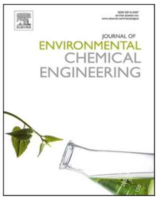
Journal of Environmental Chemical Engineering 12 (2024) 114250

Contents lists available at ScienceDirect

Journal of Environmental Chemical Engineering

journal homepage: www.elsevier.com/locate/jece



The removal of pollutants from synthetic bathroom greywater by coagulation-flocculation and filtration as a fit-for-purpose method

Andrea Szabolcsik-Izbéki [a,b], Ildikó Bodnár [a,*], István Fábián [c,d]

[a] *Department of Environmental Engineering, Faculty of Engineering, University of Debrecen, Ótemető u. 2-4., Debrecen H-4028, Hungary*
[b] *Doctoral School of Chemistry, University of Debrecen, Egyetem tér 1., Debrecen H-4032, Hungary*
[c] *Department of Inorganic and Analytical Chemistry, Faculty of Science and Technology, University of Debrecen, Egyetem tér 1., Debrecen H-4032, Hungary*
[d] *HUN-REN-DE Mechanism of Complex Homogeneous and Heterogeneous Chemical Reactions Research Group, Egyetem tér 1., Debrecen H-4032, Hungary*

ARTICLE INFO

Keywords:
Greywater analysis
Bathroom GW
Fit-for-purpose water treatment
Greywater reuse
Sustainability

ABSTRACT

It has been demonstrated that treated bathroom greywater (TBGW) is a useful substitute for fresh water for non-potable applications in households. Reuse of TBGW for irrigation, toilet flushing, car washing etc. offers a good opportunity to save drinking water and meet the sustainable development goals (SDGs). In this study, synthetic bathroom greywater (SBGW) was compiled in a controlled manner and used as a substitute for bathroom GW. Detailed statistical analysis also was performed to confirm the similarity between real and synthetic BGWs. SBGW is suitable for testing efficiency of applied treatment methods. It was confirmed that coagulation–-flocculation with iron(III) chloride and sand filtration was the most effective method of the tested 7 systems. The best and affordable treatment combination generates good-quality treated SBGW (TSBGW) (pH = 7.54 ± 0.29, TURB = 0.54 ± 0.49 NTU, BOD_5 = 21 ± 10 mgL^{-1}, COD = 32 ± 11 mgL^{-1}, and TOC = 12.7 ± 6.7 mgL^{-1}) for different non-potable purposes by complying with the regulated limit values for reuse. The elemental analysis of raw, TSBGW and tap water (TW) samples by MP-AES method provided further support for safe recycling. This study leads to the conclusion that the generation of TBGW by fit-for-purpose treatment can effectively meet the circular economy goals at household level. The recycling of GW is of limited importance in the European Union (EU) and legal regulations are not available in many countries. This study provides novel support for regulating the reuse of water in Eastern European countries.

1. Introduction

Alternative water sources (harvested rainwater from roofs, storm water, treated wastewater and greywater) represent a new approach could aid in achieving the Sustainable Development Goals (SDGs) at household level. It requires residents to apply new methods in urban water management and save the waters for non-potable purposes [1–3].

According to recent prognoses, water demand is steeply rising due to rapid urbanization, population growth, and increasing water needs for different sectors. Several studies now analyze the combined effect of urbanization and climate change on water demand [4,5]. Water security is not only the basis of food and energy security, but also of general long-term social and economic development [6–8].

Since the early 2000s, greywater (GW) has received increasing attention as a reusable domestic wastewater (WW) especially in water-scarce areas of the world. Every household generates a significant amount of GW from various activities, and it accounts for 50–80 % of daily WW release [9–11]. It has a great potential in water recycling [12] compared to rainwater that is unreliable due to climate and weather change [2]. The source of GW can be a more polluted “dark” stream (kitchen and laundry GW) or “light” stream (hand basin and bathing GW) [10–12].

The reuse of GW offers a possibility to reduce operational costs of urban water networks [12]. Recently, several comprehensive studies

---

Abbreviations: BGW, Bathroom Greywater; BOD_5, Biochemical Oxygen Demand; CF, Coagulation–flocculation; COD, Chemical Oxygen Demand; EC, Electrical Conductivity; GW, Greywater; MP-AES, Microwave Plasma Atomic Emission Spectroscopy; NGPR, Northern Great Plain Region; SBGW, Synthetic Bathroom Greywater; SEM, Scanning Electron Microscopy; SDGs, Sustainable Development Goals; TBGW, Treated Bathroom Greywater; TOC, Total Organic Carbon; TURB, Turbidity; TW, Tap water; WW, wastewater; ZP, Zeta potential.

