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A Study of Characteristics of Greywater Generated from Different Sources of Residential Buildings

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Abstract: The objective of this study is to show how the characteristics of tap water influences the characteristics of the greywater generated from kitchen, bath shower, wash basin, and laundry apart from the usage pattern. Various quantitative techniques have been used to measure pH, alkalinities, hardness, total solids, total suspended solids, total dissolved solids, dissolved oxygen, biological oxygen demand, chloride, and electrical conductivity of greywater and tap water. The study shows that greywater generated from the laundry is more polluted as compared to greywater from other sources, which is due to body fluids. The presence of food particles gives a high level of total suspended solids in the greywater coming from the kitchen. The greywater generated from brushing has a low pollution level and lower quantity of total solids, total suspended solids and total hardness as compared to greywater from other sources. The BOD levels for the greywater samples collected are in the range of 2.5 -20.25 mg/L and their quality is also affected by the quality of tap water. These findings show that greywater generated in residential buildings of Jeddah can be reused for non-potable purposes with simple and inexpensive physical treatment at individual buildings.

Key words: Characteristics, greywater, laundry, kitchen, bath shower, wash basin.

Introduction

The sustainability of potable water is the need of the world today as in most countries underground water resources are depleting due to excess use and climate change. The depletion of water resources needs immediate measures. The only solution is to recycle and reuse greywater. There has been a 55% drop in globally available fresh water per capita since 1960 as per Food and Agricultural Organizations of the United Nations (2017) calculated from FAOAQUASTAT. Globally, it is estimated that around 6 billion people will suffer from water scarcity by 2050, and at present, 3.6 billion people or 47% are living in areas with sufficient water scarcity for at least 1 month per year, as per the 2018 edition of United Nations World Water Development Report, Nature based solution for water (NBS). Water scarcity currently affects more than 40% of the global population as per United Nations, Sustainable Development goals, No. 6 (n.d.) Clean Water and Sanitation. By 2050, an additional 2.3 billion people can be expected to be living in areas with severe water stress, especially in North and South Africa and South and Central Asia as reported by Guppy et al. (2017). In lower-middle-income countries, only 28% of wastewater is treated, and in low-income countries, only 8% of industrial and municipal wastewater undergoes treatment of any kind as reported in WWAP – World Water Assessment Programme, United Nations World Water Development Report (2017). To maintain the availability of water, it is highly necessary to incorporate the best wastewater management at the community level and which is possible by reuse of the greywater generated from the kitchen, laundry, bath shower and wash basin. The quantity of greywater generated from different sources can be calculated by different methods; one of them is the product of the duration of use of each source tap and its flow rate which is measured at each source, as suggested by Noutsopoulos et al. (2018). About 25-30% of potable water consumption can be reduced by the reuse of greywater GW as per Vuppaladadiyam et al. (2018).

In the present study, the focus is on finding the effect of the quality of tap water on the characteristics of greywater samples from different sources of residential buildings. Based on the constituent, greywater is classified as light grey water and dark greywater as given by Albalawneh and Chang (2015). The greywater outsourced from bath-shower and wash basin water is light greywater, while the greywater coming out from the kitchen and laundry is known as dark greywater. The percentage of greywater generated from various sources is different in high income countries (HIC'S) and the low-income countries (LIC'S). This clearly shows that the percentage increases with an increase in the income level of the people and the quantity generated from different sources also vary in these countries as reported by Shaikh and Ahmmed (2020). The quality of greywater is influenced by a large number of factors, which include habits and lifestyle of occupants, water source, geographical location, demographics, plumbing system, and source of GW such as domestic or commercial as given studied by Gisi et al. (2015).

Bath-shower constitutes 45-48% of total greywater generated in a household and it includes soap, shampoo, body fluids and body care products. The wash basin constitutes 7-10% of total greywater and it includes toothpaste, hand wash, shaving cream and sputum. The kitchen water constitutes approximately 15-20% and contains food particles, fats, oil, dishwasher soap, bleach, and insecticide. The laundry water constitutes approximately 25-28% of the total greywater, which contains chemicals such as phosphates, polyphosphates, nitrogen compounds, alkaline materials such as sodium silicates, sodium carbonate, and sodium perborate as well as bleaches.

The main aim of this study is to characterise greywater based on its output from different sources, and also study the effect of quality of tap water on the characteristics of the greywater in addition to other factors, suggesting the possible reuse of greywater.

