facility-type, water usage for handwashing was estimated to require 3–176 L/household/day (median: 29 L/day; IQR: 15,59).

Toilet flushing was the largest contributor to household water use among those surveyed. Reported water use ranges from 25-2100 L/household/day, with a median of 200 L/household/day (IQR:125,275). Four households reported cistern-flush toilets but were unable to recall the cistern volume, so a value of 10 L per flush was assumed based on Tilley et al. (2014, p. 24), and Welling et al. (2020). Our results indicate that both cistern-flush and pour-flush toilets have similar water usage ranging from 220 to 235 L/household/day.

3.3.3. Religious

"Wudu" - an Islamic practice of washing/ablution before prayer or worship - was reported by 173 households (90%), who estimated usage between 1 and 240 L/household/day (median: 36 L/household/day, IQR: 15,60). No other religious practices requiring water were reported.

3.3.4. Cleaning

Households wash dishes on average three times per day, either on-plot (47%), off-plot (31%), or at a shared facility (14%). Dishwashing location was not recorded for 14 households (7%). One household (1%) did not report dishwashing as a household activity. Reported water usage ranged from 5 to 193 L/household/day, with a median of 44 L/household/day (IQR: 30,60).

Daily household laundry activities were reported, requiring 3–325 L/household/day (median: 30 L/household/day, IQR:18,53). Laundry activities take place in a variety of locations, either at home (13%), or off-plot in an open area (30%), shared sanitation facility (16%), or river (1%). Laundry location was not recorded for 78 households (41%). Two households (1%) did not report laundry as a household activity.

Most households (72%) reported daily mopping, requiring volumes of 0.1–120 L/household/day (median: 10 L/household/day, IQR:6,15). Over a quarter of the households surveyed (27%) had compacted mud or soil flooring unsuitable for mopping.

Toilet cleaning data was captured from almost half of the households surveyed (43%), with water volume estimates ranging from 2 to 75 L/household/day (median: 9 L/household/day, IQR:6,19). Households that share toilet facilities with other families (58%) usually also share cleaning responsibilities 1–2 times per week, depending on the total number of families. Those with private toilets reported cleaning the toilet 2–3 times per week.

3.4. Household greywater

Of the total water used by households from a variety of activities (Table 2), more than half (58%, range: 42–63%) becomes greywater through bathing, dishwashing, Wudu, handwashing, laundry, and mopping activities. Daily household greywater volumes produced in total and by each activity are indicated in Fig. 3a.

Household greywater production for a family with 4.4 members ranged from 61-1274 L/household/day, with a mean of 345 L/day (median: 300 L/day, IQR: 229,429) – equivalent to 78 L/person/day. Median household volumes produced by each activity are estimated as follows: bathing (150 L/day), dishwashing (44 L/day), Wudu (36 L/day), handwashing (29 L/day), laundry (30 L/day), and mopping (10 L/day). A total 66,238 L/day of greywater is produced by all 192 households surveyed.

When considering the proportions of greywater produced by each activity (Fig. 3b), bathing contributes the most greywater (47%). Mopping contributes the least (3%). Almost equal proportions of greywater are produced by dishwashing (14%), laundry (12%), handwashing (12%) and Wudu (11%).

3.4.1. Characteristics

Greywater produced during cooking-related activities will vary depending on the dish or dishes being prepared each day. Typical meals observed in Khulna were rice, lentil, or potato-based dishes, accompanied by at least one protein and various vegetables, spices and herbs. For bathing, residents use soap daily, and shampoo twice a week. Women wash their hair 2–3 times per week with shampoo, and men, 1–2 times a week with either soap or shampoo. Most respondents (93%) regularly wash their hands, with either soap (93%) or water (6%). Three households (2%) use soap or powder detergent for handwashing. Households reported various products for cleaning activities. Almost all households (98%) use additional products for dishwashing, including bar or liquid soap (86%), ash or sand (50%), powder (17%) or liquid detergent (2%). For laundry, most households use powder detergent (96%) or bar/liquid soap (2%), 1% use only water. Finally, for mopping, products include powder detergent (13%), bar or liquid soap (8%), liquid detergent (4%), antiseptic liquid (2%) and bleach (2%). Almost half (44%) use only water. Over a quarter (27%) of the households surveyed have flooring that is unsuitable for mopping, therefore product data was not collected.

