



# Quantity and quality characteristics of greywater from an Indian household

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**Abstract** A year-long study was conducted to assess the quantity and quality characteristics of greywater generated from different sources of an Indian household. The effect of source separation on greywater quantity and pollutant load contribution was also assessed. Composite samples were collected separately over a period of 24 h from each of the greywater source, namely hand basin, bathroom, kitchen, and laundry, and were analysed for different physico-chemical and microbiological parameters. The mean greywater generation averaged 62 L per person per day. Quantitatively, kitchen and bathroom greywater contributed 37 and 31% of the total greywater volume, respectively, while hand basin and laundry greywater accounted for 11 and 21% of the total greywater generation. Kitchen greywater contributed about 60% of the organic load in terms of biochemical oxygen demand (BOD) and chemical oxygen demand (COD), while laundry greywater was the major contributor of heavy metals and PO<sub>4</sub>-P loads. Hand basin and bathroom greywaters were the major sources of total coliforms. The analysis shows that separation of kitchen and laundry greywater is beneficial as it reduces pollutant load considerably.

**Keywords** Greywater · Greywater characteristics · Greywater treatment · Pollutant loads · Quality · Quantity

## Introduction

Sufficient supply of water of adequate quality and quantity is essential for wellbeing and development of any community. Water shortage is one of the most important issues facing the world today, and in view of the increasing population and urbanisation, the search for alternative water sources is gaining attention (Delhiraja & Philip, 2020a). In this scenario, conventional water management strategies may not be able to meet future water demands (Dwumfour-Asare et al., 2020). Since the development and exploitation of new water sources such as dams and seawater desalination are costly and are expected to cause negative environmental effects (Alfiya et al., 2018), reuse of wastewater is one of the options being investigated. Greywater (GW) which includes wastewater from hand basins, bathrooms, kitchens, and laundries constitutes 50–80% of the total water use in households, making it a reliable source of water (Prajapati et al., 2019). Greywater is relatively low in solids, organic content, heavy metals, and pathogens, and therefore is easier to treat than municipal wastewater (Delhiraja & Philip, 2020b). Separation of greywater from other wastewater substantially reduces the wastewater volume that needs to be treated centrally, and reuse of

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treated greywater reduces the water treatment requirements. Reuse of such a huge quantity of less polluted greywater for non-potable applications such as toilet flushing and garden irrigation can substantially reduce potable water consumption. This will reduce the energy expenses along with the associated cost on water conveyance and treatment (Vuppaladadiyam et al., 2019).

Direct reuse of untreated greywater may cause diseases and other health hazards to public though it is supposed to contain only about 30% of total organic load and 10–20% of the nutrients present in domestic wastewater (Prajapati et al., 2019). Microbiological risks are associated with reuse of untreated greywater for irrigation and toilet flushing (Blanky et al., 2015). Aerosols act as a medium in spreading of *Legionella* and thus possibility of infection through inhalation increases when greywater is used either for irrigation or toilet flushing (Busgang et al., 2015). This makes greywater treatment prior to its reuse essential and, therefore, detailed characterisation of greywater is important to decide upon the type and degree of treatment to be given for the intended use.

Based on the degree of pollution, greywater can be broadly classified into two categories, namely, light greywater (LGW) and dark greywater (DGW) (Ghaitidak & Yadav, 2013). Flows from bathroom and hand basin are termed as LGW, whereas wastewater from sources like kitchen sink and laundry is termed as DGW (Shaikh et al., 2019). Daily per person greywater generation depends upon the income of the individual and is generally divided equally between LGW and DGW (Shaikh & Ahammed, 2020). Light greywater contains soaps, skin cells, shaving waste, lint, toothpaste, shampoos, sand/clay particles, hair oil, other body care products, hair, body fats, toothpaste, and traces of urine and faeces (Ghaitidak & Yadav, 2013; Shaikh & Ahammed, 2020). Using hand basins after use of toilet adds to microbial population in hand basin greywater (Blanky et al., 2015). Dish washing detergents, raw meat washing, tea, coffee, dairy products, traces of food preservatives, food and vegetable residue, sand and clay particles, fruits and vegetable peels, oil and fats, paints, perfumes, bleaches, nonbiodegradable fibres from clothing, solvents, and chemicals from detergents are major composition of DGW (De Gisi et al., 2016; Eriksson et al., 2002; Li et al., 2009; Noutsopoulos et al., 2018).

Characteristics of greywater from a household depend upon multiple factors such as age, economic status, number, presence and number of children, health and awareness regarding health, and environmental effects. The characteristics of greywater differ from household to household depending upon detergents used, personal hygiene, source of water, cosmetics, and other personal habits of occupants. Greywater from different sources have different characteristics and there is a need to study each of them separately. Of the different sources, kitchen greywater is characterised with high organic content because of food and vegetable residues, oil, and fats. Laundry greywater has high concentration of phosphates because of soaps and detergents used.

Considerable variation in quantity and quality characteristics of greywater makes it difficult to select a suitable technique for its treatment. Thus, better understanding of greywater composition from different sources will help in deciding the economic and environmental friendly treatment technology. The efficiency of alternative treatment options depends upon the source of greywater. For example, if sand filters are used for treatment of LGW, it can meet the reuse standards (Friedler, 2004), while for mixed greywater (MGW) or DGW sand filtration will not be enough (Antonopoulou et al., 2013). Use of filters for treatment of DGW will result in early clogging and rapid head loss of continuously operated filters and reduction in flow rate of intermittent filters, as DGW sources are rich in solid content (Edwin et al., 2014).

A few authors recommend separate treatment of LGW and DGW (Noutsopoulos et al., 2018). Hence, to decide upon the feasible treatment option for different sources of greywater, it is important to know the detailed characteristics of greywater from each of the sources. While many studies reported the quantity and quality characteristics of greywater from households, very few studies have focused on the characterisation of different sources of greywater such as hand basin, bathroom, kitchen, and laundry (Katukiza et al., 2015). Limited studies are available from developing countries on long-term monitoring of source-based characteristics of greywater. Literatures related to mass and relative pollutant loads of mixed greywater were reported (Dwumfour-Asare et al., 2020) but few studies reported source-based mass and relative pollutant loads (Katukiza et al., 2015). In this study a year-long study was conducted

to characterise greywater from different sources of an Indian household. Detailed quantity and quality characterisation of greywater from different sources was undertaken and the effect of separation of source of greywater on greywater discharge and pollutant load contribution was assessed.

**Materials and methods**

**Sample collection**

Greywater generated from a family of married couple located at Sardar Vallabhbhai National Institute of Technology (SVNIT), Surat, India, was monitored in this study. The healthy couple were aged 22 and 30 years. The whole greywater generated in the household was collected over a period of 24 h separately from each of the greywater source, namely hand basin (HB), bathroom (B), kitchen (K), and laundry (L) in pre-marked plastic containers. Figure S1 (online resource) shows the sample collection arrangement. Greywater collected in plastic containers from each of the four sources was emptied separately in 100-L barrels. Containers were thoroughly washed before use on each day. The samples for analysis were collected daily from the four barrels at 8:00 am after thoroughly mixing the contents of the barrels. The quantity of greywater generated from each source was measured daily. Hand basin and kitchen sink were provided with outlet pipes which were directed to the collection containers. An individual was asked to collect the bathwater in plastic containers after each bathing. Similarly, laundry greywater was collected immediately after each washing operation. The sampling protocol was in accordance with Chaillou et al. (2011) and Katukiza et al. (2015). The collected samples were transported to the environmental engineering laboratory of SVNIT, Surat, and analysis of various physicochemical and microbial parameters were under taken immediately. A total of 332 greywater samples were collected from each source of greywater during the period of January 2019–January 2020.

