Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2021.26973

218 (2021) 240–251
April

Impact of greywater reuse on black water quality

Abbas Al-Omari[a,*], Zain Al-Houri[b]

[a]*Water, Energy and Environment Center, The University of Jordan, Amman, Jordan, email: abbas.alomari@ymail.com*
[b]*Civil Engineering Department, Al Albayt University, Mafraq, Jordan, email: zain_houri@yahoo.com*

Received 10 June 2020; Accepted 25 December 2020

ABSTRACT

Greywater recycling is viewed as a promising option to help bridge the enlarging gap between supply and demand in water stress areas. However, greywater recycling may negatively impact the strength and flow of the black water, which may complicate its treatment. In this paper, the impact of greywater recycling on the black water strength and flow have been investigated for three different wastewaters from Greece, Jordan and Oman, which exemplifies three different socioeconomic cases. Seven scenarios have been investigated for the Greece case, while four scenarios have been investigated for each of the Jordan and the Oman cases. The number of scenarios for each case is mainly dependent on the number of possible independent combinations of all greywater streams that can be recycled. The results showed that the black water strength and flow are slightly impacted by greywater recycling for toilet flushing. However, when greywater is recycled for irrigation, the impact on the black water strength and flow varied considerably among the scenarios, in response to the wastewater and greywater characteristics; flow and concentration. Furthermore, significant differences have been observed among the three socioeconomic cases, considered in this paper, in terms of the black water characteristics, and greywater recycling options.

Keywords: Greywater; Greywater recycling; Urban water; Black water; Wastewater collection

1. Introduction

Greywater is defined as all the domestic wastewater streams excluding toilet wastewater [1–4], others exclude kitchen wastewater too [5,6]. Greywater recycling has emerged as a viable option to bridging the gap between supply and demand in water scarce countries, such as Jordan, and to conserving the environment in water abundant countries, such as Australia and Germany [7]. To date, the majority of greywater research has focused on greywater quantification and characterization [1,8–11], and the impact assessment on water budget [12,13], the environment, public health and assessment of associated risks and challenges [3,7,14–18], assessment of public awareness and acceptance [9,10,19–22], determination of treatment options for reuse [2,10,11,23–45], investigating its economic feasibility [46], and review papers [4,47,48].

As Jordan is under a high water stress [49], the interest in greywater recycling, to help bridge part of the deficit between supply and demand, intensified in the last three decades. Similar to the worldwide trend, greywater research in Jordan has focused on quantification and investigating the impact on the water budget, characterization for the purpose of determining treatment options and suitability for the intended use, in addition to assessment of the associated health and environmental risks [9,11,50–55].

Most of the greywater research conducted so far worldwide and locally concluded that, greywater recycling is an option for reducing the gap between supply and demand, provided the associated health and environmental risks are properly addressed. However, little attention has been given to the impact of greywater recycling on the black water strength and flow. It is important to note that as greywater is recycled and separated from the wastewater,

* Corresponding author.

and due to the fact that, greywater is higher in proportion than black water, and is usually less polluted [47,56,57], the strength of the resulted black water is expected to increase by several folds. Consequently, its treatment efficiency and treatment cost are expected to be negatively affected. To date, few studies have already pointed to the possible negative impacts of greywater recycling on the black water strength and flow. Penn et al. [13] investigated the impact of greywater recycling, on the black water quality and quantity, by simulating scenarios of greywater recycling for toilet flushing and garden irrigation, at the household level. They found that, greywater recycling reduced black water flow and increased its strength. Penn et al. [58] studied the impact of greywater recycling and water efficient toilets on municipal sewer systems, by modeling a representative urban sewer system. They found that morning and evening peak wastewater flows have decreased, in addition to a reduction in velocity and proportional depth, in response to increasing the recycled greywater volume. Furthermore, the concentration of pollutants is projected to increase. In the context of analyzing the economic feasibility of greywater recycling, Frielder and Hadari [46] considered more blockages in the sewer system, and higher concentration of pollutants, as disadvantages that lead to additional cost. However, the reduction of the supply as a consequence to greywater recycling, lead to cost reduction due to the less energy needed for water supply and treatment, less energy needed for water distribution, and smaller wastewater collection systems.

It is important to note that wastewater, and consequently greywater is not something standard, its quantity and quality vary considerably from community to community, based on each community socio-economic characteristics, they fluctuate over time too. Table 1 summarizes different greywater generation rates, in some reported studies, in different countries. This variation necessitates detailed analysis of the impact of greywater recycling on the black water strength and flow, for each community, to avoid resulting in too concentrated black water that is both difficult and expensive to treat.

The scope of the two studies conducted so far on the impact of greywater recycling on the sewer system [58], and on the black water strength and flow [13], is limited to a small number of households within a single community. This paper thoroughly investigates the potential impact of greywater recycling on the black water strength and flow, taking into consideration the wastewater and the greywater strength and flow. This adds new variables to the greywater recycling for current practices and helps the decision maker to decide which greywater stream(s) to recycle, and by how much, so that the impact on the black water strength and flow is within acceptable levels. Detailed analyses, for scenarios that consist of recycling all possible combinations of the different greywater streams, have been conducted, for three socio-economically different countries, namely, Greece, Jordan and Oman. General guidelines for greywater recycling are concluded based on the results of the detailed analysis.

2. Methodology

The impact of greywater recycling, on the black water characteristics, has been investigated by conducting mass balance for the following parameters: five-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), electrical conductivity (EC), total nitrogen (TN) and total phosphorus (TP). A general mass balance for wastewater constituents is given below:

$$C_{\text{bw}} = \frac{\left(Q_{\text{rww}} \times C_{\text{rww}} - \sum_{i=1}^{n} Q_{\text{Gw}i} \times C_{\text{Gw}i}\right)}{\left(Q_{\text{rww}} - \sum_{i=1}^{n} Q_{\text{Gw}i}\right)} \quad (1)$$

$$C_{\text{bw}} = \frac{\left(Q_{\text{rww}} \times C_{\text{rww}} + \sum_{i=1}^{n} Q_{\text{Gw}i} \times C_{\text{Gw}i}\right)}{\left(Q_{\text{rww}}\right)} \quad (2)$$

Eq. (1) applies when recycled greywater streams are separated from the wastewater stream, when used for irrigation, for example; Eq. (2) applies when recycled greywater streams are not separated from the wastewater stream,

Table 1
Greywater generation rates at different countries in L/(c.d)

Country	Sink	Shower	Laundry	Dish washer	Greywater[f]	Toilet	Outdoor	TWU[d]
Greece[a]	11.3	37.5	19.2	0.6	68.6	37.3	0[c]	135.6
Jordan[b]	27.6	20.9	10.1	NA	58.6	20.9[c]	4.9	84.4
Oman[e]	9	83	13	NA	161	11	10	195
Israel[a]	18	39.2	16.6	NA	73.8	37.7	0[c]	138.1
Holand[a]	4	47	27	1	79	39	9[c]	134
India[a]	17	30	33	NA	80	25	18[c]	160
Australia[a]	66	NA	47	NA	113	41	0[c]	201
USA[a]	88.2	NA	81.8	NA	170	101	80.9[c]	378.5
Denmark[a]	43	NA	17	NA	60	27	7[c]	119

[a]Noutsopoulos et al. [59]; [b]Jamrah et al. [9]; [c]Calculated by author; [d]TWU, total water use; [e]Prathapar et al. [60]; [f]Excluding kitchen; NA, not available.

when used for toilet flushing, where C_{bw} is the black water concentration, Q_{rww} is the raw wastewater flow, C_{rww} is the raw wastewater concentration, n is the number of recycled greywater streams, Q_{Gwi} is the flow of greywater stream i, and C_{Gwi} is the concentration of greywater stream i.