Based on these results, and in combination with wider literature reporting greywater quality data in LMICs (Morel and Diener, 2006; Oteng-Peprah et al., 2018; Vuppaladadiyam et al.,2019; Shaikh and Ahammed, 2020), potential characteristics and impacts to greywater quality resulting from household practices in Khulna are suggested (Table 3).

3.4.2. Disposal

A small number of households (13%) reported using greywater generated from one activity to complete another. Laundry is the most common source of greywater for repurposing (56%), followed by bathing (36%), dishwashing (24%), and cooking/food preparation (16%). After these activities, households reported using greywater to

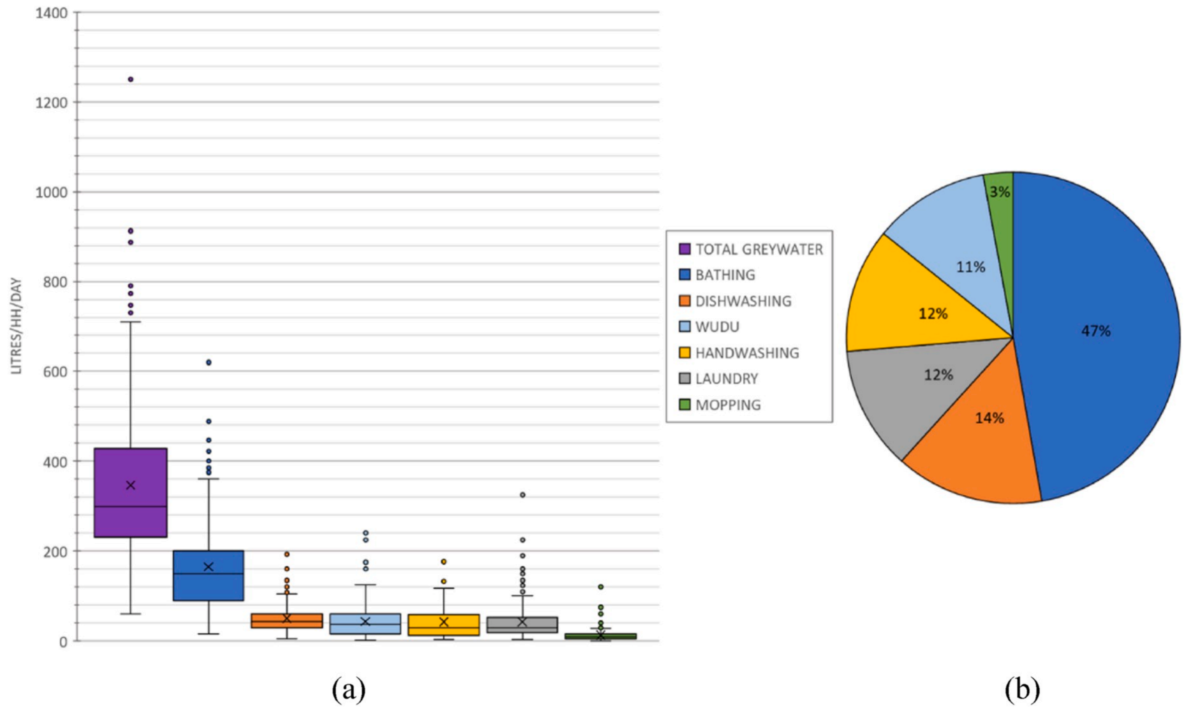

Fig. 3. Household (HH) greywater production by domestic activity in Khulna: (a) greywater volumes - mean (x), median (–); and (b) mean greywater contribution (%) – based on a household with 4.4 members.

Table 3
Suggested characteristics of greywater produced by households in Khulna.