* Corresponding author.
E-mail address: bodnari@eng.unideb.hu (I. Bodnár).

https://doi.org/10.1016/j.jece.2024.114250
Received 5 July 2024; Received in revised form 4 September 2024; Accepted 24 September 2024

have been published on the GW reuse in the urban context. Shaikh and Ahammed [13] have collected the up-to-date knowledge on the quantity and the quality of GW fractions, while Oteng-Peprah et al. [14] have presented a literature review on GW constituents, some natural and artificial treatment systems, reuse strategies and public perception regarding GW, especially in developing countries. Elhegazy and Eid [15] have covered the GW reuse potential, and the state-of-the-art GW reuse technologies. Vuppaladadiyam et al. [16] published a comprehensive review on barriers related to quality characteristics, administrative obstacles, public opinion, and worldwide overview of GW reuse experiences. Van de Walle et al. summarized the importance of GW quality characteristics and its monitoring, applying effective treatment methods and emphasized the significance of legal framework for GW management. They also highlighted the negative consumer perspectives on such reuse practices, but they had a positive outlook on integrating extensive GW reuse in water management [12].

From both health and aesthetic aspects, safe GW reuse requires adequate water treatment solutions. Various physical (e.g., sedimentation, filtration, membrane filtration), chemical (e.g., coagulation, oxidation), and biological (e.g., suspended growth, fixed films and natural processes) treatment methods can be adopted and combined as an effecting solution to improve the GW quality for safe reuse options [14,17–19]. There is no universal treatment strategy, each of them has its own advantages and limitations, so a sufficient treatment must be planned and applied based on the actual composition of the raw GW. So-called modular treatment systems for GW reuse make possible a wide range of options that can be applied as fit-for-purpose [12] mission and adapted to changes in conditions. Fit-for-purpose method is suitable for specific application. Using these treatment methods for local GW reuse will actively promote the public perception regarding various non-potable utilizations such as irrigation goals [20,21].

The efficiency of filtration was analyzed by using different filter media (silica sand, gravel, ash, peat, charcoal, zeolite or even pine tree bark) by Shaikh et al. [22] and Rakesh et al. [23]. Several types of sand filters (coarse sand, fine sand, beach sand, river sand) have been tested with particle sizes ranging from 0.3 mm to 2.5 mm. It was shown that the use of natural zeolites is advantageous because they remove suspended contaminants as regular filter media but are also capable of ion exchange and adsorption. Filtration on granular materials is considered a cost-effective and energy-saving solution which results in fewer harmful by-products than other typical GW treatment processes [24–26]. The cleaning performance depends on the size of the particles, the layer thickness and the surface chemical composition. Clogging limits the usability of filter systems, however, pretreatment of the raw GW by sedimentation or coagulation [22] is useful to circumvent this problem. In many regions, natural filter materials are available in large quantities for 1–2 $/kg.

The control of GW treatment processes (sedimentation, flotation and filtration) and adjustment of chemical compound dose (coagulation-flocculation, oxidation) during the treatment are often challenging steps in the treatment process. Monitoring a special analytical parameter such as zeta potential (ZP), we can evaluate the stability of colloidal systems. ZP is a measure of the electrical potential of the surface of particles in WW or GW and useful to predict the charge neutralization process between colloidal particles and coagulants [22,27,28].

Various coagulants can be used for coagulation–flocculation (CF) in the GW treatment process, especially salts, such as aluminum sulfate ($Al_2(SO_4)_3$), iron(III) chloride ($FeCl_3$), iron(III) sulphate ($Fe_2(SO_4)_3$) or different synthetic polymer flocculants such as polyaluminum chloride (PAC) or polyelectrolytes (PEs). These agents are also employed to precipitate the dissolved components or aggregate and remove suspended particles [29–32]. The use of iron(III) chloride leads to a higher-turbidity removal than the other agents, but its removal efficiency of organic materials is similar to the others. The biggest advantage of iron(III) chloride is the low price and the generation of more settleable flocs than those produced with PAC or PEs [29,31,33,34]. Coagulation-flocculation requires effective post-treatment process like sedimentation or filtration to remove the insoluble particles and to control the floc characterization and settling of dispersed solids [29,30,33]. Filtration is a popular separation technique, where the applied filter media characteristics (e.g. granular or non-granular media, sorption capacity) can also promote the removal of dissolved pollutant from raw water, however, the quality of GW and the effects of the pre-treatments may significantly influence the removal efficiencies of the applied methods [22].