Materials and Methods

Sample Collection and Preservation

The greywater samples were collected from kitchen, laundry, bath-shower and wash basin at different residential locations along with the tap water samples. The collection and preservation were done manually, and the minimum size of the sample is 1 litre, as given by Khan and Kaafil (2020).

Analysis of Samples

The methods used in testing different characteristics of greywater and tapwater such as alkalinity, total solids (TS), total dissolved solid (TDS) and total suspended solids (TSS). Electrical conductivity (EC), Total hardness, chloride, Dissolved Oxygen (DO) and Biological Oxygen Demand (BOD) of samples collected from various sources were calculated suggested by Kori (2011).

The pH of samples collected is measured immediately using a calibrated pH meter, which is calibrated using: buffers of pH= 4 (HACH), pH =7 (Panreac) and pH=10 (Panreac).

Total alkalinity is determined by potentiometric titration using calibrated pH meter and standardised H_2SO_4 which is standardised using sodium carbonate. All the solutions are prepared in distilled water free from carbon dioxide. The volume of H_2SO_4 required to reach pH 4.5 is the basis of calculating the total alkalinity (mg) of $CaCO_3$. The samples used are 50 cm^3 for the determination of alkalinity. The alkalinity is also determined using the titration method using phenolphthalein and methyl orange indicators.

Total hardness of $CaCO_3$ of kitchen, laundry, bath shower, wash basin and tap water are determined using the EDTA method with standardised EDTA solution, (standardised against the calcium ion solution and Eriochrome Black T) as shown in Figure 1. The hardness of the reagent blank is determined which is redistilled water used for the preparation of different solutions. The hardness content of tap water samples of different regions is determined by the same method along with the greywater samples of those regions

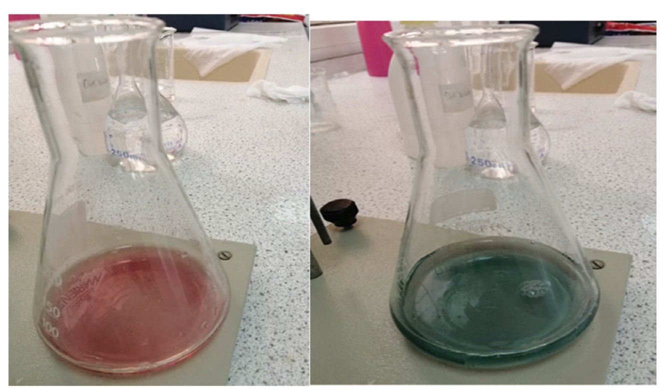

Figure 1: Standardization of EDTA for hardness.

respectively. All the collected samples for hardness are acidified to less than pH2 using H_3PO_4 or HNO_3.

The alkaline hardness is carbonate hardness, and the non-alkaline hardness is noncarbonate hardness. When the total alkalinity expressed as $CaCO_3$ is less than total hardness, then alkaline hardness is equal to total alkalinity, while non-alkaline hardness is calculated by subtracting total alkalinity from total hardness. Such samples contain carbonate and noncarbonate hardness. If the total alkalinity as $CaCO_3$ is greater than the total hardness, then alkaline hardness is equal to total hardness and the non-alkaline or noncarbonate hardness is absent. The hard cations present in samples with chloride, sulphates or nitrates result in permanent hardness.

Total solids (TS) by electrical heating at 104°C, total dissolved solids (TDS) are measured using HANNA TDS meter (H198312) for all the grey water samples as well as for tap water and Total Suspended Solids (TSS) is then calculated by subtracting TDS from TS.

The chloride content of various greywater and tap water is determined after checking for residual chlorine by the argentometric method.

BOD of kitchen, laundry, bath shower, wash basin and tap water is calculated by measuring the dissolved oxygen immediately after collection of samples for 0 days and 3 days at 27.5ºC as per Kori (2011). The dissolved oxygen for dilution water is also determined simultaneously to find BOD.

$$\text{BOD} = \frac{(D_1 - D_2)}{P}$$

D_1-= Dissolved oxygen of sample zero days

D_2 = Dissolved oxygen of sample 3 days at 27.5ºC

P = % dilution

All the characteristics of the greywater samples are compared with the tap water samples of the same area collected on the same day and time to make results more reliable. Two different regions are selected for study and a maximum of 20 samples are collected from each region to calculate the average values for all the parameters.