		Products reported or observed	Associated pollutants[b]	Impact on water quality parameters[b]
Practices	**Cooking and Food preparation**	Carbohydrates (potatoes, rice); Fruit and Vegetables (assorted and varies seasonally); Dairy (curd, ghee/clarified butter, milk); Beans, pulses (lentils, chickpeas); Fish/shellfish, Eggs, meat (chicken, mutton, or beef); Herbs and Spices (fresh and ground).	• Suspended solids – food particles, sand, soil; • Organic material - food particles; • Pathogens and Bacteria; • Oil and Grease.	• Increased BOD[c], nutrient content, turbidity. • Altered pH; • High turbidity suspended solids and discoloured physical appearance; • Bad odour; • Presence of faecal coliforms/Total Coliforms.
	Personal Hygiene (e.g., bathing and handwashing)	Soap (bar); Shampoo	• Chemical compounds – sodium-based products, parabens, synthetic fragrances; • Bacteria – skin cells, hair and traces of urine, faeces, and pharmaceuticals.	• Increased COD[c], EC[c], and turbidity; • Altered pH; • Presence of faecal coliforms/Total Coliforms.
	Religious (e.g., Wudu)	No Products[a]		
	Cleaning (e.g., dishwashing, laundry, and mopping)	Bar or Liquid Soap; Liquid Detergent; Powder Detergent; Antiseptic Liquid; Bleach; Ash/Sand.	• Chemicals – surfactants, bleach; • Xenobiotic organic compounds – surfactants; • Suspended solids – fabric fibres, food particles, sand/ash; • Inorganic material – nitrates and phosphates, sodium chloride. • Bacteria – traces of urine and faeces.	• Increased Total Phosphorus, Total Nitrogen, COD, EC, and Sodium Absorption Rate; • Altered BOD: COD – lower biodegradability; • Increased turbidity, suspended solids, and discoloured physical appearance.

Notes: In this study, personal hygiene, cleaning, and religious practices contribute 59%, 30% and 11% respectively to household greywater production.
[a] Wudu is usually practiced with only water; thus, no soap or other products were reported.
[b] (Morel and Diener, 2006; Oteng-Peprah et al., 2018; Vuppaladadiyam et al.,2019; Shaikh and Ahammed, 2020).
[c] Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Electrical Conductivity (EC).

flush and clean toilets (64%), to water ornamental plants (20%), as animal feed/water (20%), and for laundry (20%).

Location data was captured for cooking and food preparation, dishwashing, bathing, and laundry activities. Of the 162 households reporting all these activities and their locations (84%), more than half (55%) generate and dispose greywater on-plot, either indoors or outdoors near their home. Those remaining (45%), complete domestic activities away from the home, either at open areas (29%), or community bathing/toilet facilities (15%).

Although domestic activities are completed in a variety of various locations, most households (89%) reported consistent greywater disposal practices - after bathing, dishwashing, mopping, laundry, and cooking/food preparation – via open drains (67%), nearby waterbodies (17%), directly to the ground (9%), or DEWATS (7%).

4. Discussion

4.1. Household water use

In LMICs households often use multiple water sources to meet daily water demands for cooking, cleaning, or bathing (Elliott et al.,2019; Howard et al.,2020; Narayan et al.,2021). Our study found that most households (86%) use different water sources for consumptive (e.g., drinking, cooking, and food preparation) and non-consumptive purposes (e.g., all other domestic activities). Our results are consistent with the findings of Elliott et al. (2017) in the Pacific. However, they diverge from those in the broader Khulna District of Bangladesh. In the studies conducted by Benneyworth et al. (2016) and Hoque and Hope (2020), households were observed using one water source for drinking (usually tubewells) as an alternative source for all other domestic purposes, including cooking. We also found that whilst half of those surveyed reported having an on-plot piped water supply (51%), most of these households (95%) do not use the piped water for consumptive purposes due to the perceived risk of contamination and intermittent supply.