Treated GW is increasingly seen as a resource for different non-potable purposes (toilet flushing, soaking, window cleaning or car washing, irrigation, fire protection etc.) Such applications require cost-effective methods to remove organic matter, surfactants, micropollutants, and eliminate microbial activity, too. High-quality effluents from GWs for potable reuse require special and expensive water treatment methods, such as membrane separation solutions (MBRs), electrochemical solutions, and their combination with biological methods. Because of the high cost of such technologies, their use is limited only to specific applications [35,36].

Current legislation of used water recycling supports the safe application of these alternative water sources. The limits of quality requirements primarily depend on the type of reuse and the possibility of human contact with recycled water, but they are also determined by the state of water resources, the state of the environment and the willingness of the inhabitants [14,16,37]. GW reuse guidelines are often based on recommendations by World Health Organization (WHO) [38,39] and the United States Environmental Protection Agency regulations (U.S. EPA) [40]. Countries such as the United States (USA), Australia, the UK, Italy and Japan established reuse regulations, while Germany, Slovenia, Jordan, China, India and Canada have developed individual guidelines on the reclaimed greywater quality [37]. Based on the SDGs, one of the highlighted goals is to apply the reclaimed water for irrigation purposes. Similarly to the treated urban WW [41–43] GWs are also suitable for multiple uses, so the new directives try to broaden of their reuse options [15,44]. In countries where the reuse of WW is allowed, the regulations specify the quality requirements for WW (include GW) [45]. Water quality guidelines often focus on general (e.g. pH=6–9, EC=3000 $\mu S cm^{-1}$, TSS=10–200 $mg L^{-1}$), aesthetic (e.g., TURB=2–10 NTU, and BOD_5=10–30 $mg L^{-1}$) and hygienic (e.g., total coliforms or E.coli/Faecal coli; E.coli=0–100 MPN/100 mL; Total Coliform=0–1000 MPN/100 mL;) parameters, but no international guidelines for the reuse of GW have been introduced as of yet [15].

Bathroom GW (BGW) is classified as low pollutant load greywater, so it can be treated and recycled using simple and economical treating methods [46]. Laundry GW fraction (LGW) can also be an alternative water source in the households, considering that this fraction is less polluted than GW from kitchen sinks and dishwashers [47].

The reuse options of GW at household level are often tested by using synthetic BGW (SBGW) [37,47–50]. These model waters can be produced in reproducible composition to study the efficiencies of various treatment methods. Synthetic GWs are relatively stable and maintain their characteristics for extended storage periods [51–53].

The main objective of this study was to develop a SBGW that can reproducibly be produced for modelling household BGWs. Various characteristics of water samples were determined and statistical analysis was performed to compare synthetic and real BGWs. Our goal was to establish a usable fit-for-purpose method for water treatment that generates TBGW for non-potable recycling at household level such as irrigation, toilet flushing, car washing, fire extinction, etc.

2. Materials and methods

2.1. Real bathroom GW (RBGW)

The real bathroom GW (RBGW) samples were randomly selected from households of the Northern Great Plain Region (NGPR) of Hungary to represent the local conditions and standard of living of the population. Immediately after use, 10 L sample was withdrawn from about 50 L GW in the bathtub, the samples were stored in closed acid-rinsed 5-L glass and 5-L plastic containers in a refrigerator at 4 °C and processed within 24 hours. Compared to our previous study [46], more households were involved, thus bathroom water samples and drinking water samples were taken from 41 and 35 sites, respectively. The RBGWs generally contained organic matter, salt and microelements in lower concentrations compared to other RGW fractions [46].