Results and Discussion

The variation of pH of greywater samples from different sources is given in Figure 2. The pH of laundry is alkaline, and it is due to the presence of alkaline materials used in detergent as stated by Oteng-Peprah et al. (2018). The kitchen water is weakly acidic may be because of the type of dishwasher or may be due to weakly acidic tap water and the pH of the bath shower and wash basin are in the neutral range for all the samples of different regions.

Figure 3 shows the average total alkalinity of greywater and tap water sample collected from different sources and different regions. Kitchen, bath shower, wash basin and tap water samples give no colour with phenolphthalein, which means that carbonate (CO_3^{-2}) and hydroxide (OH^-) ions are absent and the alkalinity is due to hydrogen carbonate (HCO_3^{-1}) only. Whereas the laundry samples tested for alkalinity gives pink colour with phenolphthalein indicating that the laundry samples are alkaline inferring the presence of both carbonate (CO_3^{-2}) and hydrogen carbonate (HCO_3^{-1}). The types of alkalinities present in different water samples are given in Table 1.

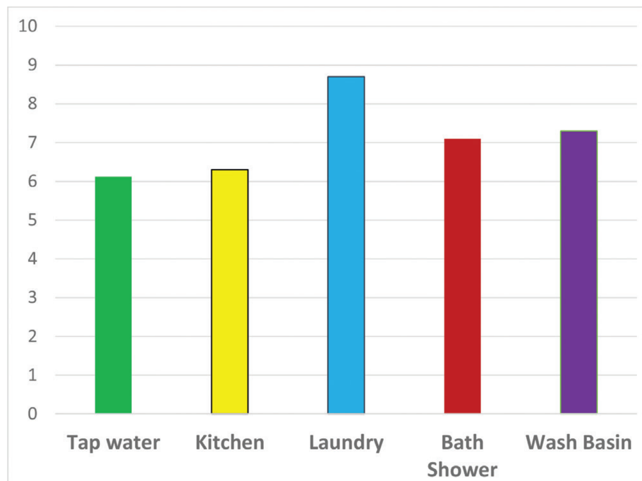

Figure 2: pH of the water samples from different sources.

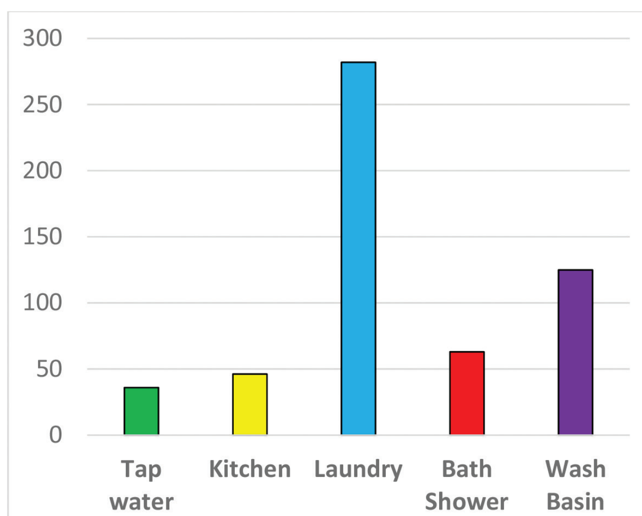

Figure 3: Total alkalinity (mg of $CaCO_3^{-2}$/L) of water samples collected from different sources.

Table 1: Types of alkalinities in water samples from different sources

Water samples	*Hydroxide alkalinity (OH^-)/ mg/L*	*Carbonate alkalinity (CO_3^{-2})/mg/L*	*Hydrogen carbonate alkalinity mg/L*	*Total alkalinity in hydrogen carbonate (HCO_3^-)/mg/L*	*Total alkalinity in mg $CaCO_3$/L*
Tap water	0	0	36	43.92	36
Kitchen	0	0	46.2	56.38	46.2
Laundry	0	96	186	344	282
Bath Shower	0	0	63	76.86	63
Wash Basin	0	0	125	152	125

The average total hardness of tap water and greywater samples from different sources are shown in Figure 4, and it is found that greywater samples have more hardness than tap water except bath shower because of the water softening agents used in shower gels, soap and shampoo. The total hardness of the greywater from kitchen, bath shower and wash basin and tap water is more than the total alkalinity expressed as calcium carbonate mg/L, whereas the greywater from laundry has a total hardness less than total alkalinity. This indicates that the laundry water has only carbonate hardness, suggesting the absence of permanent hardness. This may be due to the chemical properties of detergent which help to remove the permanent hardness of water.