**Mass pollutant loads**

For a greywater source *j*, mass load ( $P_{ij}$ ) of a pollutant *i* was calculated using its mean concentration in the

source and the mean generation per capita per day as shown in Eq. (1):

$$P_{ij} = C_{ij}Q_j \tag{1}$$

where  $P_{ij}$  is the pollutant load produced per capita per day for pollutant *i* by the greywater source *j*,  $C_{ij}$  is the average concentration of the pollutant *i* in the source, and  $Q_j$  is the mean per capita generation per day of the source. The relative load ( $r_i$ ) of a pollutant in a particular source is calculated as the ratio of the pollutant load in that source to the sum of the loads of this pollutant in all the four greywater sources (Eq. (2)).

$$r_i = \frac{P_{ij}}{\sum_{j=1}^n P_{ij}} \tag{2}$$

**Analytical methods**

Greywater samples were analysed for temperature, turbidity, pH, electrical conductivity (EC), total chemical oxygen demand (COD), biochemical oxygen demand (BOD), ammonia nitrogen (NH<sub>4</sub>-N), phosphates (PO<sub>4</sub>-P), and oil and grease according to the standard methods (American Public Health Association (APHA), 2012). Temperature, pH, and EC were measured using portable Hanna instruments (HI 98,130), while calibration was performed using standard solutions. Turbidity was measured using a turbidimeter (Systronics 135). COD was analysed using the closed reflux titrimetric method while PO<sub>4</sub>-P was analysed by stannous chloride method. The partition-gravimetric method using petroleum ether was used to determine oil and grease. Heavy metals, copper, lead, zinc, chromium, cadmium, and mercury were measured using ICP-AES (Spectro Analytical Instruments GmbH, Germany). The certified reference material (CRM) adopted for Cu, Pb, and Zn was ICP multi-element standard solution IV (Merck), while for Cr, Cd, and Hg, ICP multi-element standard solution IX (Merck) was used. Total coliforms (TC) and faecal coliforms (FC) were enumerated according to most probable number (MPN) method with appropriate dilutions as per standard methods (APHA, 2012). The BOD and COD analyses were done once and twice a week, respectively, while TC and FC analyses were done monthly. Statistical software SPSS 10.0 was used for the statistical evaluation of the results.

## Results and discussion

### Greywater generation

The quantity of greywater generated in the present study along with the values reported in the literature is presented in Table 1. Total greywater generation varied between 42 and 96 L/p/d (litre/person/day) with a mean value of 62 L/p/d and is well within the range of 14–196 L/p/d reported in the literature (Shaikh & Ahammed, 2020). Although the total greywater generation is relatively low, but it was more than the minimum recommended value of 30 L/p/d (Shaikh & Ahammed, 2020). Less greywater generation observed might be the result of the water saving tendency of the occupants. It may be noted that some studies showed significant difference in the field-measured greywater generation rates and those estimated via household surveys, with surveys overestimating the rates (Dwumfour-Asare et al., 2017). In the present study greywater generation was quantified by field measurements.

The total quantity of greywater generated by an individual during a day in the present study was less than that reported by other studies from India (Edwin et al., 2014; Vakil et al., 2014) but higher than those reported from other low-income countries (Al-Hamaiedeh & Bino, 2010; Dwumfour-Asare et al., 2017). Much lower greywater generation (14–59 L/p/d) was reported in the literature from water scarce countries such as Mali, Jordan, Yemen, and South Africa (Boyjoo et al., 2013). In Asia, Europe, and the USA, the volume of greywater generation varies between 72 and 225, 35 and 150, and 123 and 200 L/p/d, respectively (Jamrah et al., 2007; Noutsopoulos et al., 2018; Penn et al., 2012; Revitt et al., 2011; Vuppaladadiyam et al., 2019). Table 2 represents volumetric contribution and variation of

greywater generation from different greywater sources and their comparison with the literature data. The mean greywater generation from hand basin, bathroom, kitchen, and laundry were  $6.59 \pm 1.53$ ,  $18.88 \pm 3.09$ ,  $23.02 \pm 4.96$ , and  $13.13 \pm 4.04$  L/p/d, respectively (Table 2).

Among the different sources, the kitchen sink was the major greywater producer (37%), while the hand basin contributed the least (11%). These results are in agreement with that of Vakil et al. (2014) who reported 44, 27, 24, and 6% of total greywater volume from kitchen, bathroom, laundry, and hand basin, respectively, of a household in India. In a study from Jordan, Halalsheh et al. (2008) also reported kitchen as major contributor of greywater from households. On the contrary, kitchen greywater generation reported from other studies is much lower (Table 2). This can be attributed to differences in economic status, living standards, and lifestyle of people in low-income countries (LICs) and high-income countries (HICs). Use of automatic dish washer and use of more processed food, less home cooking, and more eating at restaurants in HICs are possible reasons for reduced kitchen greywater generation in those countries (Dwumfour-Asare et al., 2017).

Several studies from HICs reported considerably higher contribution of bathroom greywater (Table 2). This can be attributed to increased use of bathtubs and showers in those countries. Hand basin contributed least volume of greywater and the results are in line with findings of Antonopoulou et al. (2013) who reported greywater characteristics for households in Greece. Generation of LGW in the present study accounts for 42% of total greywater, whereas the remaining 58% was DGW.

**Table 1** Greywater generation rates reported in different studies

Country	Generation (L/p/d)	Reference
India	42–96 ( $62 \pm 11$ )	Present study
Jordan	14–80	Al-Jayyousi (2003); Halalsheh et al. (2008)
Denmark	66–85	Eriksson et al. (2009); Revitt et al. (2011)
Greece	37–98	Fountoulakis et al. (2016); Noutsopoulos et al. (2018)
Israel	100–101	Friedler (2004); Penn et al. (2012)
USA	117–196	Roesner et al. (2006); Rose et al. (1991)
Oman	154–161	Jamrah et al. (2007); Prathapar et al. (2005)
India	71–140	Edwin et al. (2014); Vakil et al. (2014)

Values in the parenthesis indicate mean  $\pm$  standard deviation based on 332 samples from each source

**Table 2** Quantitative characteristics of different sources of greywater

Country	Hand basin		Bathroom		Kitchen		Laundry		Reference
	Mean±SD	% of total GW	Mean±SD	% of total GW	Mean±SD	% of total GW	Mean±SD	% of total GW	
India	7±2 (3–11)	11	19±3 (12–28)	31	23±5 (9–40)	37	13±4 (5–32)	21	Present study
Israel	18	18	39.04	39	26.6	26	16.6	17	Penn et al. (2012)
Iran	NA	20	NA	35	NA	20	NA	20	Ahmadi and Ghanbari (2016)
Greece	9±7	10	34±33	41	12±14	23	21±20	26	Antonopoulou et al. (2013)
India	8	6	38	27	61	44		24	Vakil et al. (2014)

Values in the parenthesis indicate min–max values; mean value presents the greywater generation in L/p/d SD standard deviation. NA not available

Volumetric variation in greywater generation from different sources on a weekly and seasonal basis is shown in Fig. S2 (online resource). Significant variation was observed in quantity of greywater generation during weekdays and weekends ( $p < 0.05$ ) (Fig. S2) with higher greywater generation on weekends. This increased greywater volume on weekends could be mainly due to additional kitchen and laundry activities. These results are similar to those reported by Palmquist and Hanæus (2005) who characterised greywater from Swedish households. Greywater generation from hand basin and bathroom is more or less similar on weekdays and weekends. No significant difference ( $p < 0.05$ ) was observed in quantity of greywater generation among different seasons (Indian conditions) of the year (Fig. S2b) with mean greywater generation in summer (March to June), rainy (July to October), and winter (November to February) seasons being 63.1, 58.5, and 61.8 L/p/d, respectively.