2.2. The preparation of synthetic bathroom greywater (SBGW)

SBGW samples as a model waters were assembled for routine measurements under non-sterilized laboratory ambient conditions, by dispersing 0.4 g shower gel (Nivea, Hamburg), 0.1 g shampoo (Syoss, Schwarzkopf & Henkel Düsseldorf, Germany), 0.1 g corn oil (Kronen Öl, VFI GmbH, Wels, Austria), and 0.155 g standard Nutrient Broth (Scharlab S. L, Spain) in 1 L of tap water from Debrecen, Hungary at 40 °C. The Nutrient Broth component was used based on the study by Dalahmeh and et. al. [54,55], because this component is useful to model the organic contamination released by the human skin surface.

Biological contamination e.g. pathogens was not added to the SBGW. The sample homogenization of raw SBGW was done by intense stirring (700 rpm) with a magnetic mixer for 20 min.

2.3. Analytical measurements

The quantitative analysis of SBGW, TSBGW and TW as a reference sample was performed by using common analytical methods. The following parameters were determined: pH, Zeta Potential (ZP), Electrical Conductivity (EC), turbidity (TURB), Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), and Total Organic Carbon (TOC). The results were obtained as the average of at least three parallel measurements. The pH was measured using a WTW Multi 3320 pH-meter. The ZP and EC values were determined with a Zetasizer Nano Z device (Malvern Instruments, Ltd., Malvern, UK). Based on these measurements the optimum amount of coagulant could be established for each BGW sample. The TURB was measured with a WTW Turb 555IR equipment (WTW GmbH). BOD_5 was determined using OxiTop IS12 (WTW GmbH, Weilheim, Germany) after incubating the samples for five days. COD was determined by the standard dichromate method [56] by using NanoColor Vis Spectrophotometer (Macherey-Nagel GmbH and Co. KG, Düren, Germany). The samples were heated in a thermoreactor for 2 hours at 148 °C (WTW GmbH, Weilheim, Germany) prior to the photometric measurements. TOC measurements were made using a Shimadzu TOC-V_{CPN} device (Shimadzu Europe GmbH, Duisburg, Germany).

The elemental analysis of the samples was performed by microwave plasma atomic emission spectroscopy (MP-AES 4200, Agilent Technologies Inc., Santa Clara, United States). Before analysis of the water samples, 50 µl of 67 % (m/m) HNO_3 (reagent grade, Sharlau, Spain) was added to a 50 mL aliquot of the sample. The concentrations of micro elements (Al, Ba, Cd, Cr, Cu, Fe, Li, Mn, Ni, Pb, Sr, Zn) and macro elements (Ca, K, Mg, Na) were determined.

Before TOC and MP-AES measurements, the samples were filtered through a 0.45 µm membrane filter (Cellulose Nitrate Membrane Filter, Sharlau, Spain). According to standardized measurement procedures, membrane filtration was not required for other measurements. During the water quality study, parallel measurements were performed for all samples, where the standard deviations of the parallel results were below 1 % for pH, TURB, ZP, EC; below 3 % for MP-AES and TOC; below 5 % for BOD_5 and COD.

Before and after the filtration, the quartz sand (SiO_2) and the zeolite filter layers were characterized by Scanning Electron Microscopy (SEM). A Hitachi TM-3030 SEM (Hitachi High-Technologies Europe GmbH, Japan) was used to characterize the solid samples. The samples were dried and were attached to a fixture with double-sided adhesive tape containing graphite. Before the SEM examination, the gold-sputtered coating was not deposited on the surface of the samples. The TM-3030 can be used to observe BSE images with a magnification range from 40x to 2500x. The measurement required a vacuum and a low accelerating voltage of 5 kV. Chemical elemental composition was performed on the fractured surface with a Bruker EDX 70 detector (Berlin, Germany). Elemental mapping (energy-dispersive spectroscopy, EDS) with X-ray analysis with a wide detection area (30 mm^2) was executed on the samples as well [57,58].