In Khulna, based on household estimates, mean water usage was 594 L/household/day or 136 L/person/day. These findings align with results obtained from households across various income levels in Khulna (440 L/household/day) (Haldar et al., 2022) and Dhaka (1,108 L/household/day) (Abedin and Rakib, 2013) in Bangladesh. Globally studies indicate a wide range of water usage from 35 to 343 L/person/day (Shaikh and Ahammed, 2020), to 2–113 L/person/day (Tamason et al., 2016). Additionally, studies that categorise water usage by access levels show household usage varying from 15 to 115 L/person/day (Ensink et al.,2002); 5.3–100 L/person/day (Howard and Bartram, 2003) and 20–100 L/person/day (Morel and Diener, 2006). As we did not account for water usage from drinking, cooking and food preparation, actual household water usage is likely higher. Based on values taken from wider literature (Howard and Bartram, 2003; Sphere Association, 2018) an additional 31 L/household/day in Khulna may be attributed to these activities.

Seasonal variation in water usage is also well documented, leading to fluctuations in the quantities of water used (Tamason et al.,2016) and impacting the reliability of water sources (Howard et al.,2016; Daly et al.,2021). As our study was undertaken in only the dry season, we are unable to compare seasonal water usage for different activities. However, similar to other findings, we found that more than a quarter (36%) of households in Khulna use different water sources during the wet and dry seasons (Blum et al.,1990; Feachem, 1973).

When comparing other studies reporting water usage, the majority do not collect data across multiple seasons, and some do not disclose the season at all, limiting the scope for broader comparison (Cassivi et al., 2019). Where studies are available, they are often from rural areas and contradictory. Suggesting that water use decreases during the dry season (Ensink et al.,2002; Hadjer et al.,2005), or that there is no significant increase or decrease in water consumption due to seasonality (Esrey et al.,1992; Subbaraman et al.,2013). This implies that more evidence is needed to determine the effects of seasonality on household practices and subsequent water use (Cassivi et al.,2019; Tamason et al.,2016).

When considering each household activity and the reported locations, we found that less than half of the households in our study engage in laundry (46%), bathing (49%) and dishwashing (45%) activities away from home. Other studies indicate that activities like bathing and laundry often take place outside the home, usually in proximity to water bodies. This practice is typically adopted to avoid having to collect and transport water from outside the home, or when on-plot supplies are unavailable, unreliable, or come with high tariffs (Morel and Diener, 2006; Oteng-Peprah et al., 2018; Howard et al.,2020).

4.2. Greywater management

In Khulna, household activities such as bathing, handwashing, Wudu, dishwashing, laundry, and mopping produce an estimated 345 L/greywater/day based on an average family size of 4.4, and equivalent to 78 L greywater/person/day. These findings align with those of another study in Khulna by Haldar et al. (2022) which estimates daily greywater production of 352 L household/day, and in Dhaka by Biswas et al. (2012) who report 85 L/greywater/person/day.

Establishing a consensus on daily greywater production remains challenging due to global differences in lifestyles, household income, climate, and water availability, as noted by Morel and Diener (2006), Vuppaladadiyam et al. (2019) and Shaikh and Ahammed (2020). Moreover, there is a notable scarcity of studies on household greywater management compared to water supply and sanitation-related practices, and where previous studies do exist, they are often outdated. Vuppaladadiyam et al. (2019) suggest regional variations in greywater volumes, ranging from 16 to 161 L/person/day in the Middle East, 72–225 L/person/day in Asia, 35–150 L/person/day in Europe, and 200 L/person/day in the USA – although omitting Latin America and the Caribbean, Africa, and Oceana. In line with these trends Shaikh and Ahammed (2020), suggest 14–140 L/greywater/person/day in LMICs, and Morel and Diener (2006) report 90–120 L/person/day for households with piped water supply and no water scarcity.

The fact that the volumes reported by the above studies vary so much within regions suggests that factors other than national geography and GDP influence greywater production. Individual or household sensitivity to water resource availability, seasonality, price, and water accessibility or reliability are examples of such factors. In contrast, where local water resources are plentiful or household affordability is less constrained, water consumption and thus greywater production is likely to increase (Katukiza et al.,2015; Morel and Diener, 2006; Oteng-Peprah et al.,2018; Shaikh and Ahammed, 2020). Furthermore, in countries such as Israel or Jordan, where greywater is recycled at-source and repurposed, greywater production is likely to be significantly lower than in other contexts where greywater is discharged into a sewer, open drain, or the natural environment (Vuppaladadiyam et al.,2019).