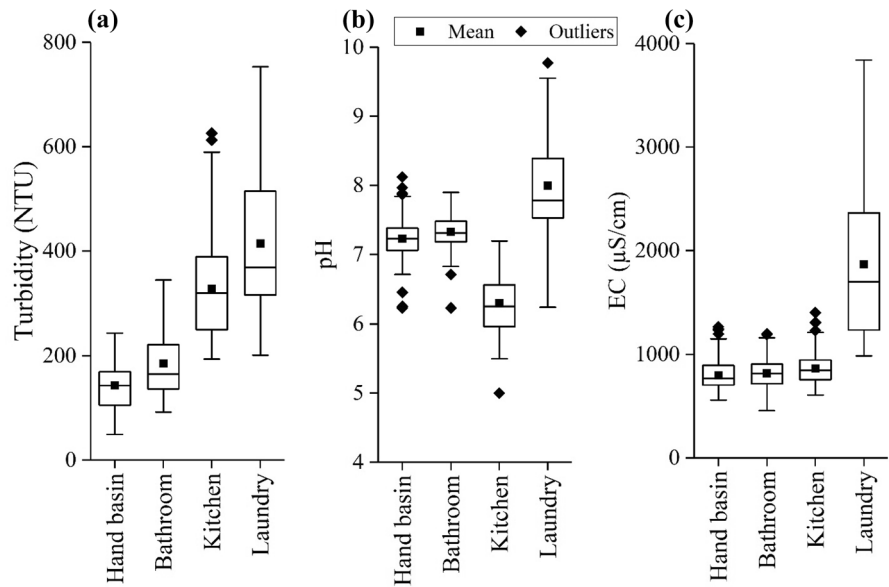
Qualitative analysis

*Physicochemical characteristics*

Based on the sampling protocol, 332 greywater samples were collected from each source of greywater and were subsequently analysed. Box plots for turbidity, pH, and EC for different greywater sources are presented in Fig. 1 and the mean and range of observed values along with the results reported in the literature are presented in Table 3. Large variation in turbidity of greywater from different sources was observed. In general, turbidity of DGW is significantly ( $p < 0.05$ ) higher than LGW sources. Mean greywater turbidity values from hand basin, bathroom, kitchen, and laundry were 143, 185, 328, and 415 NTU, respectively, and these are within the range reported in the literature. Mean turbidity of kitchen and laundry greywater is about 2–3 times higher than that of hand basin. Mean turbidity values from bathroom and laundry greywater found in the present study were close to those reported by Dwumfour-Asare et al. (2017) who characterised greywater from households in Ghana.

Laundry greywater was found to be much more polluted than LGW sources as mean turbidity of laundry greywater was higher than the highest turbidity observed in hand basin and bathroom sources. Washing of shoes and clothes might add turbidity

**Fig. 1** Physicochemical characteristics of greywater **a** turbidity, **b** pH, and **c** EC



to laundry greywater. Hair and fibres are sources of solids in laundry greywater (Eriksson et al., 2002). Higher turbidity was reported where solid soaps were used as in the present study (Chaillou et al., 2011). Disposing of food leftovers into the kitchen sink and washing of fruits and vegetables might be the sources of higher turbidity in kitchen greywater (Oteng-Peprah et al., 2018a).

The mean pH values of hand basin and bathroom greywater were close to neutral (7.23 and 7.33, respectively), whereas kitchen and laundry greywater were acidic and alkaline, respectively, with mean pH values of 6.29 and 7.99, respectively. These values are very close to the ones reported by other researchers (Antonopoulou et al., 2013; Sanchez et al., 2010; Uddin et al., 2016; Zipf et al., 2016). Great variation in pH values of kitchen and laundry greywater was observed in the present study when compared to hand basin and bathroom greywater.

Rapid degradation of food particles and oils under anoxic conditions and production of organic acids is the probable cause of lower pH values of kitchen greywater (Bakare et al., 2017; Oteng-Peprah et al., 2018a). Uddin et al. (2016) reported much more acidic kitchen greywater with pH value of 3.3. Use of sodium hydroxide-based soaps and alkaline materials used in detergents leads to increase in pH of laundry greywater (Bakare et al., 2017; Oteng-Peprah et al., 2018a, b). The pH of laundry greywater in the

present study was less than the values reported in the literature (Sanchez et al., 2010). The average pH of greywater from all the sources was within the Central Pollution Control Board (CPCB, 2015) and National Green Tribunal (NGT, 2018) standards of 6.5–8.5 and 6.5–9.0, respectively, except for kitchen greywater.

The mean electrical conductivity (EC) concentration of laundry greywater was about two times higher compared to other greywater sources. High EC in laundry greywater could be due to the use of powdered laundry detergents used by the household in the present study which contains high salt concentration (De Gisi et al., 2016). Ghunmi et al. (2008) also reported high concentration of EC in laundry greywater compared to the rest of the greywater sources of households in Jordan. High value of EC in laundry greywater is attributed to both cleaning products used and also to the very low water consumption which results in low dilution of cations and anions in greywater produced (Noutsopoulos et al., 2018). The EC values of bathroom, kitchen, and laundry greywater in the present study are in agreement with the results reported by Dwumfour-Asare et al. (2017).

#### *Organic and nutrient contents*

Figure 2 represents organic and nutrient contents in different greywater sources. Mean BOD