2.4. SBGW treatment processes

For the treatment of the SBGWs, the following methods were used either alone or in combination as a part of a planned modular treatment system: filtration on selected filter media, coagulation–flocculation with iron(III) chloride, sedimentation. The samples were analyzed after each step by the same analytical methods. Coagulation is considered favorable over flocculation because of its cost effectiveness, ease of operation and simplicity in design [29,33,34]. In this study, a relatively inexpensive coagulant, iron(III) chloride ($FeCl_3x6H_2O$, reagent grade, Sharlau, Spain), was used in a 25 gL^{-1} stock solution. To determine the optimum conditions, various amounts of the coagulant were added to 100 mL of the SBGW sample by vigorously mixing the solution for 30 s then applying a 5 min sedimentation period. The optimum was achieved when the measured ZP was 0 ± 5 mV. Larger volumes of SBGW (5 L) were treated in the CF process as follows. The initial pH of the samples was measured at ambient temperature, and the coagulation-flocculation conditions were established in our previous study [47] where we investigated various treatment conditions and optimize them for the studied GW samples. The optimum amount of the coagulant was added in a rapid mixing step (300 rpm, for 90 s) that was followed by slow mixing (50 rpm, for 15 min) and sedimentation (settling) for 20 min. After the sedimentation, the supernatant was removed by a peristaltic pump for filtration and analysis.

The filtration efficiency was tested using quartz, zeolite and mixed layer filter media. The particle size of quartz and zeolite was 0.1–1 mm and 10–20 mm, respectively. The porosity of the zeolite, quartz sand and gravel were 25, 73 and 70 % and their density were 1717, 2368 and 2611 kg m^{-3}, respectively. In the case of mixed filter media (S3 and S4 in Table 1) sand and zeolite were applied in 1:1 ratio. In order to increase the applied scale, we also performed measurements on a larger system, the dimensions of which are shown in Fig. 1.e. During the preliminary experiments, we established that there is no significant difference between the filtration efficiencies of the smaller and the larger systems, so the results obtained with systems S6 and S7 are presented. The use of the larger system made possible to filter larger quantities (300 L) of the sample. Most studies on GW treatment have used media depths between 30 – 100 cm, and anaerobic conditions have been reported at greater depths [22]. Therefore, we chose the height of the medium accordingly. Fig. 1 illustrates the structures of the applied filter systems. Table 1. summarizes the treatment methods presented in this study.

$$E\% = \frac{C_{raw} - C_{treated}}{C_{raw}} \chi 100 \qquad (1)$$

In each case, the removal efficiency was calculated using Eq. (1). Where $E\%$ is the removal efficiency, c_{raw} and $c_{treated}$ are the concentration of the raw BGW and the treated SBGW, respectively.

2.5. Statistical examination

The routine data calculations were made SPSS software package (SPSS Statistics IBM 22, New York, USA) using the functional options such as minimum, maximum, arithmetical mean and standard deviation. The Statistical software was applied in the analysis of all datasets at 95 % confidence level. Variables of interval-scale with approximate

Table 1
The treatment processes of SBGW samples.

	Treatment stage						
	Coagulation and flocculation before filtration	Sedimentation	Zeolite filter	Quartz Sand filter	Filtration on mixed bed (zeolite and sand)	Coagulation and flocculation after filtration	Sedimentation
System 1 (S1)				X			
System 2 (S2)			X				
System 3 (S3)					X		
System 4 (S4)			X	X			
System 5 (S5)	X	X					
System 6 (S6)				X		X	X
System 7 (S7)	X	X		X			

normal distributions were compared based on the t test of two independent samples. Levene's test was used to examine the homogeneity of the standard deviation of the results. In the case of analysis of variance (ANOVA), the Games-Howell post-hoc procedure was used if homogeneity of variance was violated, otherwise the Tukey and Gabriel's post-hoc procedure was used at a 95 % significance level.

3. Results and discussion

3.1. Comparison of the general composition of RBGW and SBGW samples

Based on the current European Union and international water recycling regulations [40,43,59] the pH, TURB and BOD_5 of reclaimed water are the main quality parameters and need to be determined. The minimum requirements for water reuse are set by considering these parameters.

The composition of domestic greywater is very diverse. Recently, we have confirmed that the characteristics of various GWs from the NGPR of Hungary show significant differences [46,47,60]. This finding is corroborated by the results presented in this study. We have analyzed 41 real BGWs and also the TWs collected from the same households. Based on these data, a SBGW was prepared and applied to model bathroom GW for laboratory scale tests. The TW used for the preparation of SBWG was analyzed on a regular basis and the main characteristics of SBGW were also determined. The results are summarized in Table 2.

TW(A) samples were taken from different households, TW(B) was obtained from the same location at different sampling times. The average values of the characteristic parameters for the two TWs are in reasonable agreement, the largest difference was found in EC (~ 29 %). It is noteworthy, that all parameters vary in a relatively large range in both cases. Except for EC, the standard deviations are larger for TW(A). This may reflect that the physical condition of the water pipes may differ from site to site. In the case of TW(B), the variation of the parameters may be associated with the inconsistency of the water quality provided by the supplier. In any case, the analyzed TWs satisfy the Hungarian drinking water quality criteria [61].