Three cases of different socioeconomic and water use habits have been investigated, namely, Greece, Jordan and Oman. Published data of raw wastewater flow and characteristics, and greywater flow and characteristics, have been used. For the Jordan case, greywater characteristics and flow data published in Jamrah et al. [9] have been used; wastewater characteristics for Jordan have been taken from the Ministry of Water and Irrigation articles. For the Greece case, greywater flow and characteristics published in Noutsopoulos et al. [59]; wastewater characteristics published in Amanatidou et al. [61] have been used. For the Oman case, greywater flow and characteristics published in Prathapar et al. [60]; wastewater flow and characteristics published in Al-Waheibi [62] have been used. Where, more than one greywater stream is recycled for a given scenario, the characteristics of the recycled greywater are calculated by assuming complete mixing of the different recycled greywater streams:

$$C_{GW_m} = \frac{\left(\sum_{i=1}^{n} Q_{Gwi} \times C_{Gwi}\right)}{\left(\sum_{i=1}^{n} Q_{Gwi}\right)} \quad (3)$$

where C_{GWm} is the mixed concentration of the different recycled greywater streams; n is the number of recycled greywater streams; Q_{Gwi} is the flow of greywater stream i; and C_{Gwi} is the concentration of greywater stream i.

3. Scenarios

3.1. The Greece case

For the Greece case, seven greywater recycling scenarios have been investigated. In all the scenarios, the shower greywater stream is recycled for toilet flushing, as the shower greywater and the toilet demand are equal (Table 1); all other greywater streams are recycled for irrigation. The seven scenarios consist of recycling the following greywater streams: the shower (SH) only, the shower and the dishwasher SH & DW, the shower and the sink SH & SK, the shower and the sink plus the dishwasher SH & (SK + DW), the shower and the laundry SH & L, the shower and the sink plus the laundry SH & (SK + L) and the shower and the sink plus the laundry plus the dishwasher SH & (SK + DW + L). The shower only scenario represents the case of an apartment with no irrigation demand; the shower and the dishwater, the shower and the sink, and the shower and the sink plus the dishwasher scenarios represent the case of an apartment with low irrigation demand; the remaining three scenarios represent the case of a house, where irrigation demand is relatively significant. The impact of greywater recycling on the black water BOD_5, COD, TSS, TN, TP and EC has been investigated for these scenarios.

3.2. The Jordan case

For the Jordan case, four scenarios of greywater recycling have been investigated. In all the scenarios, greywater generated at the shower is recycled for toilet flushing, as the greywater generated at the shower and the toilet demand are equal (Table 1). Greywater streams generated at the sink and the laundry are recycled for irrigation. The four scenarios simulated for the Jordan case consist of recycling the following greywater streams: the shower (SH) only, the shower and the laundry SH & L, the shower and the sink SH & SK and the shower and the sink plus the laundry SH & (SK + L). Recycling of the shower greywater only represents the situation of an apartment where irrigation demand is zero; recycling of the shower and the laundry greywater streams represents the situation of an apartment where irrigation demand is low; recycling of the shower and the sink, and the shower and the sink plus the laundry greywater streams represents the situation of a house where irrigation demand is significant. The impact of greywater recycling on the black water BOD_5, COD, TSS, TN, TP and EC has been investigated for these scenarios.

3.3. The Oman case

For the Oman case, four scenarios of greywater recycling have been investigated which consist of recycling the following greywater streams: the laundry (L) only, the laundry and the sink L & SK, the laundry and the shower L & SH and the laundry and the sink plus the shower L & (SK + SH). In all the scenarios, the laundry greywater stream is recycled for toilet flushing, as the laundry greywater flow is close to the toilet demand (Table 1). The sink and the shower greywater streams are recycled for irrigation. The laundry scenario represents an apartment with zero irrigation demand; the laundry and the sink scenario represents an apartment with low irrigation demand; the other two scenarios that include the shower greywater stream represents a house where irrigation demand is significant. The impact of greywater recycling on the black water BOD_5, COD and TSS has been investigated for these scenarios.

4. Results and discussion

4.1. The Greece case

Figs. 1–3 show that, the simulated scenarios for the Greece case can be divided into three groups based on their impact on the black water; the first group includes the SH and the SH & DW scenarios; the second group includes the SH & SK and the SH & (SK + DW) scenarios; the third group includes the SH & L, the SH & (SK + L) and the SH & (SK + DW + L) scenarios. For the first group scenarios, the increases in the black water BOD_5, TSS and COD are low, in the neighborhood of 10%, which is attributed to the fact that, the tap water normally used for toilet flushing is replaced with low strength shower greywater. In addition, as the shower greywater has been recycled for toilet flushing, no reduction in the black water flow took place [Eq. (2)]. For the SH & DW scenario, recycling of the dishwasher greywater alone, for use in irrigation, has not resulted in any negative impact on the black water characteristics, as

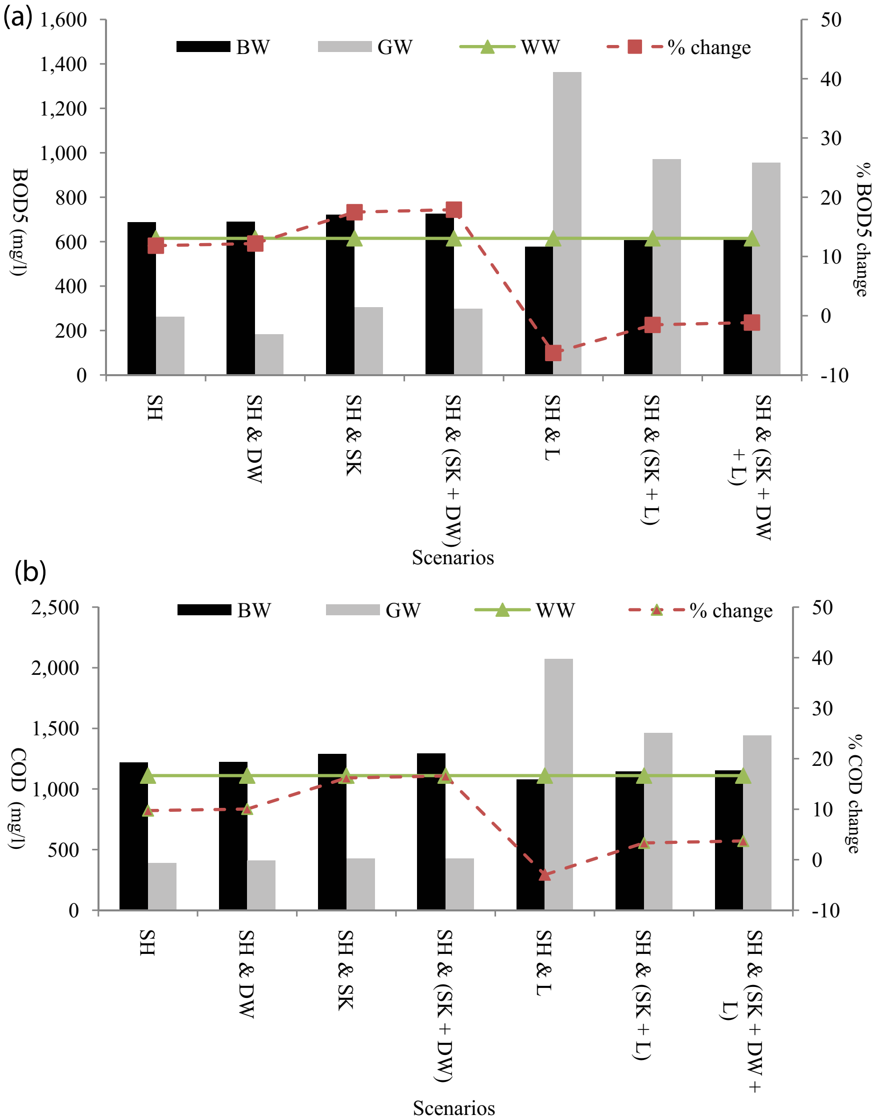

Fig. 1. Impact of greywater recycling on black water (a) BOD_5 and (b) COD for the Greece case.

the DW flow is too small, which has not caused significant reduction in the black water flow (Table 1). The increases in the black water TN and EC for the first group scenarios are too low, which is attributed to the too low concentrations of these pollutants in the shower greywater. In addition, the dishwasher flow is too small (Table 1), which has not resulted in significantly reducing the black water flow.