**Table 3** Qualitative characteristics of greywater produced and comparison with literature data

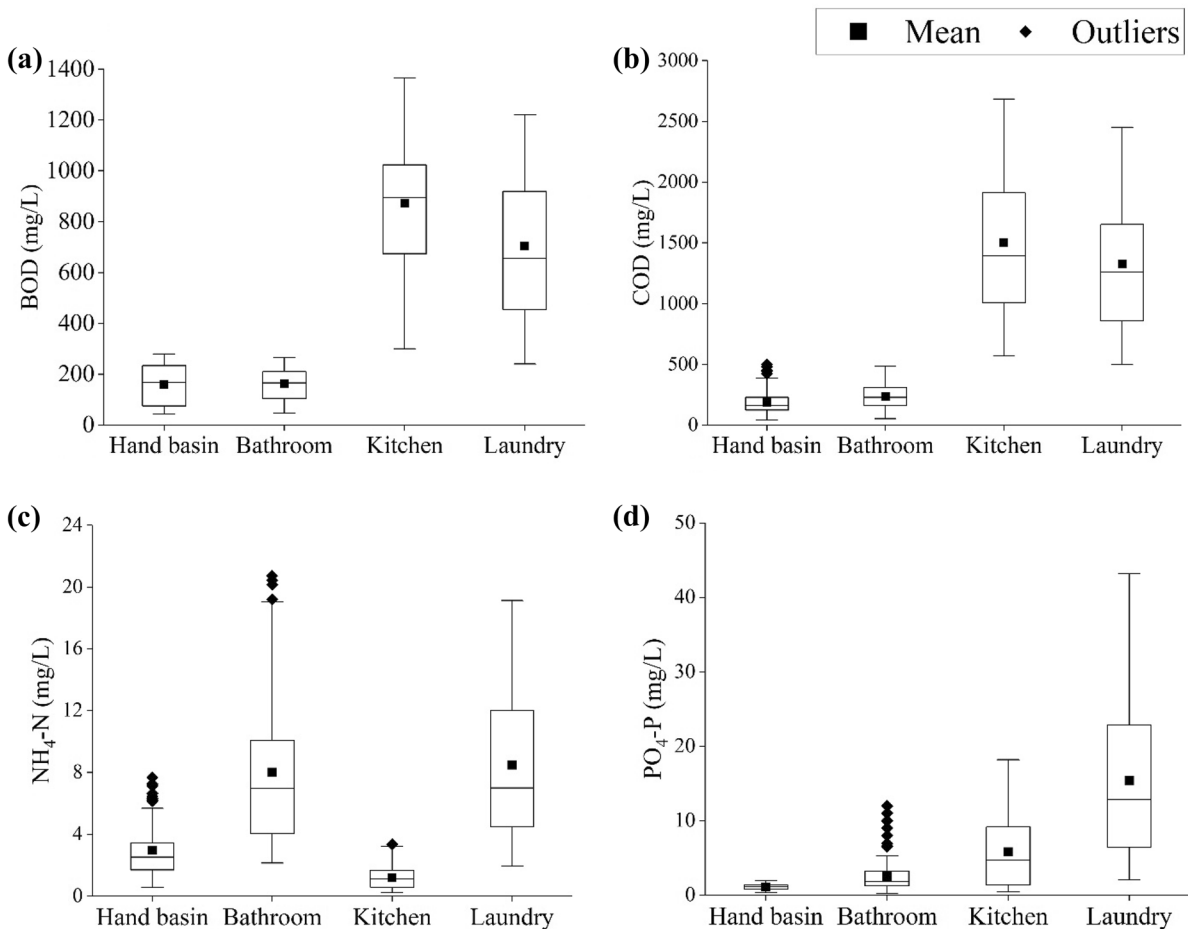
Parameter	Unit	n	Present study												Reported values (literature)										
			Tap water			Hand basin			Bathroom			Kitchen			Laundry			Hand basin		Bathroom		Kitchen		Laundry	
			Mean±SD	min-max	Mean±SD	min-max	Mean±SD	min-max	Mean±SD	min-max	Mean±SD	min-max	Mean±SD	min-max	Mean±SD	min-max	min-max	min-max	min-max	min-max	min-max	min-max			
Temperature	°C	332	24.6±2.2	22.8–29.6	25.5±1.6	22.0–29.5	25.6±1.5	21.5–29.9	25.8±1.7	21.3–29.6	25.4±1.8	–	–	–	15.0–32.0	24.4–30.9	22.4–35.0								
Turbidity	NTU	332	0.77±0.35	49–243	143±43	92–344	185±64	194–626	328±93	201–753	415±136	3–164	3–164	51–549	100–528	42–729									
TDS	mg/L	332	247±98	283–539	412±66	323–544	445±52	330–724	479±86	499–1840	1019±361	181–578	181–578	277–601	245–1095	1060–2444									
pH		332	7.17±0.22	6.23–8.12	7.23±0.26	6.21–7.90	7.33±0.22	5.00–7.19	6.29±0.44	6.24–9.77	7.99±0.70	6.00–9.82	6.00–9.82	5.57–8.20	3.30–9.80	5.00–10.33									
EC	µS/cm	332	480±102	557–1265	797±139	456–1200	816±144	606–1403	864±137	984–3841	1868±710	199–4342	199–4342	14–1544	449–3130	36–7030									
BOD	mg/L	52	ND	44–280	160±78	47–264	161±62	300–1364	864±271	240–1810	719±357	10–568	10–568	8–673	79–1850	44–3358									
COD	mg/L	120	15±3	58–500	189±100	51–482	236±101	569–2681	1477±592	497–2450	1333±600	47–1171	47–1171	25–903	26–8071	58–4155									
NH <sub>4</sub> -N	mg/L	120	0.1±0.1	0.6–7.7	3.0±1.7	2.2–20.7	8.0±4.8	0.2–3.4	1.2±0.8	2.0–19.1	8.5±5.0	0.3–30.0	0.3–30.0	0.1–15.0	0.0–23.0	0.1–11.3									
PO <sub>4</sub> -P	mg/L	120	0.1±0.0	0.3–2.0	1.1±0.4	0.2–48.0	6.3±11.7	0.5–18.2	5.8±4.8	2.0–43.2	15.4±10.7	0.0–15.0	0.0–15.0	0.1–48.8	0.4–26.0	0.2–171.0									
Oil and grease	mg/L	12	BDL	2–24	11±10	22–87	58±33	55–233	130±69	3–27	15±10	–	–	37–78	27–240	8–35									
TC	MPN/100 mL	10	4.6±5.9	3.3×10 <sup>2</sup> –7.0×10 <sup>4</sup>	2.2×10 <sup>4</sup> ±3.2×10 <sup>4</sup>	1.4×10 <sup>2</sup> –3.3×10 <sup>4</sup>	6.6×10 <sup>3</sup> ±1.0×10 <sup>4</sup>	1.1×10 <sup>1</sup> –9.0×10 <sup>2</sup>	4.6×10 <sup>2</sup> ±3.8×10 <sup>2</sup>	2.1×10 <sup>2</sup> –2.1×10 <sup>4</sup>	4.6×10 <sup>3</sup> ±6.5×10 <sup>3</sup>	0.0–1.7×10 <sup>6</sup>	0.0–1.7×10 <sup>6</sup>	1.0×10 <sup>1</sup> –1.1×10 <sup>6</sup>	1.1×10 <sup>3</sup> –2.4×10 <sup>6</sup>	2.0×10 <sup>2</sup> –6.1×10 <sup>9</sup>									
FC	MPN/100 mL	10	BDL	7–63	27±22	2–63	15±20	2–63	15±19	2–63	16±20	3.2×10 <sup>1</sup> –1.7×10 <sup>3</sup>	3.2×10 <sup>1</sup> –1.7×10 <sup>3</sup>	0.0–3.7×10 <sup>5</sup>	2.3×10 <sup>2</sup> –3.2×10 <sup>5</sup>	1.3×10 <sup>1</sup> –2.1×10 <sup>5</sup>									
Cu	µg/L	3	5±3	25.0–27.0	26.0±1.4	12.0–14.0	13.0±1.4	11.0–20.0	15.5±6.4	83.0–108.0	95.5±17.7	5.0–7.3	5.0–7.3	0.0–120.0	20.0–260.0	50.0–322.0									
Zn	µg/L	3	16.8±9.7	88.0–130.0	109.0±29.7	24.0–33.0	28.5±6.4	87.0–109.0	98.0±15.6	402.0–1893.0	1147.5±1054.3	2030.0	2030.0	59.0–6300.0	0.1–1800.0	90.0–440.0									
Cr	µg/L	3	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	<2.5	<2.5	25.0–390.0	4.0–25.0										
Cd	µg/L	3	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	–	–	0.0–10.0	0.5–7.0	0.6–38.0									
Pb	µg/L	3	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	–	–	4.9–103.6	5.0–140.0	3.0–63.0									
Hg	µg/L	3	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	–	–	0.6–36.0	0.3–40.0	0.3									