There is a small increase in the pH and electrical conductivity (EC) of RBGW and SBGW compared to TWs as expected, BOD_5, COD and TOC significantly increase due to the high organic content.

The BOD_5, TOC, and TURB values are very similar for these samples, while the pH, conductivity, and COD values were slightly higher for SBGW compared to RBGW. These differences may reflect that the samples contain different personal care products. The relatively large variation of the parameters for SBGW is not without precedent [48,62]. Theoretically, it may reflect the noted variation in the quality of TW(B), which was used for the preparation of the test solutions. Furthermore, although the same commercially available personal care products were used for the preparation of SBGW samples, their actual composition may have changed over the duration of this study.

Statistical analysis was carried out using the SPSS program. The characteristics of the RBGW and SBGW samples were examined by a two-sample t-test and the homogeneity within the group was checked using the Levene test. The results are summarized in Table S1.

In order to demonstrate whether differences in the quality of TW have an effect on the general characteristics of RBGW and SBGW samples, two-sample t-test and two-factor analysis of variance were used. The results obtained after the analysis are summarized in Table S2.

According to the statistical evaluation of the results, the deviation of some parameters for the real and model GW samples cannot be explained by the fluctuations in the TW quality only. The significant differences in the average values of pH, ZP, COD and TOC of RBGW and SBGW is presumably caused by the different types and various amounts of personal care product and their detergent content used in households. Several studies on RBGW support this conclusion [17,51,63,64]. The difference in the EC values for RBGW and SBGW samples may originate from the difference in the EC values between applied TWs and application of standard Nutrient Broth component of SBGW preparation. Nutrient Broth is a well-known component of lab-scale GW preparation in the literature [54,55], which is a mixture of nutrients, minerals and other elements representing the RBGW components.

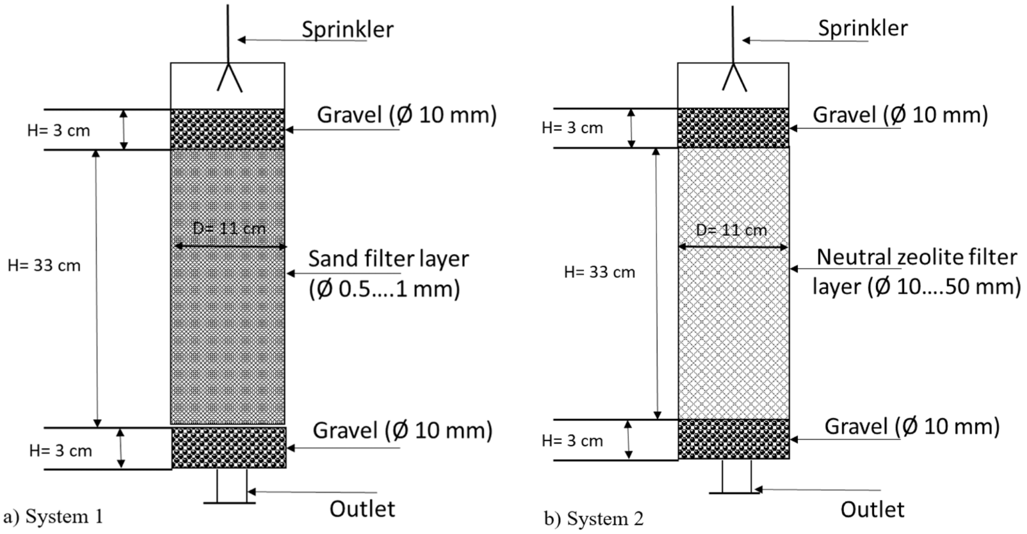
3.2. Comparison of elemental composition of RBGW and SBGW samples

The macro and micro elemental composition of the water samples were also examined. The concentration of 4 macro elements (Na, Ca, Mg, K) and 12 micro elements (Al, Ba, Cd, Cr, Cu, Fe, Li, Mn, Ni, Pb, Sr, Zn) were determined by MP-AES technique. Table S3 provides information on how many times the presence of micro elements could be confirmed in the water samples and Table 3 lists the results of elemental analysis.