The kitchen, bath shower, wash basin and tap water samples show the presence of both carbonate and non-carbonate hardness. This means that the washing materials used cannot remove the permanent hardness. The type of hardness found in different water samples is listed in Table 2.

Figure 5 shows a comparison of total solids (TS) present in different greywater samples. Kitchen water contains the highest quantity of total solids compared to greywater from other sources and it is mostly in the form of total suspended solids (TSS) as given in Figure 6. The laundry samples have more total solids (TS) than bath shower and washbasin and it is in the form of total dissolved solids (TDS) as shown in Figure 7. This may be due to the properties of detergent which

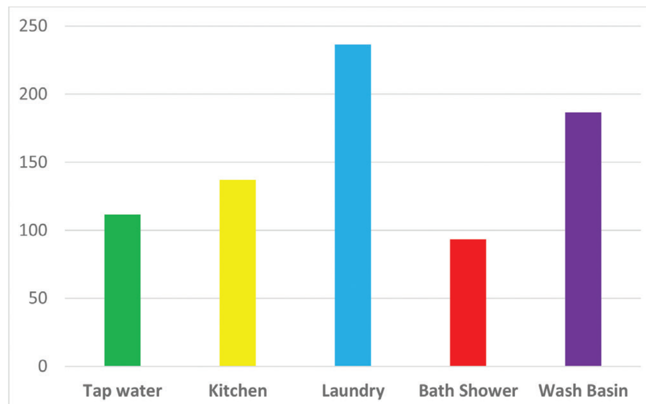

Figure 4: Total hardness (mg of $CaCO_3^{-2}$/L) of the water samples from different sources.

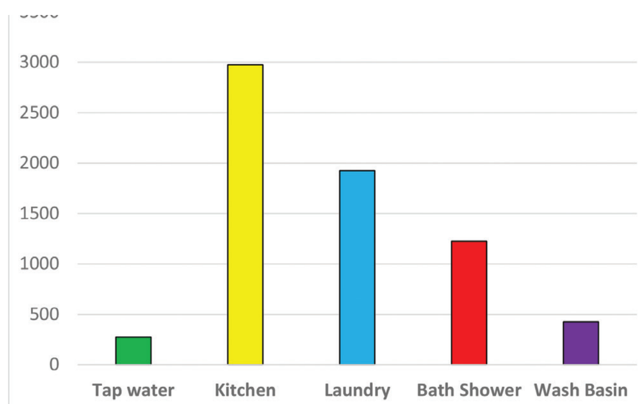

Figure 5: Total solids (mg/L) of the water samples collected from different sources.

Table 2: Types of hardness in water samples from different sources

Types of water	*Total hardness ($CaCO_3$) mg/L*	*Carbonate hardness mg/L*	*Non-carbonate hardness mg/L*
Kitchen	137	46.2	90.8
Laundry	236.5	236.5	0.0
Bath Shower	93.3	63	30.3
Wash basin	186.55	125	61.55
Tap water	111.46	36	75.46

chemically reacts with the insoluble impurities and make them soluble. The bath shower samples have more total solids than wash basin and mostly it is in the form of total suspended solids (TSS). The wash basin samples have the least total solids (TS) compared to the greywater from different sources (Figure 5) and have an equal amount of total dissolved solids (TDS) and total suspended solids (TSS) (Figures 6 and 7). The electrical conductivity of different water samples is shown in Figure 8, which shows the highest electrical conductivity value for laundry, which means a high quantity of dissolved solids compared to other greywater samples. This also means it has a greater number of ions which are generally chloride, sulfates, phosphates, carbonates, or hydrogen carbonates. The laundry water is found to have more alkalinity and more chloride as well.

All the greywater samples from different sources show the absence of residual chlorine and the chloride (Cl^-) content is higher compared to the tap water as shown in Figure 9. The laundry samples show a large increase in chloride content followed by the kitchen then wash basin whereas the bath shower has the least

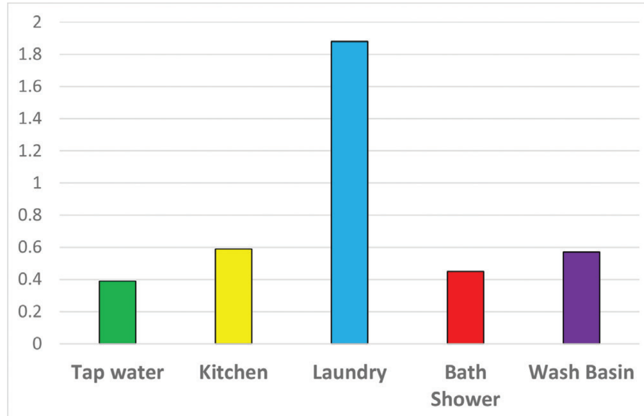

Figure 8: Electrical Conductivity (mS/cm) of the water samples collected from different sources.