Household greywater production may also be significantly lower where laundry, bathing, or dishwashing are done away from the home at nearby waterbodies (Morel and Diener, 2006). Furthermore, given the significant differences in water access in urban and rural areas, as well as less research from urban areas on water consumption and greywater production (Cassivi et al.,2019), it is therefore likely that such differences in greywater production are not accounted by regional or GDP-based groupings, nor evidenced sufficiently by existing research.

Greywater return rates (i.e., greywater generated as a proportion of water use) have been reported by several studies. Globally, reported return rates include 51–89% (Shaikh and Ahammed, 2020), and 41–91% (Boyjoo et al., 2013). Consistent with these studies, our study reports a 58% return rate (with a range of 42–63%). Interestingly, although our survey was completed in low-income areas of Khulna, our return rate (58%) is similar to that of 60% reported in middle-class neighbourhoods of Dhaka where piped water coverage is much higher (Biswas et al.,2012).

When considering the greywater contributions of each domestic activity, we found that bathing is the largest proportion of domestic greywater produced in Khulna (47%). Conversely, others recognise bathing, dishwashing, and laundry as the most significant contributors to the total greywater produced by households. Katukiza et al. (2015) report 42% for laundry, 37% for bathing and 21% for dishwashing. Shaikh and Ahammed (2020) report 28% (for dishwashing), 27% (bathing), and 7% (laundry). However, in contrast with others' our study reports almost equal proportions of greywater are produced by, dishwashing (14%) laundry (12%), handwashing (12%) and Wudu (11%) in Khulna.

4.3. Greywater characteristics

Drawing on the findings of this study and considering the wider literature, we propose that each domestic activity introduces an array of contaminants into the greywater generated, thereby altering its overall quality. While greywater is considered less polluted than blackwater, cooking, bathing, and laundry greywater is generally still considered high risk due to the variety of contaminants and high nutrient (e.g., nitrates and phosphates) concentrations, risking both public and environmental health (Katukiza et al.,2012; Shaikh and Ahammed, 2020; Khajvand et al.,2022).

Kitchen-generated greywater tends to have higher microbial and organic loads due to food preparation and washing activities (Al-Gheethi et al., 2016). In contrast, greywater from laundry activities tends to have higher volumes of physical or chemical pollutants, attributed to the use of soaps or laundry detergents and the washing of soiled clothes. Greywater from personal hygiene activities, such as showering or handwashing may also contain faeces and other associated pathogens (Bakare et al., 2017; Oteng-Peprah et al., 2018; Shaikh and Ahammed, 2020).

Common characteristics of greywater sampled in LMICs indicate alkaline pH ranges, influenced by cleaning products. Turbidity, caused by soaps, detergents, and suspended particles like food or sand from mopping, dishwashing, and food preparation, is typically higher in kitchen greywater (Bakare et al., 2017; Oteng-Peprah et al., 2018). Similarly, COD and BOD concentrations are typically highest in kitchen greywater (Shaikh and Ahammed, 2020).

Contaminants present in greywater are known to have a detrimental impact on soil and waterbody health. Sodium, originating from cooking and detergent use, has the potential to harm the environment by damaging soil properties and inhibiting plant growth (Oteng-Peprah et al., 2018). Oil and grease from food preparation and cooking form a translucent film on the water's surface, creating anoxic conditions and limiting oxygen uptake by aquatic plants and animals (Bakare et al., 2017). Similarly, phosphorus, originating from soaps and cleaning materials causes eutrophication in waterbodies, depleting oxygen levels and increasing algal growth (Singh and Saraswat, 2016).

While the long-term pollution implications of greywater are not well known, authors have identified that using greywater for irrigation can reduce crop yields due to high sodium and heavy metal traces originating from detergents and other chemical compounds (Shaikh and Ahammed, 2020). Furthermore, greywater often contains faeces and other associated pathogens from washing clothes and bathing - presenting a risk to public health (WHO, 2006).