RBGW and SBGW have considerably higher K and Na concentrations than the TWs. This is due to the detergents which are most likely added as alkali ion salts.

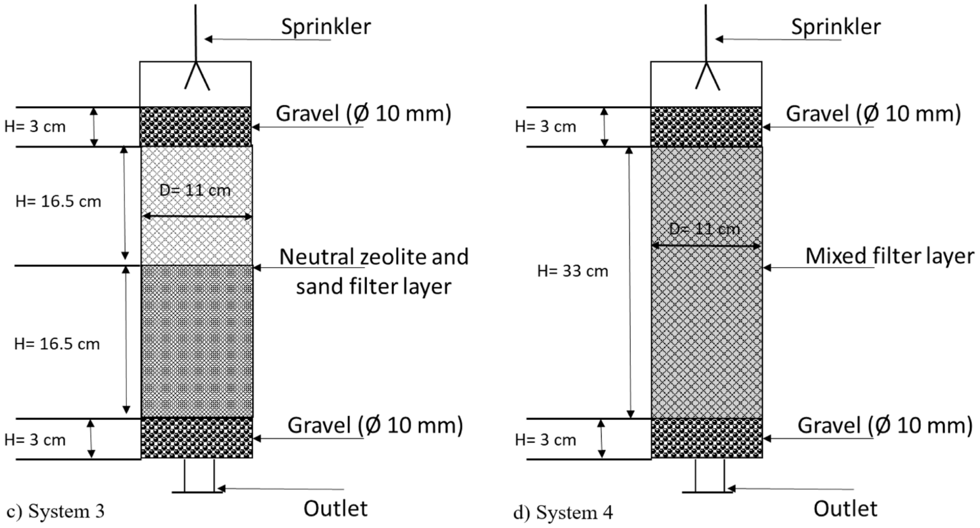
Clear trends do not emerge when the micro elemental compositions of the studied waters are considered. In general, the water quality satisfies the relevant regulation (Government Regulation [61]. Each element is present in RBGW and SBGW at lower than recommended maximum concentration level for irrigation water by FAO [38,41,65].

According to the analytical results, the SBWG presented here shows similar features to RBGWs and can be utilized for modelling the water treatment processes of RBGWs.



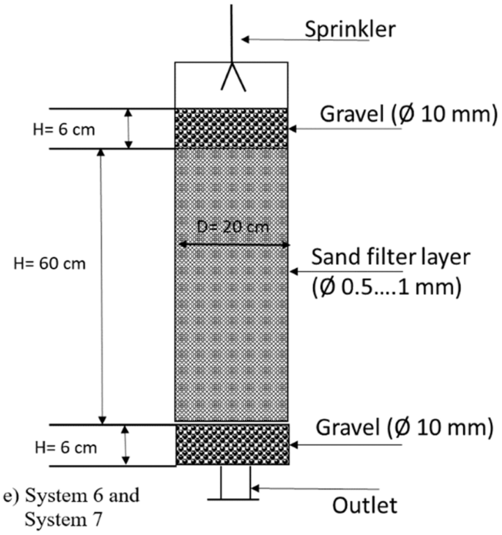
a) System 1

b) System 2



c) System 3

d) System 4



e) System 6 and System 7

Fig. 1. Set-up of filter columns used for SBGW treatment.a) System 1, filter layer: sand; b) System 2, filter layer: zeolite.; c) System 3, mixed filter layer: zeolite and sand, ratio= 1:1); d) System 4: mixed filter layer: sand and zeolite, ratio= 1:1; e) System 6 and System7, filter layer: sand; H= layer height; D= diameter; Ø= diameter of the particles.

Table 2
Characterization of different types of water.