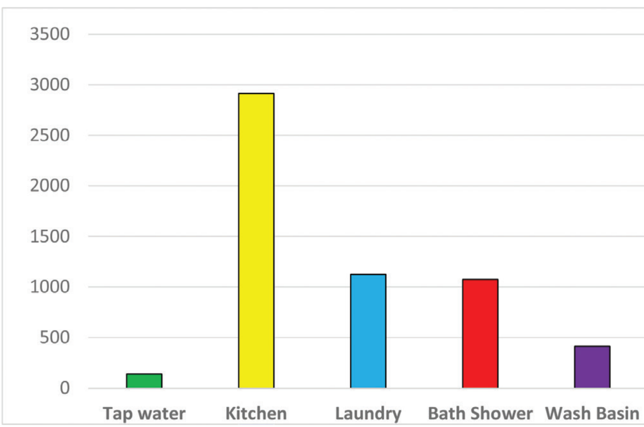

Figure 6: Total suspended solids (mg/L) of the water samples collected from different sources.

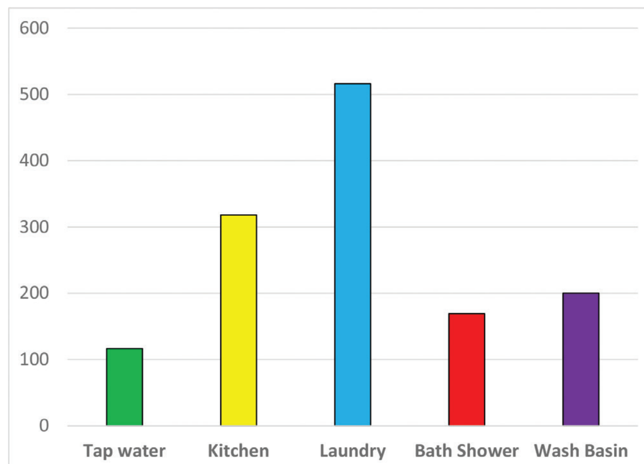

Figure 9: Chloride (mg/L) of the water samples collected from different sources.

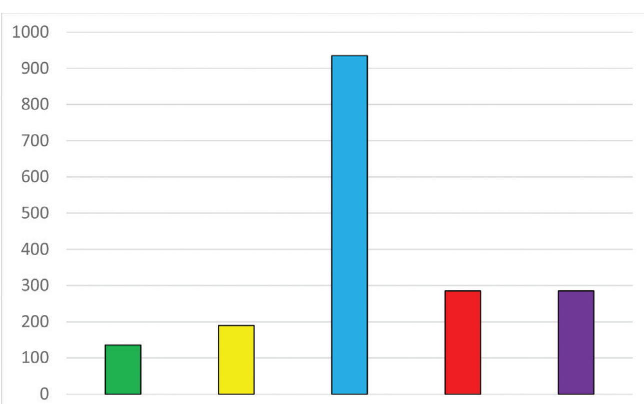

Figure 7: Total dissolved solids (mg/L) of the water samples collected from different sources.

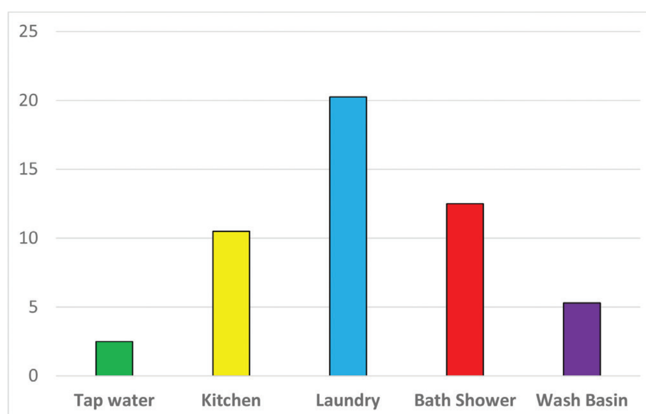

Figure 10: BOD (mg/L) of the water samples collected from different sources.

increase. More chloride content of tap water proves that the water is well chlorinated and the increase in chloride of various greywater samples is due to the type of washing liquids and detergents used.

