Greywater Characteristics and Potential Use for Toilet Flushing in Aqaba City

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Abstract- Knowing greywater characteristics is essential to evaluate the potential for reuse and to determine the appropriate treatment system. This research was carried out to estimate the quantity and analyze the quality of greywater generated in the urban city of Aqaba. The results revealed, that an average of 107 Lpcd was generated which is the largest recorded so far in Jordan comparing to other urban cities. Greywater compromises 53% of total fresh water consumption and 75% of total households' wastewater. The study also showed that no less than 17% of fresh water can be saved when reusing greywater for toilet flushing, this amount can reduce extraction of Al-Disi aquifer or desalinate water which may shifted to serve other cities in the kingdom. Average concentrations of COD, BOD, TSS, NO_3-N, NH_4-N, TN, and pH during the time of analysis of 24-hour were 962, 253, 212, 2.5, 2.1, 5.3 mg/L and 7.5 respectively which indicates strong greywater. In Aqaba, 64% of the citizens were positive to reuse greywater for toilet flushing and other public using, such as street cleaning, landscape and greening, for different reasons such as increase water saving, reduce water bill, and wastewater discharge to the environment while the main driver for recycling was the water shortage.

Index Terms- Greywater, quantity and quality; Residential, Jordan, Reuse, Acceptance

I. INTRODUCTION

Considered the second poorest country with respect to water in the world, the kingdom of Jordan with an area of about 90,000 km^2 and a population around 10 million[1] which lies among the dry and semi- dry climatic zone is characterized by its minimal volumes of rainfall and high percentage of evaporation. The maximum annual precipitation is about 600 mm in the northwest highlands while in the southern areas the precipitation is less than 50 mm. According to the Ministry of water and irrigation 2017, approximately 93.5% of the rainfall evaporates, 4.4% recharges the groundwater, and the rest 2.1% finds its way to the surface water. In 2003 the residential water supply level was in the range of 60-70 Lpcd, and increased to 125 Lpcd, meanwhile the internationally accepted level is 200 Lpcd to ensure healthy and adequate life [2][3].

As the water demand-supply gap is increasing in the kingdom[4], an alternative water resource is essential to bridge that gap. Treated wastewater is already contributed to the water budget as Jordan among the top countries reusing wastewater. There are now 23 wastewater treatment plants (WWTPs) treating domestic wastewater in different types of treatment systems, these systems are divided into trickling filters, activated sludge and waste stabilization ponds. Although wastewater reuse recognition is growing and the amount of reclaimed water produced is increasing (163 Million Cubic Meter (MCM) of wastewater was treated in 2017 comparing to 98 MCM in 2007) [2], the use of reclaimed water still limited to irrigation and cooling in industry where standards and regulations are available. As to other usages, such as residential and public toilet flushing and landscapes, greening, street washing, few successful project were reported.

Greywater has become increasingly popular in the world as unconventional source of water for its economic and environmental benefits [5]. Greywater is the domestic wastewater excluding that generated from toilets [6][7][8], and in some cases kitchen [9]. It constitutes about 50 to 80% of the total households' wastewater [9] and usually contains fewer pollutants than raw wastewater. With an adequate treatment, and if used for toilet flushing, greywater can reduce water demand by 30% up to 45% of a typical household freshwater, if the use in irrigation and laundry are added [8] [10]. A study conducted in Syria showed that using treated greywater for toilet flushing could save about 35% of the drinking water [11].

Although greywater reuse is not a new topic to Jordan, it has been practiced on a small scale only (within a single house or small public establishment), for the reasons to conserve much water and save money. A study conducted by the "Center of the Study of the Built Environment" (CSBE) in 2002, revealed that on-site greywater in domestic context was used directly without biological treatment (sometimes mechanical filtration) and mainly for landscaping and restricted agriculture in different Jordanian villages and cities, as many of the substances contained in greywater are not harmful to plants, and some are actually plant nutrients. For example, in rural area in the north Jordan, a house owner has diverted greywater directly to irrigate his olive trees after storing it in a reservoir in his backyard. Furthermore, in the capital city of Amman another greywater system was introduced in a dual-plumbed house where underground collection tank and filtration system were installed. Grey water (excluding kitchen sink) were collected, filtered and used in irrigation [12].