The black water TP concentration showed no increase for the shower scenario, as the TP concentration in the shower greywater is equal to that of the raw wastewater (Fig. 3). The black water TP concentration showed a drop for the SH & DW scenario, due to the high TP concentration in the dishwater greywater, which comes from detergents (Fig. 3). The second group of scenarios, which is dominated by recycling the sink greywater for irrigation, showed moderate increases in the black water BOD_5, COD and TSS concentrations, in the neighborhood of 15%. These moderate increases are due to the reduction in the black water flow [Eq. (1)]. The increases in the TN and EC of the black water for this group of scenarios are low, in the neighborhood of 10%. The SH & SK scenario showed little impact on the black water TP concentration due to the low TP concentration in the sink greywater. However, the SH & (SK + DW) scenario resulted in a slight reduction in the black water TP concentration, because the TP concentration in the (SK + DW) greywater stream is almost equal to that of the wastewater. In addition, the TP concentration in the SH greywater stream is too low as compared to that of the raw wastewater.

The third group of scenarios is dominated by the laundry greywater stream, which is characterized by high BOD_5 and COD, higher than that of the raw wastewater, which lead to too little increases/decreases in the BOD_5 and COD of the black water (Fig. 1), as high mass of these pollutants have been removed [Eq. (1)]. It is important to mention that, the high BOD_5 and COD of the laundry greywater stream contradicts the philosophy behind greywater recycling, which is based on recycling low strength greywater streams, that can be treated by simple and easy

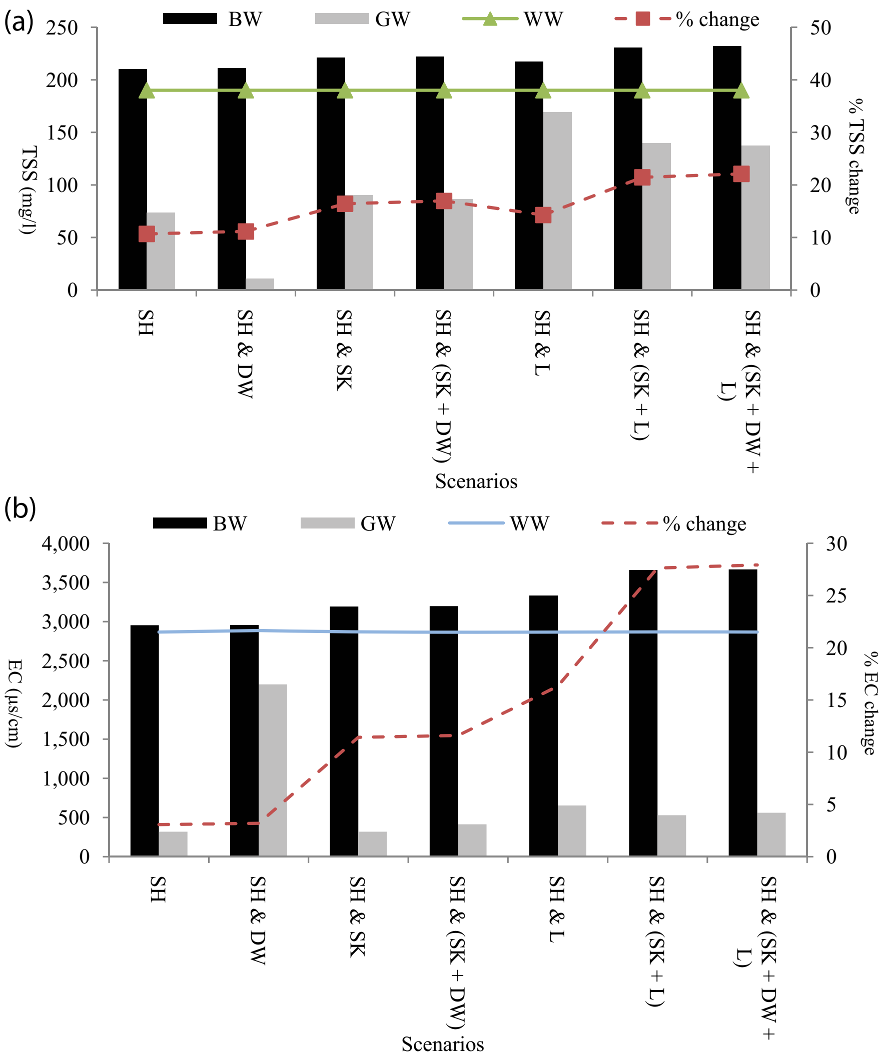

Fig. 2. Impact of greywater recycling on black water (a) TSS and (b) EC for the Greece case.

technologies to operate at the household level. In this case, it is not technically feasible to recycle the laundry greywater stream despite its low impact on the black water characteristics. Figs. 2 and 3 show that, the third group of scenarios has moderate impact on the TSS of the black water, in the vicinity of 20%, for the SH & (SK + L) and the SH & (SK + DW + L) scenarios, and 14% for the SH and L scenario, and slightly high impact on the black water TN and EC for the SH & (SK + L) and SH & (SK + DW + L) scenarios, in the vicinity of 28%, and moderate impact for the DW and L scenario (16%). However, the impact of the third group scenarios on the TP of the black water is moderate, in the range of 12%, except for the SH & (SK + DW + L), which caused a little high impact on the TP concentration (23%), which can be attributed to recycling the DW greywater stream, which is rich in phosphorus from detergents.

4.2. The Jordan case

Figs. 4–6 show slight increases in the black water concentrations for all the simulated parameters, BOD_5, COD, TSS, EC, TN and TP, for the shower scenario. The main reason behind these slight increases is that, the black water flow has not changed, as the shower greywater has been recycled for toilet flushing. In addition, the shower greywater stream, which is slightly polluted, has been recycled for toilet flushing instead of using the clean tap water [Eq. (2)]. For the shower and the laundry scenario, Figs. 4–6 show that the BOD_5, COD, TSS and TN of the black water have shown moderate increases, in the range of 15%. These moderate increases are attributed to the reduction in the black water flow, as the laundry greywater stream has been separated from the wastewater for use in irrigation. Figs. 5 and 6 show significant decreases in the black water TP and EC for this scenario, which are attributed to the high TP and EC of the laundry greywater stream, higher than that of the wastewater, which resulted in removing high TP mass. From the wastewater, consequently, reducing the TP and the EC of the black water [Eq. (1)]. For the SH and SK scenario, the black water concentrations showed significant increases for all the simulated parameters (BOD_5, COD, TSS, TN, TP and EC), in the neighborhood of 50%.