BDL below detectable limit

Adopted from Antonopoulou et al. (2013); Bakare et al. (2017); Blanky et al. (2015); Boyjoo et al. (2013); Busgang et al. (2015); Christova-Boal et al. (1996); De Gisi et al. (2016); Delhiraja and Philip (2020a, b); Dwumfour-Asare et al. (2017); Eriksson et al. (2002); Ghatidak and Yadav (2013); Katukiza et al. (2015); Li et al. (2009); Oteng-Peprah et al. (2018a, b); Sall and Takahashi (2006); Sanchez et al. (2010); Shaikh et al. (2019); Shaikh and Ahammed (2020); Uddin et al. (2016); Vuppaladadiyam et al. (2019); Zipf et al. (2016)); method detection limit (MDL) adopted for analysis of Cr, Cu, Pb, Zn, Cd, Hg are 0.007014, 0.004552, 0.022272, 0.001495, 0.004257, and 0.006883 mg/L, respectively

concentrations from hand basin and bathroom were 160 and 161 mg/L, respectively, while these were 864 and 719 mg/L for kitchen and laundry greywater, respectively. The mean BOD value for kitchen greywater in the present study is well within the minimum 79 mg/L (Maimon et al., 2014) and maximum 1850 mg/L (Ghunmi et al., 2008) reported in the literature. Similarly, mean BOD value for laundry greywater is within the range of 44–3358 mg/L reported in the literature (Jamrah et al., 2006; Uddin et al., 2016). Mean BOD concentration in kitchen and laundry were 4–5 times higher than that of hand basin and bathroom greywater (Table 3). The presence of food and drink residuals with oil and fat along with dirt from vegetables are the reasons for high organic content in kitchen greywater (Dwumfour-Asare et al., 2017; Noutsopoulos et al., 2018). Another reason for

higher organic contents in kitchen and laundry greywater is the use of chemicals in dishwashing and laundry detergents (Ghaitidak & Yadav, 2013). Much higher BOD concentration from different sources was reported by Katukiza et al. (2015) which can be attributed to the much lower quantity of greywater generated. Though surfactant concentration was not analysed in this study, it is reported that detergents and surfactants contribute up to 40% of the organic constituents in greywater (Delhiraja & Philip, 2020a). Surfactants may also inhibit bacterial activity (Mosche & Meyer, 2002). Dark greywater sources are reported to be rich in organics due to surfactants and xenobiotic compounds (Khalil & Liu, 2021). BOD concentrations from all the sources of greywater were significantly higher than the permissible limits laid by CPCB (2015) and NGT (2018).



**Fig. 2** Organic and nutrient contents in greywater from different sources: **a** BOD, **b** COD, **c** NH<sub>4</sub>-N, and **d** PO<sub>4</sub>-P



COD follows similar trends of BOD for all the greywater sources. Mean COD values for hand basin, bathroom, kitchen, and laundry greywater were 189, 236, 1477, and 1333 mg/L, respectively. The COD of hand basin and bathroom greywater is well within the range reported in the literature (Donner et al., 2010; Dwumfour-Asare et al., 2017). COD concentration for laundry greywater in the present study is also within the range of 58–4155 mg/L reported by Jamrah et al. (2006) and Janpoor et al. (2011), respectively. Kitchen greywater had mean COD value 6–7 times higher than the mean COD values of hand basin and bathroom greywater. Higher COD concentration in kitchen greywater can be attributed to the presence of dirt from vegetable washing, food, and drink residuals (Oteng-Peprah et al., 2018a). Laundry greywater was also a major contributor of COD with a mean value of  $1333 \pm 600$  mg/L. Detergents used and cloth impurities were the sources of organic carbon detected in laundry samples (Antonopoulou et al., 2013). Higher organic contents were reported where solid soaps were used (Chaillou et al., 2011; Singh et al., 2021), and in the present study solid soaps were used for both kitchen and laundry activities. The COD concentration from all four sources of greywater was above 50 mg/L, the standard laid by NGT (2018) and CPCB (2015) for effluent discharge from sewage treatment plants.

Table S1 (online resource) depicts biodegradability of greywater in terms of COD/BOD ratio along with the values reported in the literature. A COD/BOD ratio of less than 2.5 represents easy biodegradability of greywater (Li et al., 2009). All the sources of greywater considered in present study showed easy biodegradability (Table S1). The results are similar to the observations by De Gisi et al. (2016), Friedler (2004), and Noutsopoulos et al. (2018), who reported greywater from all the sources were biodegradable. Wide range of COD/BOD ratio had been reported in the literature and all ratios found in the present study are well within this range except for bathroom greywater. Bathroom greywater showed higher biodegradability compared to reported values in the literature. Use of biodegradable detergents might lead to increase in organic fraction of hand basin and bathroom greywater. The present study supports the finding that kitchen greywater is a highly biodegradable source of greywater (Edwin et al., 2014; Friedler, 2004). Kitchen greywater has lower soluble COD

fractions and greater biodegradability due to the presence of biodegradable food particles (Noutsopoulos et al., 2018).

Among the different sources, bathroom and laundry greywater had higher  $\text{NH}_4\text{-N}$  concentration (8.0 and 8.5 mg/L, respectively) compared to other sources. Mean  $\text{NH}_4\text{-N}$  concentration of hand basin and kitchen greywater is within the reported range in the literature (Table 3). Higher  $\text{NH}_4\text{-N}$  concentration in bathroom greywater is due to the use of washing products and traces of urine. Protein containing shampoos and choice of detergents might be the other sources of  $\text{NH}_4\text{-N}$  in bathroom greywater (Jong et al., 2010). Other household products which have ammonia and ammonia containing cleansing products are source of  $\text{NH}_4\text{-N}$  in greywater (Jong et al., 2010). Mean  $\text{NH}_4\text{-N}$  observed in all the greywater sources is within the range reported in the literature (Table 3). Mean concentration of  $\text{NH}_4\text{-N}$  from all sources of greywater falls well within the recommended limit of < 1.0–25.4 mg/L (Radin Mohamed et al., 2013) for reuse in irrigation. Greywater has limited amount of nitrogen which is mainly in particulate form, while in domestic wastewater most of the nitrogen is in soluble form as  $\text{NH}_4$  (Elmitwalli & Otterpohl, 2007). The  $\text{NH}_4\text{-N}$  concentrations from bathroom and laundry were above 5 mg/L, CPCB (2015) and NGT (2018) standards for effluent discharge, while they were within the range for greywater from hand basin and kitchen.