Wastewater characteristics are well known and available in Jordan, however, there is lack in data of greywater. Knowing grey water characteristics is essential for the design and constructing of proper reusing treatment unit, and necessary for the assessment of environmental impact and the energy potential of its maintaining, thus, the objectives of this research is (i) to estimate the quantity of greywater produced in the urban city of Aqaba, (ii) seek potentials of using reclaimed greywater for toilet flushing or other potential using and fresh water saving, (iii) investigate the quality of greywater and its variation during the whole day, (iv) and to investigate the social acceptance toward reusing reclaimed greywater for toilet flushing in Aqaba.

II. METHODOLOGY

Study cite, Aqaba City:

Aqaba City in the far south is the only costal city in Jordan, from which it gains its strategically importance for the presence of the only port and being the main touristic city. With a population of about 198,500 capita and an area of about 375 square kilometer [1], Aqaba is privileged to be the only city in the kingdom with a continuous water supply where it relies entirely on Al-Disi aquifer for its fresh water use. The current per capita consumption of water is around 202 Lpcd as indicated from "Aqaba Water", and is expected to rise with the growing population and infrastructure. 5 (MCM) of expensive desalinated water (JOD 0.8/m^3 of desalinated water to 0.30-0.50/m^3 of fresh water) is being provided to the city each year since 2016 to decrease the water deficit gap. However, while the water demand still exceeds the supply, there is an urgent need to introduce a sustainable water resource such as wastewater.

In Aqaba, there is only one centralized wastewater treatment plant is treating water using waste stabilization ponds (WSP) as an ecological process, and activated sludge (AS) for the biological process. It has received about 7 MCM of wastewater in 2015 of which 2.5 MCM and 4.5 MCM entering the ecological and the biological plants respectively, About two-thirds the amount of incoming water to the biological treatment plant is treated and pumped into the distribution network and sold to beneficiaries, furthermore, industrial and agricultural sectors are benefiting from all of the reclaimed water produced by the mechanical treatment plant [13]. A project for expanding the plant is coming on the stream to increase the treatment capacity to meet the increasing of wastewater production especially in tourist season where over 500,000 visitors in the city exert numerous pressures on both the water supply system and wastewater production, while the first "nutrients recovery" workshop is being established.

Greywater can be a reliable and sustainable water resource which may produce more fresh water to be used, thus increase the standards of life of people lives in the city of Aqaba and reduce demand-supply gap. By allocating more fresh water to Aqaba citizens, the abstraction of "Al-Disi" aquifer, or desalinated water can be reduced or shifted to serve other cities in the kingdom which may increase the available water for citizens there.

Greywater Characteristics: Quantity

Greywater generated quantity was measured by the similar methodologies applied by (Mourad et al) & (Rezaul et al), where a survey questionnaire and personal interviews were conducted during the period from June through August 2018. The representative sample was calculated using the following equation [11] [14] [15]:

$$n \geq (1/\mathcal{E}^2)N/ (1/\mathcal{E}^2+N)$$

where:
n: sample size
N: population
$\mathcal{E}$: sample error from 1% to 20%

Taking the total population of the city and assuming 10% sample error, 100 responses were needed by the equation above. Chosen randomly; 50% were men and 50% were women to ensure gender equality. The interviews took place at homes, offices, universities, streets and bus stations.

Questionnaire includes questions such as family members, billed water in the last few months, volume of flushing tank, number of cars, and frequency of domestic activities such as shower, face and hand washing, tooth brushing, clothes, dish washing, house cleaning, garden watering, car washing and toilet use both during winter and summer time. The following equations were used:

$$Gd = Gp+Gf$$
$$Gp = (FsQs + FaQa + FtbQtb + FhwQhw + FfwQfw)$$
$$Gf = (FlQl + FdwQdw + FcQc + FvQv) / FM$$
$$Q= f \times t$$

Where: Gp,Gf are personal and family greywater generation (Lpcd), and Gd is the daily total greywater generation per person.
Fs, Fa, Ftf, Ftb, Fhw, Ffw, Fl, Fdw, Fc, Fv, are the daily frequency of using showers, ablution, toilet flushing, tooth brushing, hand washing, face washing, laundry, dish washing, cleaning, and vehicle washing respectively, and FM is number of representing the family members.

While the Q are the corresponding average water consumption in litters for one use of the previous activities, equal to flow rate (f) multiplying by time (t) required to finish the single activity.
Water required for toilet flushing was calculated using the following equation:

$$Wtf = Qtf\ Ftf$$

While quantity of each toilet flush (Qtf) was estimated from the volume of each toilet tank.