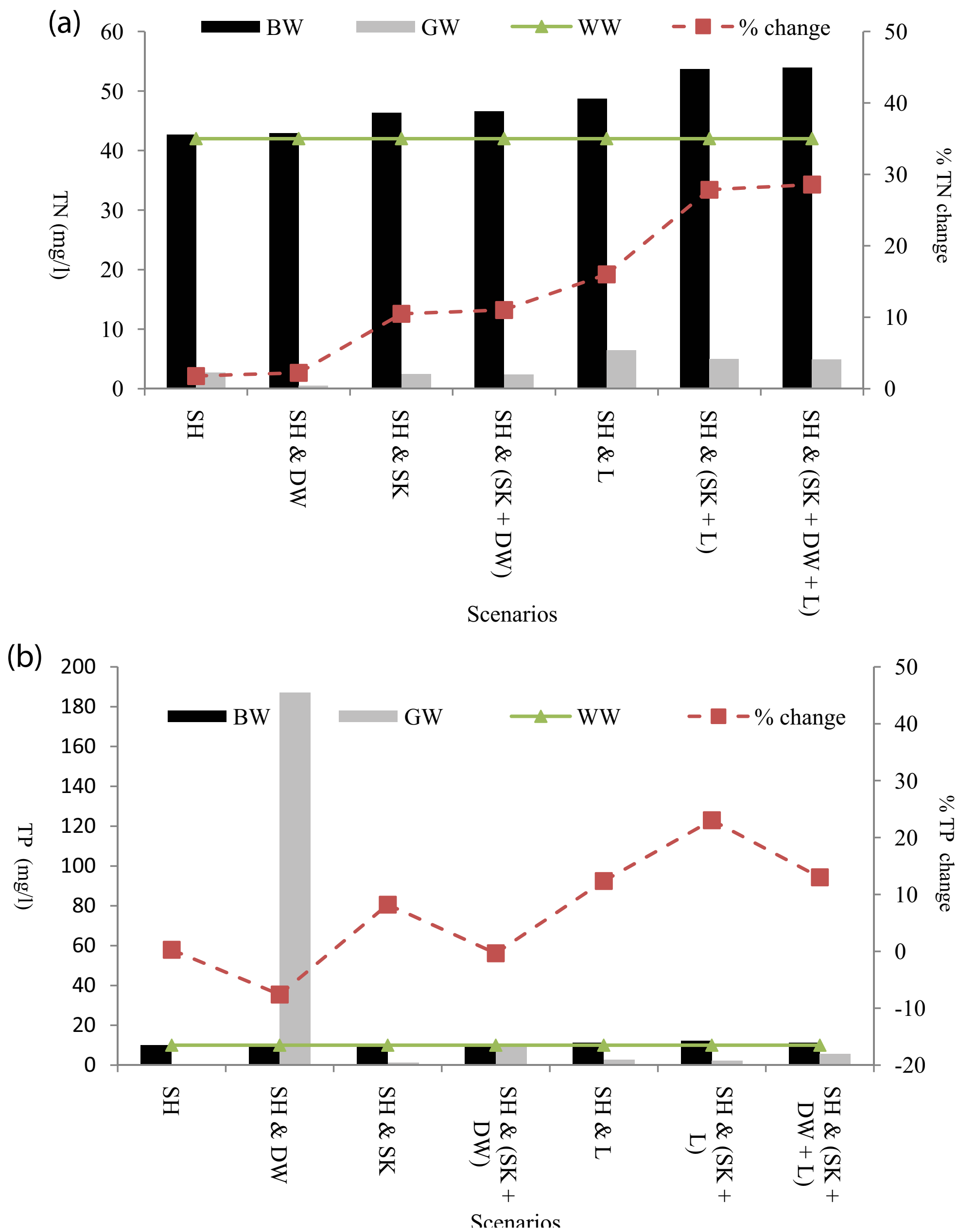

Fig. 3. Impact of greywater recycling on black water (a) TN and (b) TP for the Greece case.

These significant increases are attributed to separating the high flow sink greywater from the raw wastewater (Table 1), which lead to reducing the black water flow significantly, consequently, increasing the concentrations of all the simulated parameters [Eq. (1)]. For the SH & (SK + L) scenario, the black water concentrations for BOD_5, COD, TSS and TN have shown significant increase of 88%, 88%, 71% and 87%, respectively. This is due to separating the high flow SH & (SK + L) (Table 1) from the raw wastewater for use in irrigation, which resulted in reducing the black water flow significantly, consequently, increasing the black water concentration for these parameters dramatically [Eq. (1)]. The SH & SK and the SH & (SK + L) scenarios should be avoided, as they have resulted in increasing the black water concentration dramatically. One way to reduce the impact of recycling the sink and the laundry greywater streams on the black water strength is to recycle the sink and the laundry greywater streams partially. The level to which these streams can be recycled can be calculated by mass balance, so that specified black water concentrations at the inlet to the wastewater treatment plant are met. The EC and the TP concentrations of the black water, for the SH & (SK + L) scenario, showed significant decreases, which is attributed to the fact that, the TP concentration of the black water laundry greywater stream is higher than that of the raw wastewater.

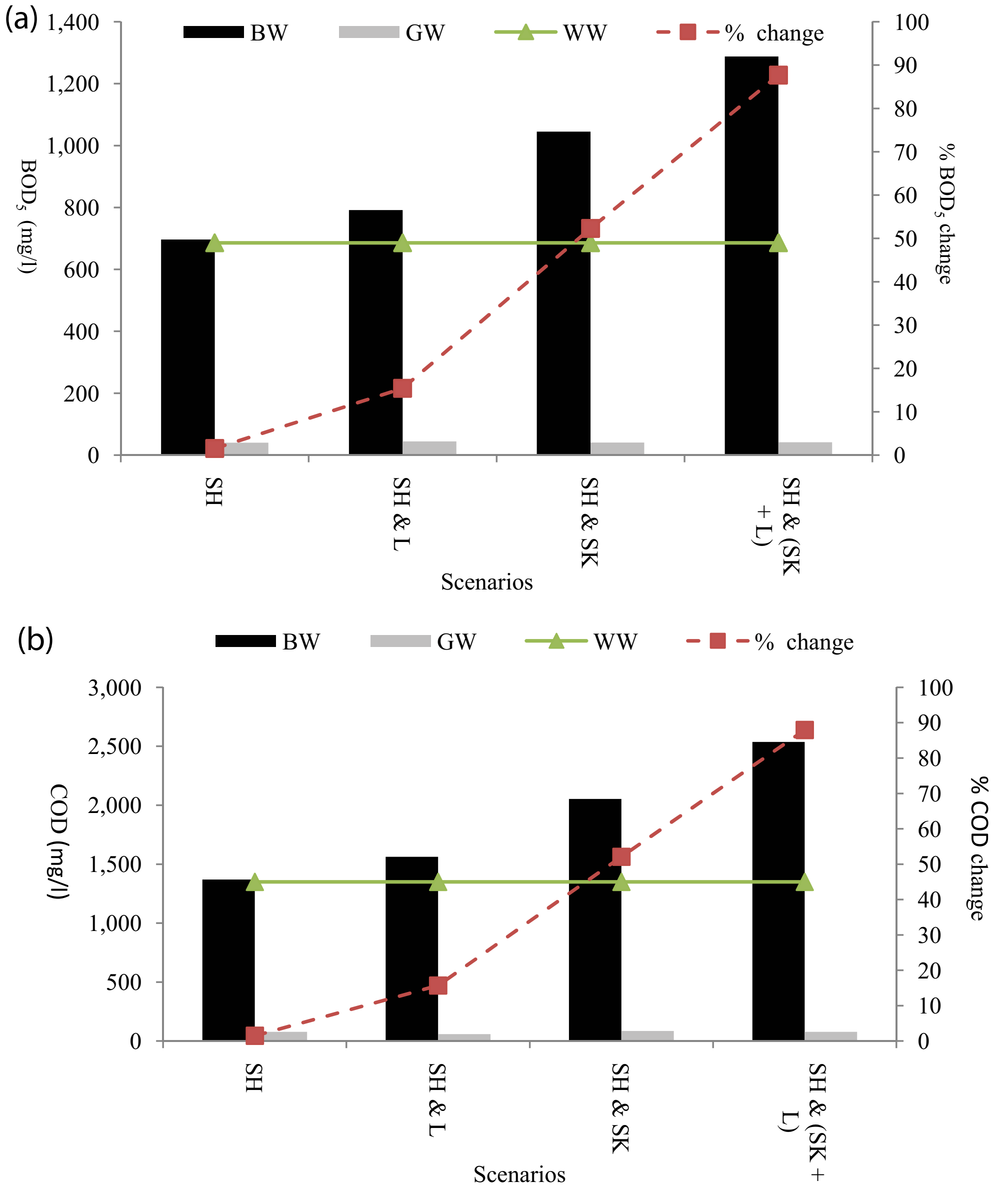

Fig. 4. Impact of greywater recycling on black water (a) BOD_5 and (b) COD for the Jordan case.