Great variation in  $\text{PO}_4\text{-P}$  concentration in laundry greywater was observed (Fig. 2d). Mean  $\text{PO}_4\text{-P}$  concentration in laundry greywater (15.4 mg/L) was 14 times higher than that in hand basin greywater (1.1 mg/L), about 3 times higher than the mean concentration in bathroom and kitchen greywater. The concentration of  $\text{PO}_4\text{-P}$  from all the sources of greywater was higher than those reported by Chaillou et al. (2011) but lower than those reported by Friedler (2004) and Halalsheh et al. (2008). The observed concentration of  $\text{PO}_4\text{-P}$  in all the greywater sources is much less than those reported by Edwin et al. (2014) while characterising greywater from Indian households. Use of  $\text{PO}_4\text{-P}$  containing detergents, soaps, and other cleaning materials are the sources of  $\text{PO}_4\text{-P}$  in laundry greywater (Shaikh & Ahammed, 2021a). Powdered laundry detergents (used in present study) contain  $\text{PO}_4\text{-P}$  and are often very

alkaline (De Gisi et al., 2016). Sall and Takahashi (2006) reported bathroom greywater as one of the major sources of  $\text{PO}_4\text{-P}$  in greywater. Dishwashing detergents and urine from bathroom are sources of  $\text{PO}_4\text{-P}$  in kitchen and bathroom greywater, respectively (Bakare et al., 2017). The results are in agreement with the observations of Boyjoo et al. (2013) and Oteng-Peprah et al. (2018a).

$\text{PO}_4\text{-P}$  concentration for bathroom greywater determined in this study was much higher than those reported by Antonopoulou et al. (2013) while characterising of Greek households which might be because of much lower quantity of bathroom greywater generated. The concentration of  $\text{PO}_4\text{-P}$  for kitchen greywater found in the present study was higher compared to that of Antonopoulou et al. (2013), indicating the use of phosphorus-containing detergents in the present study. On the other hand, it is much lower compared to the values reported by Friedler (2004). Greywater from all the sources can be reused for irrigation as it falls well within the recommended limit of 0.6–27.3 mg/L (Radin Mohamed et al., 2013).

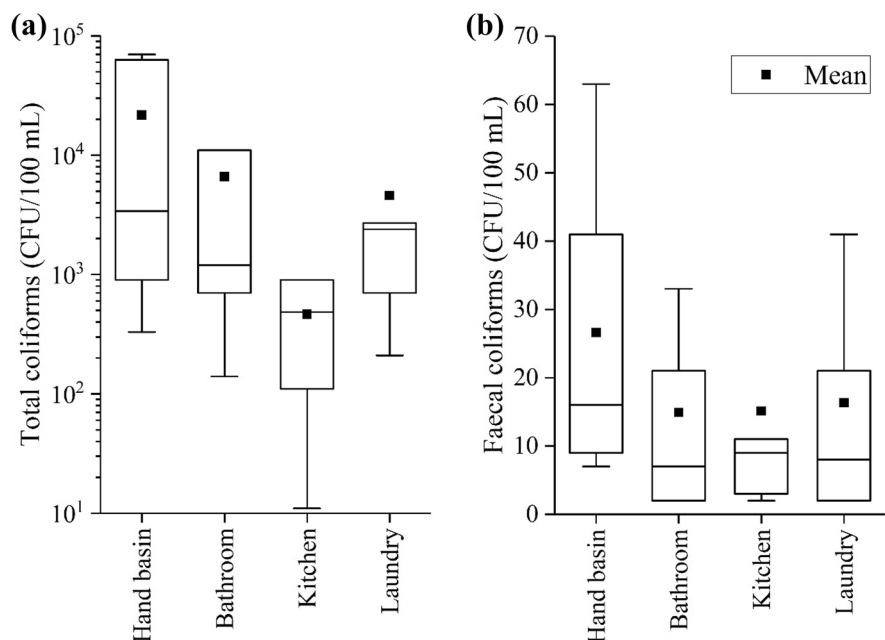
### Microbiological characteristics

Microbial concentration in greywater from different sources is presented in Fig. 3. Total coliforms (TC)

and faecal coliforms (FC) were detected in all the samples tested. TC concentrations were up to 2–3 orders higher compared to FC in different sources of greywater. For example, bathroom greywater had a mean FC concentration of 15 MPN/100 mL while TC concentration was  $6.6 \times 10^3$  MPN/100 mL. Similarly, in kitchen greywater FC and TC concentrations were 15 and  $4.6 \times 10^2$  MPN/100 mL, respectively. The TC concentration of hand basin greywater in the present study is much less than the value ( $1.7 \times 10^6$  MPN/100 mL) reported by Zipf et al. (2016) from a greywater sample collected from a university campus in Brazil. Also, concentrations of TC from bathroom, kitchen, and laundry greywater are less than the corresponding values reported by Katukiza et al. (2015). This can be attributed to low income and less awareness of people in slum area of Uganda where characterisation study was carried out by Katukiza et al. (2015).

As expected, hand basin greywater had the highest mean FC concentration (27 MPN/100 mL) followed by laundry, kitchen, and bathroom greywater (16, 15, and 15 MPN/100 mL, respectively). Washing hands after toilet use might be the reason for higher FC concentration in hand basin greywater (Blanky et al., 2015; Busgang et al., 2015). Observed concentration of FC from all the sources in the present study was much lower than the respective values reported

**Fig. 3** Variation of indicator organisms in different sources of greywater: **a** total coliforms and **b** faecal coliforms



in the literature (Jamrah et al., 2006; Li et al., 2009; Vakil et al., 2014). The greywater from all the sources met the CPCB (2015) and NGT (2018) standards for effluent discharge for FC while TC concentration was above the permissible limits of different standards. Hence, greywater cannot be used without treatment.

*Heavy metals*

Greywater samples from different sources were analysed for six heavy metals, namely copper (Cu), zinc (Zn), chromium (Cr), cadmium (Cd), lead (Pb), and mercury (Hg) (Table 3). Cd, Pb, and Hg were not detected in any of the greywater samples tested, while Cr was found only in laundry greywater. Copper and zinc were present in all the samples tested. The mean concentrations of Cu in hand basin, bathroom, kitchen, and laundry greywater were 26.0, 13.0, 15.5, and 95.5 µg/L, respectively. Mean Cu concentrations in laundry greywater were 3, 7, and 6 times higher than those in hand basin, bathroom, and kitchen greywater, respectively. The mean concentrations of Zn in hand basin, bathroom, kitchen, and laundry greywater were 109.0, 28.5, 98.0, and 1147.5 µg/L, respectively. The mean concentration of Zn and Cu in laundry greywater was significantly ( $p < 0.01$ ) higher than the rest of the greywater sources. Leaching from fittings, pipes, plumbing materials, coatings, and galvanized tanks are the sources of Cu and Zn in greywater (Noutsopoulos et al., 2018). Jewellery and home maintenance products might be another source of Cu and Zn in greywater (Eriksson et al., 2009). Laundry greywater is the major source of heavy metals like Cu, Zn, and Cr and the present results support earlier findings

(Donner et al., 2010; Palmquist & Hanæus, 2005). Detergents and personal care products could also be the sources of metals in greywater (Dwumfour-Asare et al., 2017). Concentration of heavy metals analysed in the present study complies with the WHO drinking water standards (Cotruvo, 2017) and also met the IS 10500 (BIS, 2012) drinking water standards except for Cu in laundry greywater. Studies of metal concentration in greywater reveal that their presence in greywater was unlikely to present any major problem for greywater reuse.