Time (t) required for different activities by individual or within the family was estimated based on a group of 10 volunteers of different gender, age, and marital status. Each member performed and repeated different activities for 20 times, 10 times during summer and 10 times during winter, and time required to complete each was recorded. Average flow rate (f) was measured using a known volume of measuring container and the time needed to fill the container was recorded.

Greywater characteristics: Quality

Just like other Jordanian cities, the plumbing practices in Aqaba are not consistent and do not conform the standards required by the regulations. Vast majority of houses in Aqaba city are constructed in a way that greywater from bathrooms is being mixed with toilet water "black water" before meet at the manhole outside the house. This makes the interception and use of graywater relatively uneasy. A typical three floors, six apartments building (approximately 5 people in each apartment) was chosen for the study, one toilet pipe (black water) from one bathroom in the ground floor was separated from other bathroom water (sink, shower, laundry) and directed alone to the main sewer. The rest toilets in the building were closed during the period of the study (24 hours) and residents of the building were asked to use the isolated toilet not theirs, it was feasible since the whole building was owned by the same family members. Greywater was collected from flow of kitchen sinks, clothes washing machines, bathtubs, showers, and sinks before coming into contact with black water sewer, and stored in a 1 m^3 tank. A sample every three hours was collected for a during a period of 24 hours (9:00, 12:00, 15:00, 18:00, 21:00, 00:00, 3:00, 6:00, 9:00) plus another one mixture sample from the previous samples collected and stored at 4 °C. The analysis was performed at the same day directly after each sampling event by the credited Laboratories of Aqaba Waste Water Treatment Plant.

Greywater quality is essential in order to determine the appropriate treatment technology, for this purpose the main pollution parameters were analyzed, these include (COD, BOD_5, TSS, NO_3-N, NH_4-N, TN, and pH). Methods were described by literature (*Standard Methods For the Examination of Water and Wastewater, 22nd Edition*).

Social Acceptance:

Another online survey was conducted from 12nd Nov. to 12nd Feb. 2019, Employing "Google forms", The survey was published on social media websites (Facebook, Twitter) and the most popular chatting application (What`s App) and was open for everyone to participate. The survey includes two parts: firstly, introduction: to make sure that the survey was perfectly understood, a brief introduction about the topic and its goals was developed, that contains definition of greywater and wastewater beside some information about the former and its applications in non-potable uses. The second part was the questions themselves which included social acceptance of reusing greywater for toilet flushing, people`s opinions about the main driver for reusing greywater, expected benefits, thoughts and concerns.

III. RESULTS AND DISCUSSION

Greywater Quantity

Table (1) represents the frequency of different activities during Winter season by individuals and within a single household with the corresponding quantity of water needed per one use of each activity and per capita, while Table (2) represents the same information in Summer time.

Table 1:Personal and Family Water Uses (Winter)

Activity	Frequency (per day)	Volume per one use (L)	Total Quantity (L/ capita)
Shower	0.43	60	25.8
Ablution	3	2	6
Tooth brushing	2	0.75	1.5
Hand and face wash	3	1.5	4.5
Toilet flushing	5	7	35
Cooking	1	20	4*
Laundry	0.43	240	20.64*
Dish washing	2	20	8*
Cleaning	0.28	15	0.84*
Vehicle wash	0.14	10	0.28*

Table 2: Personal and Family Water Uses (Summer)

Activity	Frequency (per day)	Volume per one use (L)	Total Quantity (L/ capita)
Shower	2	30	60
Ablution	4	3	12
Tooth brushing	2	1.5	3
Hand and face wash	6	2	12
Toilet flushing	5	7	35
Cooking	1	25	5*
Laundry	0.57	240	27.36*
Dish washing	4	25	20*
Cleaning	0.57	20	2.28*
Vehicle wash	0.14	15	0.42*
* Divided by average family member (5)			

Greywater generation depends on water consumption, as water consumption increases the quantity produced will also do, and due to seasonality in water consumption in Aqaba city [18], where the consumption is a function of temperature, greywater quantity is increasing during summer season (June, July, and August) from 142 Lpcd where the water consumption is high, and decreasing to 72 Lpcd during winter (November, December, and January) when the consumption is lower. Kitchen sink represents all wastewater that comes from kitchen activities, this includes dish washing, cleaning fruit and vegetables, and water needed during food preparation, the quantity of dish washing was calculated while quantity of other activities was estimated.