4.3. The Oman case

Figs. 7 and 8 show that, recycling of the laundry greywater for toilet flushing showed little impact on the black water COD, BOD_5 and TSS, as the concentrations of these pollutants in the laundry greywater stream are low. In addition, the laundry greywater stream is recycled for toilet flushing, which means that the black water flow has not changed. The laundry and the sink scenario showed little impact on the black water BOD_5, TSS and COD, which is mainly due to the relatively low flow of the sink greywater, which has not resulted in reducing the black water flow significantly. The laundry and the shower, and the laundry and the shower plus the sink scenarios, showed high impact on the BOD_5 and the COD of the black water (60%–75%), which is attributed to the too high flow of the shower greywater stream (Table 1), which resulted in significantly reducing the black water flow, consequently, increasing the concentrations of the BOD_5 and the COD of the black water [Eq. (1)]. However, in such a case, the shower greywater can be recycled partially; the flow that can be recycled can be calculated by mass balance based on the maximum allowed concentrations at the inlet to the wastewater treatment plant. Figs. 7 and 8 show that, the impact of these two scenarios on the TSS of the black water is moderate, in the neighborhood of 20%, which is attributed to the relatively high concentration of the recycled greywater TSS, which lead to reducing the TSS of the black water.

Figs. 1–8 show that recycling certain greywater streams for toilet flushing resulted in little impact on the black water strength and flow, for the three investigated cases, which is mainly attributed to the fact that, no reduction in the

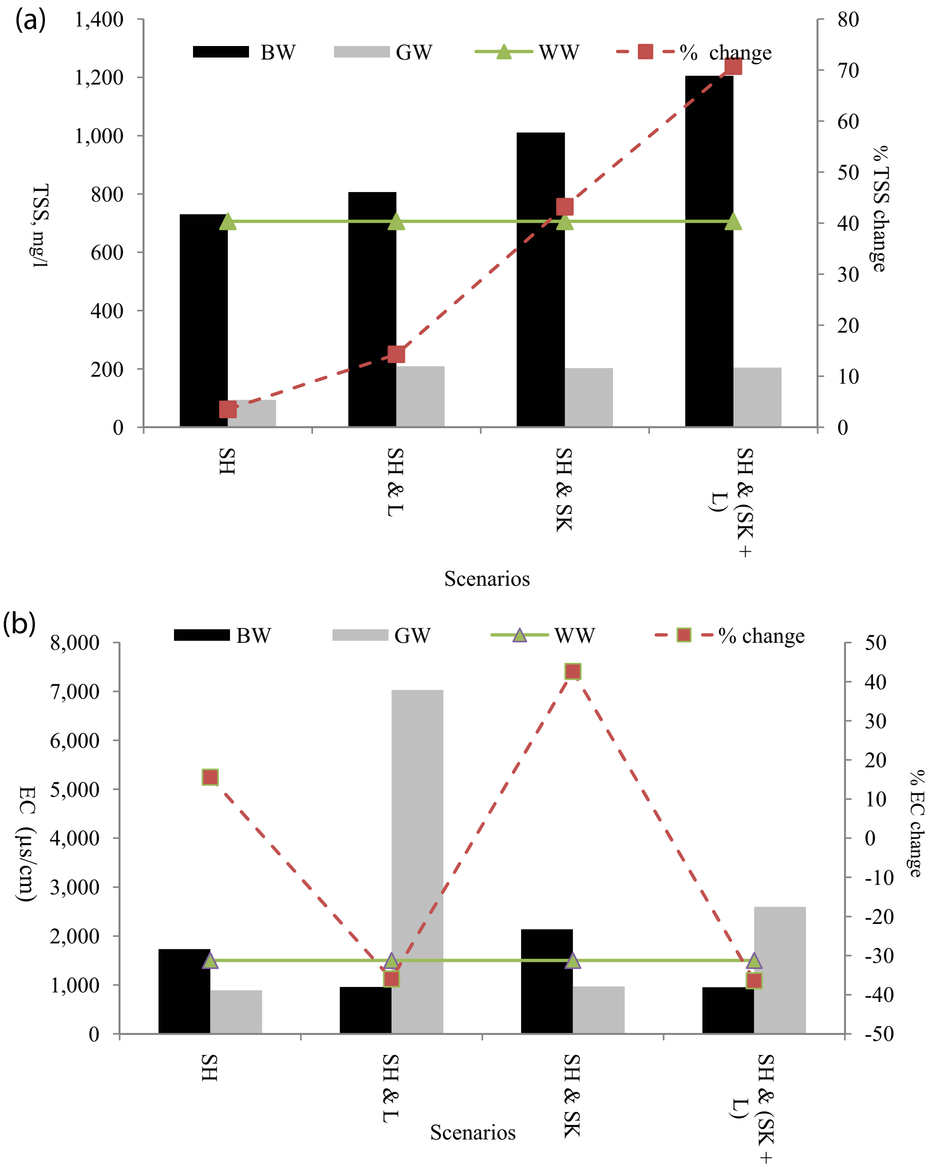

Fig. 5. Impact of greywater recycling on black water (a) TSS and (b) EC for the Jordan case.

black water flow took place. However, when the recycled greywater streams are used for irrigation, the resulting black water concentration is functioning in a combination of the raw wastewater and the recycled greywater characteristics; flow and concentration, and their relative values.

Recycling of a low flow, low concentration greywater stream for irrigation slightly impacted the black water concentration. This is because the removed pollutant mass is small, which made small changes in the numerator and denominator of Eq. (1), consequently, the change in the black water concentration became small. However, recycling of a low concentration and high flow greywater stream for irrigation has increased the black water concentration significantly. This is mainly due to the significant reduction in the black water flow [Eq. (1)]. Due to the fact that, greywater flow is usually higher than irrigation demand, at the household level, the low strength, high flow greywater stream can be recycled partially. Recycling of high flow, high concentration greywater stream, may not impact the black water concentration negatively, it may rather result in reducing it, as high pollutant mass is removed; however, the high concentration of the greywater stream contradicts the philosophy behind greywater recycling.

The three cases presented in this paper showed considerable variation in the greywater strength and flow among them, consequently different results for the scenarios considered have been obtained. This means that detailed analysis is a must before deciding which greywater stream(s) to recycle and to what extent to avoid bringing the black water concentrations to high levels that complicate its transport and treatment.