From Figure 10, it is concluded that the biological oxygen demand (BOD) level of laundry samples and bath shower is higher than kitchen, and wash basin. This shows the presence of more aerobic bacteria in the laundry and bath shower samples compared to other greywater samples. The main bacterial source is body fluids such as sweat and other fluids. The BOD is least for washbasin samples which may be due to the use of antibacterial chemicals in hand wash, tooth paste and shaving cream.

Table 3: Comparison of characteristics of greywater with available data*

Parameters	*Different sources of sample*				
	Tap water	*kitchen*	*Laundry*	*Bath shower*	*Wash basin*
pH					
Author	6.1-6.14	5.80-6.68	8.50-8.70	6.80-7.36	6.74-7.45
Abeer				6.40 -8.10	6.60-7.60
Irshad (LIC)		5.58-6.20	9.40-9.60	6.30-6.73	6.5-7.1
Md.Ashique			6.67	7.05	
Parameshwar		6.2	9.4	7.5	7.5
Golda	7.1	6.9	9.1	7.4	7.2
TDS/mg/L					
Author	135.6	190	935	285	285
Abeer					
Parameshwar		245	1060	277	237
Golda	154.8	633	710.4	287.8	473
TSS/mg/L					
Author	140	2915	1125	1075	415
Abeer				48-120	14-15
Irshad (LIC)		308-644	760-1852	101-206	
Parameshwar		308	1852	148	48
Golda	21.1	398.7	141.2	122.7	89.2
TS/mg/L					
Author	275	2975	1925	1225	425
Golda	28.7	1468.4	586	425	450.3
BOD/mg/L					
Author	2.5	10.5	20.25	12.5	5.3
Abeer				23-200	42-130
Irshad (LIC)		293-1100	269-1266	81-271	35-92
Md.Ashique			299	143	
Parameshwar		293	269	81	43
Golda	226	932.4	186.5	135	138.7
Chloride/mg/L					
Author	116.5	318	516.5	164	200
Golda	18.3	63.5	37.3	11.5	11.7
Total Hardness/mg/L					
Author	111.46	137	236.5	70.3	186.5
Golda	97.2	357.8	721	49.2	47.2

* *Source*: Ahmed et al. (2018), Albalawneh and Chang (2015), Golda et al. (2014), Parameshwar et al. (2016) and Shaikh and Ahmmed (2020).

The lower BOD level in our greywater samples may be due to the lower BOD level of tap water which may be due to enough chlorination of tap water, and which is evident from the high chloride content of tap water samples as the source of tap water is from desalination of sea water. In addition to this, the lower BOD of our kitchen samples may be due to the water collected in the morning from the vegetarian kitchen.

Comparison with the Available Data

An attempt has been made in this study to compare the characteristics of greywater with the available results (Ahmed et al., 2018; Albalawneh and Chang, 2015; Golda et al., 2014; Parameshwar et al., 2016; Shaikh and Ahmmed, 2020), which is given in Table 3. From the studies, it is found that some parameters such as pH and total hardness comply whereas total solids, total dissolved solids, BOD and chloride content show variation. The total solids and chlorides are very high, and BOD is very low in the greywater samples analysed compared to the available data. These variations are due to various reasons and some of them are source, region and habits of the occupants and quality of tap water.

Conclusion

The greywater from the kitchen is weakly acidic, laundry alkaline and other greywater samples are neutral. Laundry samples are alkaline in nature as they have carbonate (CO_3^{-2}) and hydrogen carbonate (HCO_3^{-1}) ions and other greywater samples contain only hydrogen carbonate (HCO_3^{-1}), this means that laundry water has buffering action. The greywater from laundry has only carbonate hardness while non-carbonate hardness is absent, which is generally due to ions such as calcium, and magnesium. The greywater samples from other sources have both carbonate and non-carbonate hardness. The greywater from the kitchen has more total solids and it is mostly suspended in the sample which decreases the clarity of greywater. The BOD levels of greywater from different regions and different sources are much lower than those reported till now.

The low level of organic pollutants in the analysed greywater received from wash basin, bath shower and kitchen constitutes almost 60-70% of total greywater generated in residential buildings, which indicates that it requires only physical treatment before reuse. This will save high energy and the cost of desalination. The characteristics of the greywater from various sources are better compared to countries which are due to the good quality of tap water and the lifestyle. This makes it possible to recycle the greywater in individual buildings.

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