Source separation

*Mass and relative loadings of pollutants originating from different greywater sources*

Table 4 presents the mass loadings from different greywater sources. The mass load of a pollutant was calculated as the product of its mean concentration in each source with its mean volume. Among the different sources, kitchen greywater had the highest mass BOD load of 19.9 g/p/d followed by laundry greywater with 9.4 g/p/d. Mass load for kitchen greywater observed in the present study was greater than 14.9 g/p/d reported by Katukiza et al. (2015) from households of Uganda. Noutsopoulos et al. (2018) also reported much lower organic loads from different greywater sources. This might be because of the higher greywater generation rates in their study. Hand basin and bathroom greywater had mass BOD loads of 1.1 and 3.0 g/p/d, respectively. Mass BOD load for bathroom greywater is much lower than that reported by Noutsopoulos et al. (2018)

**Table 4** Mass pollutant loads from different greywater sources

Parameter	Unit	Present study					Reported values (Katukiza et al. (2015); Noutsopoulos et al. (2018))			
		Hand basin	Bathroom	Kitchen	Laundry	Total	Hand basin	Bathroom	Kitchen	Laundry
BOD	g/p/d	1.1	3.0	19.9	9.4	33.4	3.5	9.6–13.4	14.9–25.0	15.7–23.0
COD	g/p/d	1.2	4.5	34.0	17.5	57.2	4.9	14.0–27.9	24.2–34.0	35.0–62.6
NH <sub>4</sub> -N	mg/p/d	20	150	30	110	310	3	20	6	31
PO <sub>4</sub> -P	mg/p/d	10	120	130	200	460	-	-	-	-
TC	MPN/p/d	1.43 × 10 <sup>5</sup>	1.24 × 10 <sup>5</sup>	1.10 × 10 <sup>4</sup>	6.02 × 10 <sup>4</sup>	3.38 × 10 <sup>5</sup>	-	8.51 × 10 <sup>9</sup>	2.84 × 10 <sup>8</sup>	6.05 × 10 <sup>9</sup>
FC	MPN/p/d	1.75 × 10 <sup>2</sup>	2.81 × 10 <sup>2</sup>	3.48 × 10 <sup>2</sup>	2.14 × 10 <sup>2</sup>	1.02 × 10 <sup>2</sup>	-	-	-	-
Cu	mg/p/d	0.17	0.25	0.36	1.25	2.03	0.09	1.17	0.86	0.71
Zn	mg/p/d	0.72	0.54	2.26	15.07	18.59	0.50	2.70	2.60	3.20

for Greek households and also less than 13.4 g/c/d reported by Katukiza et al. (2015). Very few studies are available in the literature on the mass loads of pollutants from different greywater sources.

Mass COD loads for hand basin and bathroom greywater were 1.2 and 4.5 g/p/d, respectively. Mass COD loads for kitchen and laundry greywater were 34.0 and 17.5 g/p/d, respectively. Results for kitchen greywater are in agreement with Noutsopoulos et al. (2018). Much lower mass load was observed for laundry greywater in the present study compared to the literature (Katukiza et al., 2015; Noutsopoulos et al., 2018).

Bathroom and laundry greywater had higher  $\text{NH}_4\text{-N}$  load with 150 and 110 mg/p/d, respectively, compared to hand basin and kitchen greywaters which contributed only 20 and 30 mg/p/d. As expected, laundry greywater had the highest  $\text{PO}_4\text{-P}$  load of 200 mg/p/d, followed by 130, 120, and 10 mg/p/d from kitchen, bathroom, and hand basin greywater. In the present study, the observed concentration of  $\text{NH}_4\text{-N}$  from different sources of greywater is higher than that of the respective values reported by Noutsopoulos et al. (2018) except for hand basin greywater.

Hand basin and bathroom greywater contributed higher TC load compared to greywater from kitchen and laundry. On the other hand, kitchen greywater was the largest contributor of FC ( $3.48 \times 10^2$  MPN/p/d) followed by bathroom, laundry, and hand basin greywater ( $2.81 \times 10^2$ ,  $2.14 \times 10^2$ , and  $1.75 \times 10^2$  MPN/p/d, respectively). The TC loads found in this study are much lower than the values reported by Katukiza et al. (2015) for respective sources of greywater. No data are available in the literature on the FC load from different sources of greywater.

Laundry greywater had significantly higher mass load of Cu and Zn with 1.25 and 15.07 mg/p/d, respectively, than the rest of the greywater sources. Mass load of Cu from hand basin and bathroom greywater was in the range of 0.17–0.25 mg/p/d, while it was 0.54–0.72 mg/p/d for Zn. Noutsopoulos et al. (2018) reported much higher loads of Cu and Zn from bathroom and kitchen greywater sources compared to the values observed in the present study.

Relative mass loadings were calculated as the ratio of mass loading from a particular greywater source to the total mass loading. Figure 4 illustrates the relative daily pollutant load from different greywater

sources. Hand basin greywater was the major contributor of TC with 42% of total TC mass load, though it accounts for only 11% of total greywater volume. Hand basin greywater was the least contributor of organic content, nutrients, and heavy metals (Cu and Zn) with less than 9% of total mass loading of each of the pollutants. Noutsopoulos et al. (2018) reported mass loading of organic and nutrients between 3 and 7% of total load for hand basin greywater.

Bathroom greywater makes up 31% of total greywater volume and contributed almost half of the total  $\text{NH}_4\text{-N}$  load. This can be attributed to the higher volumetric contribution and traces of urine in bathroom greywater. Bathroom greywater was the second highest contributor of TC mass load after hand basin greywater, accounting for 37%. It also contributed 25 and 28% of total  $\text{PO}_4\text{-P}$  and FC mass loading and less than 10% of total mass load of organic content, Cu, and Zn considered in present study. LGW sources are the major contributors of microbial load and least contributors of organic content and heavy metals and the results are in consistent with Noutsopoulos et al. (2018) who characterised greywater from Greek households and reported LGW contributed 18–29% of all pollutants considered in their study.

While kitchen greywater contributes 37% of total greywater volume, it accounts for about 60% of total mass loadings of BOD and COD and thus is the



**Fig. 4** Relative load contribution from different greywater sources

major contributor of organic content. Results are in line with Noutsopoulos et al. (2018) who reported 41% of the total BOD mass load being contributed by kitchen greywater. Results are also in consistent with Vakil et al. (2014) who reported 36 and 45% of total mass loadings of BOD and COD were contributed by kitchen greywater while accounting for 44% of total greywater volume. Similarly, Friedler (2004) reported that 48 and 42% of total BOD and COD mass load were contributed by kitchen greywater. Kitchen greywater was also a major contributor of FC with a 34% of total FC loading contribution. On the other hand, kitchen greywater contributed very little to  $\text{NH}_4\text{-N}$ , TC, Cu, and Zn with 9, 3, 18, and 12% contribution of total mass loadings of respective pollutants.

Laundry greywater makes 21% of the total greywater generated, but it contributes 44, 62, and 81% of total mass loadings of  $\text{PO}_4\text{-P}$ , Cu, and Zn. It is also a major contributor of organic content and  $\text{NH}_4\text{-N}$ . Laundry greywater was second major contributor of total organic load after kitchen greywater. Noutsopoulos et al. (2018) reported that 40% and 52% of total mass loading of COD and ammonia was contributed by laundry greywater. About 56 and 33% of total mass loading of BOD and COD were contributed by laundry greywater in a study conducted by Vakil et al. (2014) in a single Indian household and reported 24% share of laundry greywater of the total greywater volume. Laundry greywater contributed 21% of total mass loading of FC which is similar to 27% reported by Vakil et al. (2014).