4.4. Greywater disposal

To reduce pressures created by increased water demand and depletion of water resources, countries are adopting alternative approaches – including greywater use - to conserve and supplement potable water supplies (Shaikh and Ahammed, 2020). Although we found minimal greywater use in Khulna (13%), studies report household water savings of 50–80% where greywater is used for multiple purposes. Furthermore, as water used for toilet flushing, cleaning, and watering plants, needs not meet drinking water standards, minimal treatment is requirement between activities (Vuppaladadiyam et al.,2019).

Our results suggest that, despite households engaging in domestic activities in different locations, most (89%) consistently dispose greywater via open drains (67%), waterbodies (17%), to the ground discharge (9%), or DEWATS (7%) – aligning with findings of other studies conducted in unsewered areas (Carden et al.,2007a, 2007b; Raude et al.,2009; Alexander and Godrej, 2015; Katukiza et al.,2015; Dwumfour-Asare et al.,2017, 2018).

Although most of Khulna's residential areas have networked drainage of varying quality, low-income and informal communities typically have improvised drainage channels and ditches constructed by residents (Haldar et al.,2021). This was particularly the case for those surveyed in Ward 17 – where inadequate shallow compacted soil channels increase the likelihood of groundwater contamination and flooding during the rainy season and attract animals and disease vectors (e.g., mosquitoes, rats). Similarly, in Wards 10 and 11, many households were connected to secondary or tertiary drains overseen by KCC, however, they are mostly inadequate due to poor construction or blockages created by solid waste and accumulated sediment.

Based on the findings of the study, policymakers and practitioners should work with residents to raise awareness of both water and environmental conservation, particularly by encouraging greywater use for non-potable activities, and promoting better greywater disposal practices. This, in conjunction with the effective upgrading, operation, and maintenance of the city's existing drainage network to ensure proper functioning, will provide an interim solution to address some of the challenges presented by greywater in Khulna. To determine further greywater management approaches for Khulna, more research is needed that quantifies household greywater quality - to understand the current impacts on public and environmental health given a range of pollutants and concentrations. As residents generate and dispose of greywater at home and elsewhere, the implications for public and environmental health may be far-reaching, necessitating careful attention and management from service-providers and other stakeholders beyond the household-level.

4.5. Limitations

The use of a cross-sectional study design employing descriptive analysis, although suitable for exploratory research, is constrained in identifying underlying relationships and causal mechanisms. Furthermore, the cross-sectional design employing convenience sampling, coupled with fieldwork conducted solely during the dry season, limits the representativeness of our results for Khulna city, while also potentially overlooking variability in water usage linked to seasonality, weekday/weekend practices, and other factors. Lastly, the reliance on self-reported household data by a single household representative, based on recalled estimates, introduces the possibility of bias by over or underestimation of water use, and the individual habits of other household members.

5. Conclusions

This is the first study to investigate household greywater management practices in low-income communities in Bangladesh. We found that most households use piped water, supplemented by seasonal rainwater harvesting and greywater use, for non-consumptive purposes such as bathing, cleaning, and toilet flushing. Conversely, for consumptive purposes, although most households have an on-plot piped connection, residents prefer to use off-plot tubewells, public taps, or delivered water due to the perceived risk of contamination and intermittency of on-plot piped water. Varied daily volumes of household greywater are produced from combined domestic activities, including, bathing, dishwashing, laundry, handwashing, Wudu, and mopping. Notably, bathing greywater constitutes almost half of the total household greywater produced. Greywater produced in Khulna is expected to have diverse biological, chemical, and physical properties that are affected by domestic activity, products used, and individual behaviours. Although greywater producing activities are often completed in different locations – sometimes away from the home - all greywaters are treated similarly, with most disposed untreated via open drains or directly to waterbodies with subsequent implications for public and environmental health.

CRediT authorship contribution statement

R. Lewis: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Writing – review & editing. **R. Scott:**

Writing – review & editing, Supervision, Methodology, Conceptualization. **B. Bala:** Supervision, Methodology, Writing – review & editing. **H. Jahan:** Writing – review & editing. **J. Bartram:** Conceptualization, Supervision, Writing – review & editing. **T. Radu:** Conceptualization, Methodology, Supervision, Writing – review & editing.

Declaration of competing interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijheh.2024.114376.

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