Taking into consideration an average family members of 5 people, the winter-summer average amount of greywater produced in Aqaba city is about 107 Lpcd which consists with the international average generation rate of 90 to 120 Lpcd [11]. This result is higher than that reported by Ghunmi et al. (2008) and Jamrah and Ayyash (2008) for the urban cities of Amman, Irbid, Russaifa, and Zarqa of 59, 63, 51, 58 Lpcd respectively [16][17]. This might be for the reasons of the higher per capita consumption of water in Aqaba due to the continuous water supply, life style of Aqaba citizens, and the higher income comparing to these cities. And lower than that recorded in Alain city in United Arab Emirates of 192 Lpcd [14], this difference is due to the different life style between the two people, homes type, income, and water tariff although both cities share almost the same climate. Excluding kitchen wastewater or as called "Brown water" will result an average value of 80 Lpcd greywater which is a better quality wastewater to be treated and used in toilet flushing.

Figure (1) shows the average percentages of water consumption for different activities both in summer and winter. Toilet flushing represents 17% of total water consumption of 202 Lpcd, while the highest percentage is for shower 20% which may be due to the higher temperature in the city. Showering activity is characterized by a high daily frequency but a low water volume consumption in summer comparing to that in winter by a low daily frequency but high water volume consumption (See Table 1,2). Laundry and kitchen sink are among the high values as well, while ablution and washing have almost similar percentages of 5% and 4% respectively. Total greywater generated represents almost 53% of total fresh water consumption, this result is lower than that reported by Jamrah and Ayyash (2008) for other Jordanian Urban cities (See Table.3). The rest of consumption represents the highest percentage (30%); this goes to other unmentioned uses such as drinking, garden watering, outdoor cleaning, leakage, and water-based air conditioners that run for 24 hours a day during summer and being used widely in the city. Air conditioners consume huge quantities of water which can't be described as greywater or wastewater; the reason is that water used by these devices is being consumed as it evaporates during the process of cooling.

A previous study was conducted for Aqaba city in 2010 to estimate the percentage of water end uses. The estimated percentage for toilet flushing is 17.6% is similar to ours, while its different with regard to the shower activity of 21% and 12% in 2010, most probably because the per capita consumption of water increased since 2010 (See [19]).

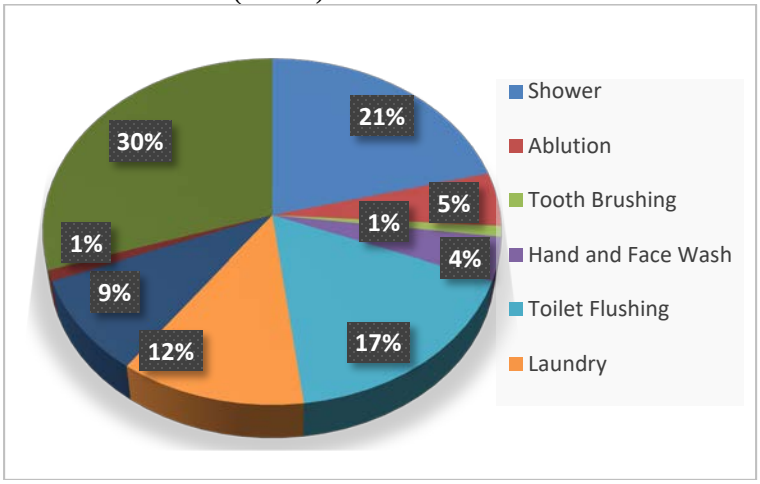

Figure 1. Water consumption for different activities

Table 3. Greywater generation in different cities

	Greywater (Lpcd)	Percentage to fresh water (%)
Aqaba	107	53
Amman	59	70
Irbid	63	78
Rusaifa	51	75
Zarqa	58	71

Alain	192	69
Saida	43	33

The quantity of water needed for toilet flushing is about 35 Lpcd which can be covered by greywater generated even during winter. If collecting greywater mainly for toilet flushing, greywater can save almost 17% of total fresh water consumption. Using a quick calculations and assuming the price of fresh water is JD 0.4/m^3, and a sewage charge of JOD 0.29/m^3; a typical family of 5 members can save about JOD 10.8 of their quarterly water bill (USD 1.0 = JOD 0.71). Greywater can also cover different non-potable water applications in houses which may increase the potential savings up to 29% if laundry was considered (JOD 18.3 of the quarterly paid water bill). A similar result will be obtained when brown water (kitchen wastewater) is excluded and greywater includes streams from wash basins, sinks, laundry, and bath tubes. This might result to a less polluted wastewater which can be treated easily, and still can cover the need for flushing beside other applications.