It is important too, to pay attention to the environmental costs and risks associated with the use of treated greywater

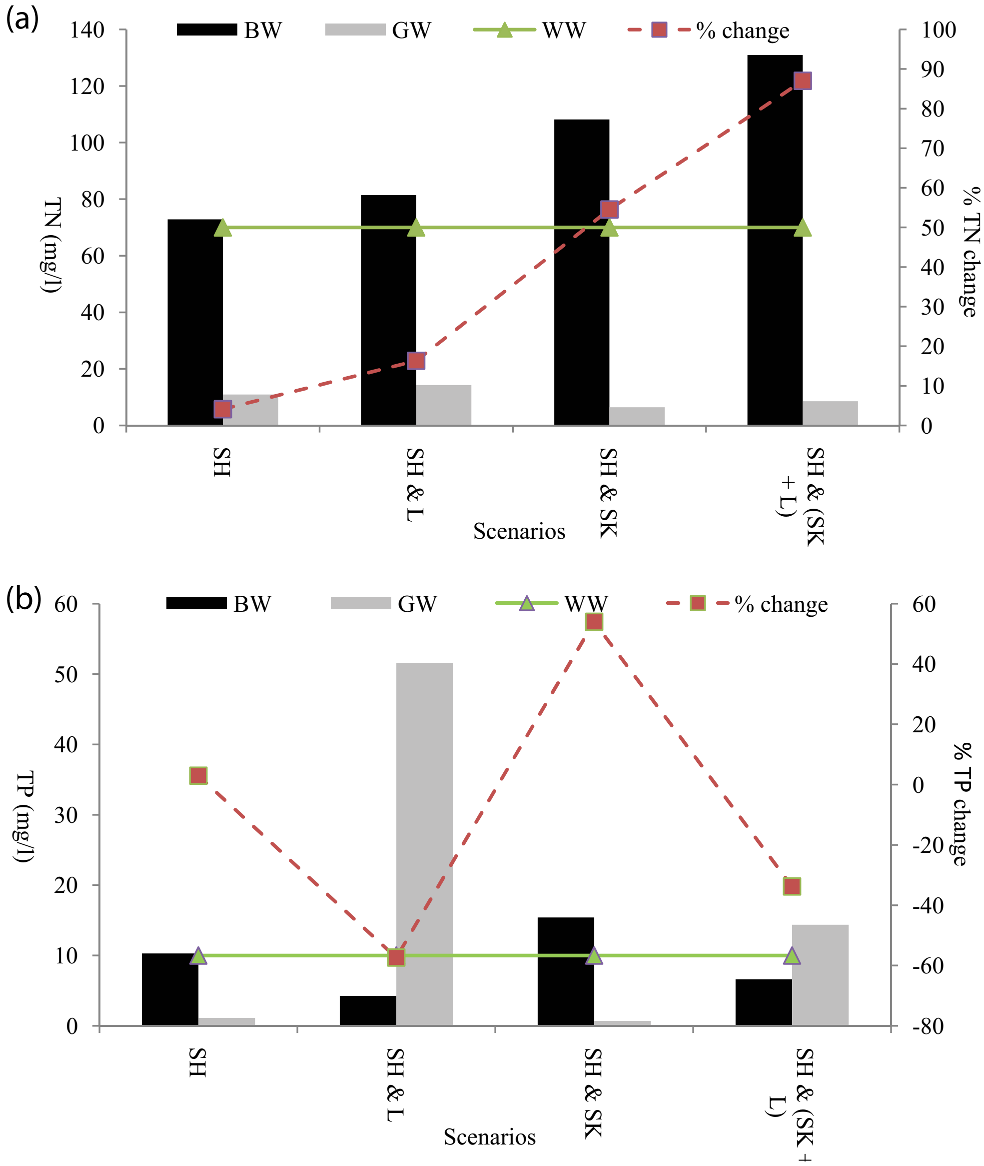

Fig. 6. Impact of greywater recycling on black water (a) TN and (b) TP for the Jordan case.

in irrigation, especially when practiced for a long time, such as degradation of soil quality and health impacts on humans. The detailed discussion of these long term impacts and risks is beyond the scope of this paper. However, the literature on the negative long term impacts and risks associated with using greywater in irrigation is extensive are given in [3,63,64]. To minimize these long term negative impacts, the standards/guidelines for greywater use in irrigation, which are country specific, must be met. A detailed summary of these standards/guidelines for different countries is given in Vuppaladadiyam et al. [4].

5. Conclusions

Greywater recycling has been promoted to help bridge the gap between supply and demand in water stress areas, and to protect the environment in water abundant countries. However, due to the fact that greywater strength and flow vary considerably from community to community, the decision of its recycling should be based on detailed analysis of the impact on the black water strength and flow. Based on the results of the scenarios simulated in this paper, recycling of the different greywater streams for toilet flushing is not expected to impact the black water strength significantly, because the black water flow has not changed. However, when greywater is recycled for irrigation the following guidelines apply: low strength, low flow greywater streams can be recycled safely, as they will not result in significant reduction in the black water flow nor in the black water strength; recycling of high flow, low strength greywater streams, will result in increasing the black water strength significantly, due to the high reduction in the black water flow, and small removed pollutant mass; so high flow, low concentration greywater streams should

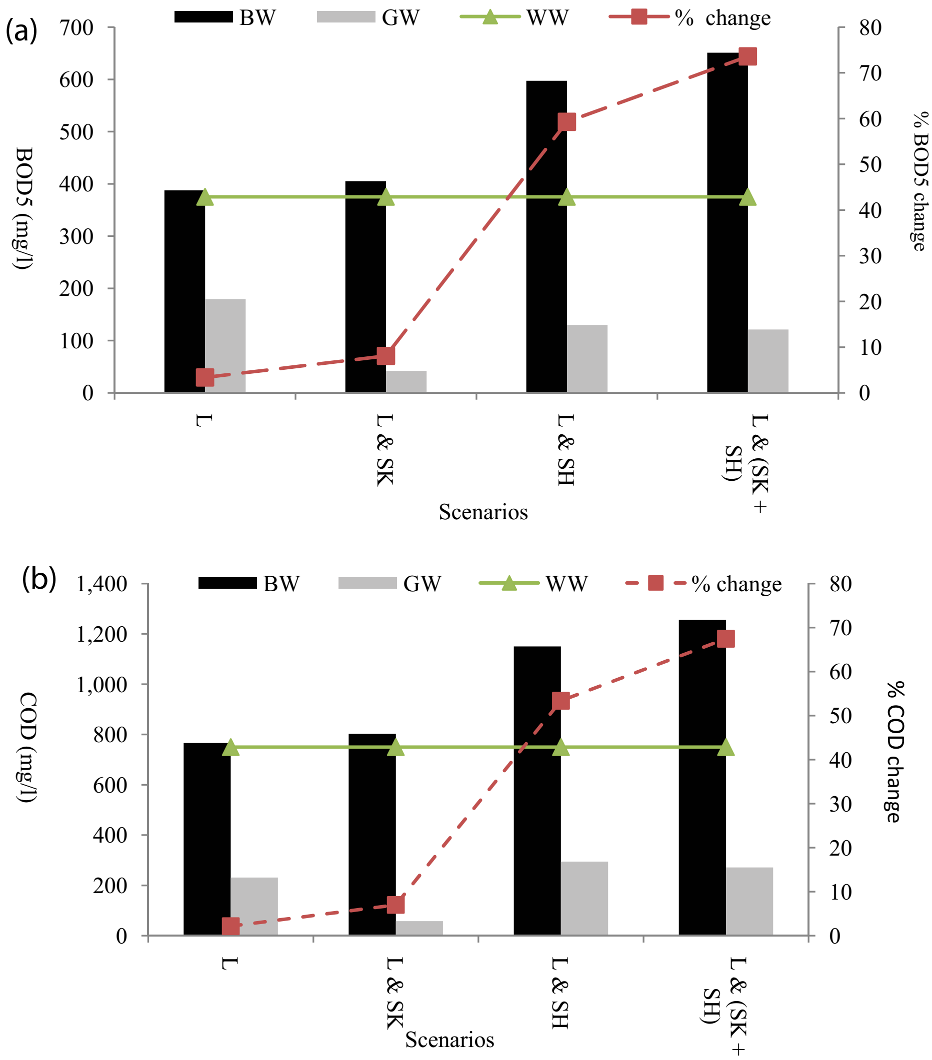

Fig. 7. Impact of greywater recycling on the (a) BOD_5 and (b) COD for Oman case.