While LGW contributed only 10–12% of the total mass loadings of organic content of greywater, the DGW accounts for 88–90%. Noutsopoulos et al. (2018) reported LGW contributed only 15% of total organic load and accounts for 50% of total greywater volume, and similar results are obtained in the present study. Vakil et al. (2014) reported that LGW sources accounted for 33% of greywater volume but contributed only 8% and 22% of total mass loadings of BOD and COD, respectively. Dark greywater sources contributed 88% of total mass loading of BOD which are in line with 92% as reported by Vakil et al. (2014) while characterising greywater from Indian household. The LGW sources contributed only 2–25% of total mass loading of  $\text{PO}_4\text{-P}$  and 3–12% of total mass loadings of heavy metals. LGW is significantly less polluted than DGW for all pollutants except microbial load.

### *Effect of source separation*

Figure S3 represents the net volume available after exclusion of mass source or group of sources of greywater as a proportion of the original total discharge. In order to study the effects of source separation, six different scenarios were evaluated. In each case at least one source of greywater is excluded from total greywater and its effects on volume and pollutant mass loads were calculated. The idea behind partial source exclusion is to explore the net greywater discharge available for reuse and the pollutant load reduction.

Available greywater volume was reduced by 11% after exclusion of hand basin greywater. Hand basin has been neglected as a major source of greywater by many researchers (Dwumfour-Asare et al., 2017). Hand basin greywater contributed 42 and 17% of total mass loadings of TC and FC. Exclusion of hand basin greywater does not contribute much to pollutant load reduction as it is left with 97% of BOD, 98% of COD, 94% of  $\text{NH}_4\text{-N}$ , 98% of  $\text{PO}_4\text{-P}$ , 92% of Cu, and 96% of Zn load. Hence exclusion of hand basin greywater is not recommended.

Separation of bathroom greywater significantly reduces volume by 31%. Though exclusion of bathroom greywater reduces pollutant mass load of  $\text{NH}_4\text{-N}$ , TC, and FC to 51, 63, and 72%, respectively, 91, 92, 75, 88, and 97% of total mass loadings of BOD, COD,  $\text{PO}_4\text{-P}$ , Cu, and Zn, respectively, remain after the separation and hence separation of bathroom greywater is not recommended.

Separation of kitchen greywater results in major impact both on proportional discharge and proportional mass load of different pollutants. Kitchen greywater is a significant contributor of greywater volume along with organic content and FC in greywater. Exclusion of kitchen greywater from the rest of the greywater results in reduction of available discharge volume by 37%, but simultaneously 60, 59, 29, and 34% of total mass loadings of BOD, COD,  $\text{PO}_4\text{-P}$ , and FC were reduced. Exclusion of kitchen greywater also reduces the load of Cu and Zn. Therefore, exclusion of kitchen greywater is recommended as it is a major contributor of total mass of organic content,  $\text{PO}_4\text{-P}$ , and FC.

Exclusion of laundry greywater leads to 36, 44, 62, and 81% reduction of  $\text{NH}_4\text{-N}$ ,  $\text{PO}_4\text{-P}$ , Cu, and Zn mass, respectively, though reduction in discharge



volume is only 21%. Separation of laundry greywater reduces BOD and COD mass loadings by 28 and 31%, respectively. Exclusion of laundry greywater does not significantly influence the microbial load. As laundry greywater is a major contributor of organic content, nutrients, and heavy metals, exclusion of the same while designing the treatment system is highly recommended.

Separation of LGW sources (hand basin and bathroom) reduced the available volume to 58% but available mass loading for BOD, COD,  $\text{PO}_4\text{-P}$ , Cu, and Zn still remain as 88, 90, 73, 79, and 93%, respectively, of original pollutant mass loadings. In contrast, separation of DGW sources (kitchen and laundry) reduced available discharge by 58% but net pollutant mass load is reduced to 12%, 10%, 27%, 21%, and 7% for total BOD, COD,  $\text{PO}_4\text{-P}$ , Cu, and Zn, respectively. Separation of DGW sources is beneficial but microbial threat still exists as LGW sources are rich in microbial concentration (Noutsopoulos et al., 2018; Shaikh & Ahamed, 2021b). This analysis clearly indicates the importance of source separation in terms of proportional discharge and proportional load calculation.

Toilet flushing and garden irrigation are the most feasible greywater reuse options at present. Toilet flushing and garden irrigation will not require water of potable quality and so the required degree of treatment is limited. The demand for recycled greywater for toilet flushing and garden irrigation in urban areas is estimated to comprise about 9–46% of the generated greywater (Boyjoo et al., 2013; Friedler, 2004). Reuse of greywater (after treatment) for toilet flushing could considerably reduce the water demand (Alfiya et al., 2018). The quantity of greywater generated in the present study could be enough for toilet flushing, and this could reduce water demand by at least 30–38% (De Gisi et al., 2016; Dwumfour-Asare et al., 2017).

When demand for recycled greywater is lower than the generated greywater, it is better to choose among the different greywater sources to be treated for recycling purpose rather treating the whole greywater. Light greywater accounts for almost half of the total greywater generated. The quantity of LGW generated will satisfy the requirements for toilet flushing and LGW can be treated on-site, while DGW along with blackwater stream can be discharged into municipal sewer system. This will help reduce cost of on-site

treatment and will reduce potential of negative health, environment, and aesthetic effects.

## Concluding remarks

Detailed quantity and quality characterisation of greywater from different sources of an Indian household was undertaken and the effect of source separation on greywater discharge and pollutant load contribution was assessed. The total greywater generation observed in the present study was 62 L/p/d which was above the minimum recommended limit of 30 L/p/d and was higher than the values reported from some of the low-income countries and lower than those from high income countries. Volumetric contributions from hand basin, bathroom, kitchen, and laundry were 11, 31, 37, and 21%, respectively.

Pollutant load in LGW is much lower compared to DGW and can be treated by simple treatment systems, implying that about half of the greywater can be reused economically, reducing the load on centralised treatment plants. Greywater from kitchen contributes to over half of the organic load followed by laundry, bathrooms and hand basin greywater. High volume and pollutant load contribution of kitchen greywater make it a source of concern. LGW sources (hand basin and bathroom) were the major contributors of microbial load in terms of TC. Exclusion of bathroom greywater reduces greywater volume considerably but reduction in pollutant load is insignificant, making it the most undesirable selection. Laundry greywater contains high metal and  $\text{PO}_4\text{-P}$  content, the use of which for garden irrigation in the long term could lead to salt accumulation in the soil and stunting of plants with low  $\text{PO}_4\text{-P}$  tolerance.

Separation of greywater from different sources is recommended. If the demand for treated greywater is less than greywater production, instead of treating mixed greywater or DGW, the less-polluted ones (LGW sources) can only be treated on site and heavily polluted sources together with blackwater can be discharged to the municipal sewer system. Separation of kitchen and laundry greywater is beneficial as it reduces pollutant load considerably though reduction in volume of greywater generation was observed. LGW contains only 12, 10, 27, 21, and 7% of total mass loadings of BOD, COD,  $\text{PO}_4\text{-P}$ , Cu, and Zn, respectively. Since greywater quantity and quality



characteristics of a household, apartment, or community fluctuate considerably with time, simple treatment techniques which are least affected by these fluctuations are to be chosen for treating greywater.

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**Author contribution** INS performed the experiments and analysed the results. MMA guided the whole study and was a major contributor in preparing the manuscript. All authors read and approved the final manuscript.

**Availability of data and material** All relevant data are included in the paper or its Supplementary Information.

**Declarations**

**Ethics approval** Not applicable.

**Consent for publication** Not applicable.

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