Greywater Quality

Greywater quality is a function of household's activities, socioeconomic and cultural factors besides many others [8][20]. In the city of Aqaba, Friday and Saturday are holidays, however, Friday is the most important day of the week where most families and friends gather or go out for a long day picnic. Saturday is the cleaning day as many housewives have the chance to clean the house, do laundry and start preparing for the next working and school days, that may include many cleaning and hygienic activities. As samples were captured on Saturday, measurements of COD concentrations were within the range of 84-1760 mg/L which are higher than typical urban greywater, this might be due to the existence of significant amounts of chemicals from kitchen and laundry detergents. BOD concentrations were lower and ranged from 50-524 mg/L. BOD and COD have similar variation tendencies during the day where two peeks appeared at lunch and dinner time (12:00-15:00, 21:00-00:00) when the main contributor to greywater is kitchen wastewater and an obvious valley from 03:00-06:00 as people are still sleeping and lessening of activities at houses. COD/BOD ratio average was 3.8 which indicates bad biodegradability. TSS ranged from 12-547 mg/L with a one obvious peek at dinner time, suspended solids usually come from food particles of kitchen wastewater, fiber from laundry, skin and hair from showering water. Knowing suspended solids content gives information about particles that may cause clogging of filters in the treatment system. In terms of Nitrogen, greywater showed deficiency of Nitrogen due to the absence of urine and feces which are the main sources of Nitrogen in black water.

The mixture sample to somehow could be considered as the average of the results, as it was close to the real average of the records, giving values for COD, BOD, TSS, NO_3-N, NH_4-N, TN, and pH of 917, 293, 172, 2.8, 1.9, 5.3 mg/L ad 7.7 respectively while the real average was 962, 253, 212, 2.5, 2.1, 5.2 mg/L and 7.5 respectively. These results represent only the quality of greywater at the time of analysis and further researches should be carried out in order to better conclude the quality of Aqaba greywater. However, greywater have a higher quality than mixed wastewater and with a proper treatment it can result a higher quality of reclaimed water than mixed domestic wastewater, colorless, and none pathogenic microorganism if a disinfection unit is used.