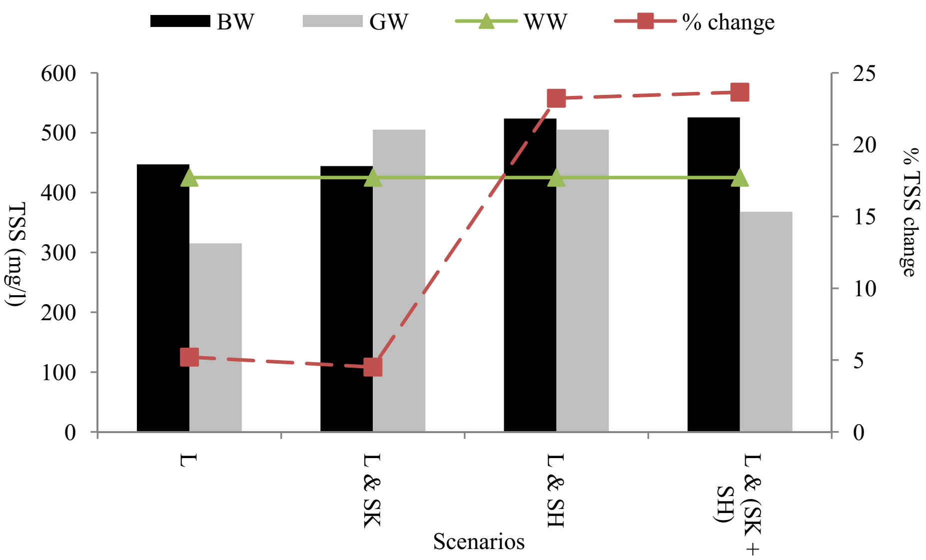

Fig. 8. Impact of greywater recycling on the TSS for Oman case.

be recycled partially based on detailed mass balance, so that the black water concentration is not increased dramatically. Recycling of high strength greywater stream(s) will result in reducing the black water strength, however, it is not recommended to do so as this practice contradicts the philosophy behind greywater recycling, which is based on recycling low strength greywater streams that can be treated at the household level with little effort, technical experience and acceptable cost.

References

[1] L. M. Casanova, C.P. Gerba, M. Karpiscak, Chemical and microbial characterization of household greywater, J. Environ. Sci. Health. Part A Toxic/Hazard. Subst. Environ. Eng., 34 (2001) 395–401.
[2] A. Ledin, E. Eriksson, M. Henze, Aspects of Groundwater Recharge Using Grey Wastewater, IWA Publishing, London, 2001, pp. 354–370.
[3] J. Ottoson, T. Stenstrom, Faecal contamination of greywater and associated microbial risks, Water Res., 37 (2003) 645–655.
[4] A. Vuppaladadiyam, N. Merayo, P. Prinsen, R. Luque, A. Blanco, M. Zhao, A review on greywater reuse: quality, risks, barriers and global scenarios, Rev. Environ. Sci. Biotechnol., 18 (2019) 77–99.
[5] D. Christova Boal, R.E. Eden, S. McFarlane, An investigation into greywater reuse for urban residential properties, Desalination, 106 (1996) 391–397.
[6] P. Wilderer, Applying sustainable water management concepts in rural and urban areas: some thoughts about reasons, means and needs, Water Sci. Technol., 49 (2004) 8–16.
[7] B. Jeppesen, Domestic greywater re-use: Australia's challenge for the future, Desalination, 106 (1996) 311–315.
[8] E. Friedler, Quality of individual domestic greywater streams and its implication on on-site treatment and reuse possibilities, Environ. Technol., 25 (2004) 997–1008.
[9] A. Jamrah, A. Al-Omari, L. Al-Qasem, N. Abdel Ghani, Assessment of availability and characteristics of greywater in Amman, Water Int., 31 (2006) 210–220.
[10] A. Jamrah, A. Al-Futaisi, S. Prathapar, A. Al Harrasi, Evaluating greywater reuse potential for sustainable water resources management in Oman, Environ. Monit. Assess., 137 (2008) 315–327.
[11] M. Halalsheh, S. Dalahmeh, M. Sayed, W. Suleiman, M. Shareef, M. Mansour, M. Safi, Greywater characteristics and treatment options for rural areas in Jordan, Bioresour. Technol., 99 (2008) 635–664.
[12] A. Campisano, C. Modica, Experimental investigation on water saving by the reuse of washbasin greywater for toilet flushing, Urban Water J., 7 (2010) 17–24.
[13] R. Penn, M. Hadari, E. Friedler, Evaluation of the effects of greywater reuse on domestic wastewater quality and quantity, Urban Water J., 9 (2012) 137–148.
[14] A.M. Dixon, D. Butler, A. Fewkes, Guidelines for greywater re-use: health issues, Water Environ. J. Promot. Sustainable Solutions, 13 (1999) 322–326.
[15] C. Diaper, A. Dixon, D. Butler, A. Fewkes, S. Parsons, T. Stephenson, M. Strathern, J. Strutt, Small scale water recycling systems – risk assessment and modeling, Water Sci. Technol., 43 (2001) 83–90.
[16] A. Maimon, A. Gross, Greywater: limitations and perspective, Curr. Opin. Environ Sci. Health, 2 (2018) 1–6.
[17] A. Albalawneh, T. Chang, C. Chou, Impacts on soil quality from long-term irrigation with treated greywater, Paddy Water Environ., 14 (2016) 289–297.
[18] K. Oh, J. Leong, P. Poh, M. Chong, E. Lau, A review of greywater recycling related issues: challenges and future prospects in Malaysia, J. Cleaner Prod., 171 (2018) 17–29.
[19] E. Friedler, E. Lahav, H. Jizhaki, T. Lahav, Study of urban population attitudes towards various wastewater reuse options: Israel as a case study, J. Environ. Manage., 81 (2006) 360–370.
[20] S. Russell, C. Lux, G. Hampton, Beyond information: integrating consultation and education for water recycling initiatives, Soc. Nat. Resour., 22 (2009) 56–65.
[21] K.J. Omerod, C.A. Scott, Drinking wastewater: public trust in potable reuse, Sci. Technol. Hum. Values, 38 (2013) 351–373.
[22] S. Dalahmeh, M. Assayed, W. Suleiman, Themes of stakeholder participation in greywater management in rural communities in Jordan, Desalination, 243 (2009) 159–169.
[23] E. Friedler, R. Kovalio, A. Ben-Zvi, Comparative study of the microbial quality of greywater treated by three on-site treatment systems, Environ. Technol., 27 (2006) 653–663.
[24] A. Jamrah, A. Al-Futaisi, M. Ahmed, S. Prathapar, A. Al-Harrasi, A. Al-Abri, Biological treatment of greywater using sequencing batch reactor technology, Int. J. Environ. Stud., 65 (2008) 71–85.
[25] A. Wheatley, S. Surendran, Greywater treatment and reuse from a 50-person trial, Urban Water J., 5 (2008) 187–194.
[26] E. Aizenchtadt, D. Ingman, E. Friedler, Analysis of the long-term performance of an on-site greywater treatment plant using novel statistical approaches, Urban Water J., 6 (2009) 341–354.
[27] L. Abu Ghunmi, Characterization and Treatment of Greywater; Options for (re) Use, Ph.D. Dissertation, Wageningen University, Wageningen, The Netherlands, 2009.
[28] F. Li, K. Wichmann, R. Otterpohl, Review of the technological approaches for greywater treatment and reuses, Sci. Total Environ., 407 (2009) 3439–3449.
[29] L. Abu Ghunmi, G. Zeeman, M. Fayyad, J. Van Lier, Greywater treatment in a series anaerobic – aerobic system for irrigation, Bioresour. Technol., 101 (2010) 41–50.
[30] H. Maobe, High Rate Algal Pond for Greywater Treatment in Arid and Semi-Arid Areas, Ph.D. Dissertation, Hokkaido University, Hokkaido, Japan, 2014.
[31] S. Kant, F. Jaber, R. Karthikeyan, Evaluation of a portable in-house greywater treatment system for potential water reuse in urban areas, Urban Water J., 15 (2018) 309–315.
[32] B. Prajapati, M. Jensen, Greywater treatment through biofilm development and sediment accumulation in a horizontal batch-operated open reactor, Urban Water J., 16 (2019) 594–599.
[33] H. Abdel-Shafy, A. Al-Sulaiman, Assessment of physico-chemical processes for treatment and reuse of greywater, Egypt J. Chem., 57 (2014) 215–231.
[34] H. Abdel-Shafy, A. Al-Sulaiman, M. Mansour, Anaerobic/aerobic treatment of greywater via UASB and MBR for unrestricted reuse, Water Sci. Technol., 71 (2015) 630–637.
[35] S. Barıscı, H. Sarkka, M. Sillanpaa, A. Dimoglo, The treatment of greywater from a restaurant by electrosynthesized ferrate(VI) ion, Desal. Water Treat., 57 (2016) 11375–11385.
[36] G. Barzegar, J. Wu, F. Ghanbari, Enhanced treatment of greywater using electrocoagulation/ozonation: investigation of process parameters, Process Saf. Environ. Prot., 121 (2019) 125–132.
[37] M. Chong, Y. Cho, P. Poh, B. Jin, Evaluation of Titanium dioxide photocatalytic technology for the treatment of reactive Black 5 dye in synthetic and real greywater effluents, J. Cleaner Prod., 89 (2015) 196–202.
[38] M. Chrispim, M. Nolasco, Greywater treatment using a moving bed biofilm reactor at a university campus in Brazil, J. Cleaner Prod., 142 (2017) 290–296.
[39] J. Church, M. Verbyla, W. Lee, A. Randall, T. Amundsen, D. Zastrow, Dishwashing water recycling system and related water quality standards for military use, Sci. Total Environ., 529 (2015) 275–284.
[40] R. Daghrir, A. Gherrou, I. Noel, B. Seyhi, Hybrid process combining electrocoagulation, electroreduction, and ozonation processes for the treatment of grey wastewater in batch mode, J. Environ. Eng., 142 (2016) 1–13.
[41] M. Fountoulakis, N. Markakis, I. Petousi, T. Manios, Single house on-site grey water treatment using a submerged membrane bioreactor for toilet flushing, Sci. Total Environ., 551 (2016) 706–711.
[42] D. Ghaitidak, K. Yadav, Effect of coagulant in greywater treatment for reuse: selection of optimal coagulation condition