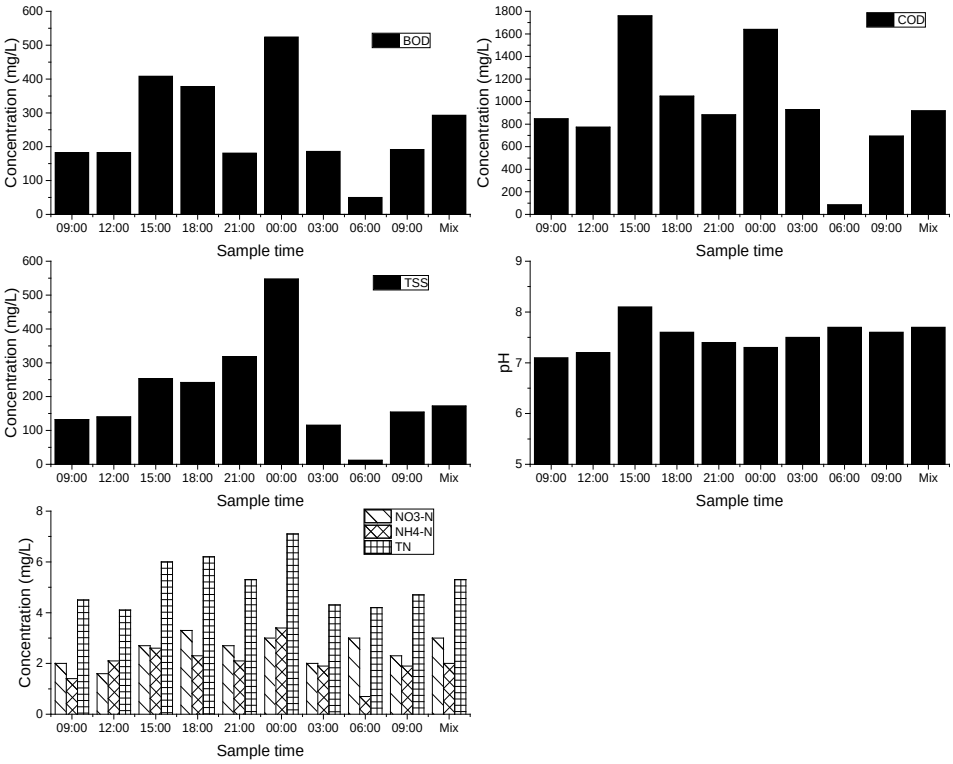

Figure 2. Variation of different parameters during 24-hour

Strong greywater needs more advanced and complex treatment technology, rather than simple ecological or mechanical treatment. Among the vast variety of treatment systems, MBR seems to be the most preferable on small scale or within several communities for its high efficiency removing organic substances, SS and turbidity. Furthermore, the contagious invertebrate egg, bacteria and virus and so on. Occupying a small area MBR unit can be installed and maintained easily for communities or residential areas and its feasibility to automated running.

Greywater separation and collecting can be a challenge in the build-up areas. Converting pipes of black water solely to the main sewer and shifting all other greywater source pipes to the treatment unit require a lot of plumping works and may not be preferable for many people. On the other hand, for those new planning residential and urban areas it will be easier simply if the dual plumping system is activated effectively especially that regulations are available.

Social Acceptance

Domestic wastewater source separating treating and reuse will be useless with the absence of beneficiaries approval, so the online survey aimed to evaluate the acceptance of urban reclaimed greywater recycling for toilet flushing after the advanced treating using MBR and disinfection in Aqaba and show peoples thoughts and concerns. The survey received 387 responses, the majority of participants were lies within the age range of 36 to 45 years old and have completed their university studying. It is showed that, 64% of the interviewees agreed to collect greywater, treat and reuse it for toilet flushing and other non-potable uses if meets the standards, while 14% were not sure about their opinions and the rest showed a negative response. This percentage is quiet high comparing to that reported in Alain city of 18% [14], and relatively low comparing to that reported in Saida city of 83% [11], this percentage can be increased by increasing awareness among society towards reasons and importance of such unconventional resource.

Because reclaimed greywater has a higher quality and more biologically stable than reclaimed mixed domestic water which can be stored up to 3 weeks with an advanced disinfection method, another question was arising, whether they agree to use reclaimed mixed wastewater instead of greywater for the same applications, 47% framed reclaimed wastewater positively while 35% framed it negatively and the rest were not sure again. As a result, people prefer to use reclaimed greywater than mixed wastewater where the potential human risk is lower.

People believed there is an urgent need to introduce new unconventional water resources such as greywater justifying that water shortage in Jordan being the main driver. 69% thinks they will reduce the water bill cost by using greywater for toilet flushing, 87% thinks there would be an environmental importance in reducing the wastewater production and discharge.

The survey revealed that whatever the reason is (increase fresh water, reduce water bill, or even saving the environment), inevitably there is an importance to collect, treat and use greywater for toilet flushing rather than fresh water.

IV. CONCLUSION

This study aimed to estimate greywater quantity generated in the city of Aqaba by employing a questionnaire survey covered 100 people, it showed that average of greywater generated was 107 Lpcd from 72 Lpcd in winter to 142 Lpcd in summer which represent 53% of fresh water consumption and 75% of total households' wastewater. The quantity of greywater in Aqaba is the highest compared to other Jordanian cities. Toilet flushing consumed 35 Lpcd, this amount can be covered totally by greywater and save 17% of fresh water up to 29% if other applications such as laundry was added.

The study also conducted that greywater quality in Aqaba is strong with its organic content although the average total quantity of greywater generated is high. The variation of parameters tendencies during the 24-hour analysis showed a similar trend with obvious peeks at meals time when kitchen wastewater is the main contributor.

As new urban areas are planned, and the city is expanding, greywater separation, treatment, and reuse in Aqaba can be an optimized choice which will not only save fresh water or reduce water bill but also improve standards of life of people in other cities of Jordan by allocating more fresh water for them.

Another online survey questionnaire was designed to evaluate public acceptance toward greywater reuse particularly for toilet flushing. 64% framed reusing greywater positively for the reasons of saving freshwater, reducing water bills, and saving the environment where the water shortage was the main driver of reuse in the view of people. Finally government should play a vital role in increasing the awareness among people toward new unconventional water resources such as greywater.

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