using analytic hierarchy process, Desal. Water Treat., 55 (2015a) 913–925.
[43] D. Ghaitidak, K. Yadav, Reuse of greywater: effect of coagulant, Desal. Water Treat., 54 (2015b) 2410–2421.
[44] A. Vuppaladadiyam, N. Merayo, A. Blanco, J. Hou, D. Dionysiou, M. Zhao, Simulation study on comparison of algal treatment to conventional biological processes for greywater treatment, Algal Res., 35 (2018) 106–114.
[45] J. Zhu, M. Wagner, P. Cornel, H.B. Chen, X.H. Dai, Feasibility of on-site grey-water reuse for toilet flushing in China, J. Water Reuse Desal., 8 (2018) 1–13.
[46] E. Friedler, M. Hadari, Economic feasibility of on-site greywater reuse in multi story buildings, Desalination, 190 (2006) 221–234.
[47] L. Abu Ghunmi, G. Zeeman, M. Fayyad, J. Van Lier, Greywater treatment systems: a review, Crit. Rev. Env. Sci. Technol., 41 (2011) 657–698.
[48] M. Oteng-Peprah, M. Acheampong, N. DeVries, Greywater characteristics, treatment systems, reuse strategies and user perception-a review, Water Air Soil Pollut., 229 (2018) 1573–2932.
[49] A. Al-Omari, S. Al-Quraan, A. Al-Salihi, F. Abdulla, A water management support system for AZB in Jordan, Water Resour. Manage., 23 (2009) 3165–3189.
[50] J. Jaber, M. Mohsen, Evaluation of non-conventional water resources supply in Jordan, Desalination, 136 (2001) 83–92.
[51] O. Al-Jayyousi, Greywater reuse: towards sustainable water management, Desalination, 156 (2003) 181–192.
[52] E. Surani, Research Influence on Policy: The Greywater Reuse Case of Jordan, Final Report Submitted to IDRC-CRDI, Evaluation Unit, 2003. Available at: http://hdl.handle.net/10625/29194
[53] O. Al-Jayyousi, Greywater reuse: knowledge management for sustainability, Desalination, 167 (2004) 27–37.
[54] L. Abu Ghunmi, G. Zeeman, J. Van Leir, M. Fayyad, Quantitative and qualitative characteristics of grey water for reuse requirements and treatment alternatives: the case of Jordan, Water Sci. Technol., 58 (2008) 1385–1396.
[55] H. Al-Hamaiedeh, M. Bino, Effect of treated greywater reuse in irrigation on soil and plants, Desalination, 256 (2010) 115–119.
[56] B. Jefferson, A. Laine, S. Parsons, T. Stephenson, S. Judd, Technologies for domestic wastewater recycling, Urban Water J., 1 (2000) 285–292.
[57] E. Eriksson, K. Auffarth, M. Henze, A. Ledin, Characteristics of grey wastewater, Urban Water J., 4 (2002) 85–104.
[58] R. Penn, M. Schütze, E. Friedler, Modeling the effects of on-site greywater reuse and low flush toilets on municipal sewer systems, J. Environ. Manage., 114 (2013) 72–83.
[59] C. Noutsopoulos, A. Andreadakis, N. Kouris, D. Charchousi, P. Mendrinou, A. Galani, L. Mantziaras, E. Koumaki, Greywater characterization and loadings physicochemical treatment to promote on site reuse, J. Environ. Manage., 216 (2018) 337–346.
[60] S.A. Prathapar, A. Jamrah, M. Ahmed, S. Al Adawi, S. Al Sidairi, A. Al Harassi, Overcoming constraints in treated greywater reuse in Oman, Desalination, 186 (2005) 177–186.
[61] E. Amanatidou, G. Samiotis, E. Trikoilidou, D. Tzelios, A. Michailidis, Influence of wastewater treatment plants' operational conditions on activated sludge microbiological and morphological characteristics, Environ. Technol., 37 (2016) 265–278.
[62] M. Al-Waheibi, Conventional Activated Sludge Technique and Membrane Bioreactor Technology at Al Ansab Sewage Treatment Plant, Master's Thesis, Sultan Qaboos University, Muscat, Oman, 2015.
[63] M. Travis, A. Wiel-Shafran, N. Weisbrod, E. Adar, A. Gross, Greywater reuse for irrigation: effect on soil properties, Sci. Total Environ., 408 (2010) 2501–2508.
[64] R. Birks, S. Hills, Characterization of indicator organisms and pathogens in domestic greywater for recycling, Environ. Monit. Assess, 129 (2007) 61–69.