Para-meter	Unit	TW(A)[a]		TW(B)[b]		RBGW		SBGW	
		Min-Max	Mean ± SD	Min-Max	Mean ± SD	Min-Max	Mean ± SD	Min-Max	Mean ± SD
n		35		52		41		53	
pH	-	6.77–8.01	7.39± 0.36	7.01–7.81	7.52 ± 0.16	6.73–7.95	7.44 ± 0.33	7.59–8.02	7.79 ± 0.11
ZP	mV	-	-	-	-	(−32)- (−0.6)	(−16) ± 9.5	(−39)-(−13)	(−28) ± 7
$EC_{25^{\circ}C}$	μScm^{-1}	439–631	528± 48	507–870	682 ± 74	412–753	549 ± 55	695–971	832 ± 55
TURB	NTU	0.01–3.17	0.67 ± 0.77	0.06–0.92	0.33 ± 0.21	2.31–130	29± 29	10–84	31± 15
BOD_5	mgL^{-1}	1–8	3.89± 1.8	1–6	3.21 ±1.4	7–883	142± 168	85–300	152 ± 38
COD	mgL^{-1}	4–20	13± 5	4–17	11 ±4	22–225[c]	89 ± 46[c]	370–661	501 ± 99
TOC	mgL^{-1}	0.86–3.33	2.26± 0.8	2.20–6.00	2.81 ± 0.66	7.71–118	43 ± 25	41–87	59 ± 10

[a] TW(A): tap water samples from the place of origin of real bathroom water samples.
[b] TW(B) tap water samples used for the preparation of model bathroom water samples.
[c] The number of samples analyzed was 15.

Table 3
The elemental composition of different water samples in mgL^{-1}.

	Recommendation for maximum concentration of the trace elements in irrigation water[a]	n[b]	TW(A)	TW(B)	RBGW	SBGW
			35	24	41	24
Macro element						
Ca	-	Min-Max	45–84	15–92	42–381	59–96
		Mean ± SD	71 ± 7	65 ± 17	106 ± 71	77 ± 11
K	-	Min-Max	0.46–12	0.40–9.7	1.26–19.1	3.0–9.54
		Mean ± SD	2.7 ± 1.7	3.0 ± 1.9	7.16 ± 4.15	4.76 ± 1.28
Mg	-	Min-Max	5.5–21	9.7–19	5.9–44	14–18
		Mean ± SD	16 ± 3	15 ± 2	20 ± 6	16 ± 1.1
Na	-	Min-Max	2.46–37	17–52	8.8–115	31–72
		Mean ± SD	23± 6	27 ± 8	41 ± 17	49± 11
Micro element						
Al	5.00	Min-Max	BDL[c]	0.016–0.57	0.016–0.062	0.016–0.067
		Mean ± SD	-	0.22 ± 0.27	0.031 ± 0.015	0.023 ± 0.015
Ba	-	Min-Max	0.037–0.58	0.009–0.54	0.057–0.61	0.072–0.19
		Mean ± SD	0.37 ± 0.13	0.18 ± 0.10	0.35 ± 0.10	0.14 ± 0.04
Cd	0.01	Min-Max	BDL[c]	BDL[c]	BDL[c]	BDL[c]
		Mean ± SD	-	-	-	-
Cr	0.05	Min-Max	0.001	0.006–0.084	0.001–0.005	0.003–0.015
		Mean ± SD	-	0.038 ± 0.041	0.002±0.002	0.009±0.008
Cu	0.20	Min-Max	0.050–0.13	0.013–0.12	0.027–0.38	0.019–0.095
		Mean ± SD	0.022 ± 0.027	0.040 ± 0.025	0.14 ± 0.073	0.048 ± 0.018
Fe	5.0	Min-Max	0.026–0.067	0.025–0.121	0.028–1.27	0.026–0.058
		Mean ± SD	0.037 ± 0.015	0.041 ± 0.033	0.11 ± 0.20	0.034 ± 0.008
Li	2.5	Min-Max	0.001–0.021	0.0097–0.016	0.011–0.020	0.008–0.012
		Mean ± SD	0.011 ± 0.004	0.0122 ± 0.003	0.014 ± 0.003	0.010 ± 0.001
Mn	0.2	Min-Max	0.002–0.056	0.003–0.022	0.005–0.021	0.002–0.080
		Mean ± SD	0.009±0.011	0.007±0.005	0.012 ± 0.005	0.005 ± 0.002
Ni	0.2	Min-Max	0.002–0.004	BDL[c]	0.001–0.028	0.002–0.003
		Mean ± SD	0.003 ± 0.001	-	0.007 ± 0.007	0.003 ± 0.001
Pb	5.0	Min-Max	0.037–0.11	BDL[c]	0.044–0.19	0.011
		Mean ± SD	0.070 ± 0.015	-	0.080±0.022	-
Sr	-	Min-Max	0.46–1.90	0.11–1.26	0.50–1.23	0.28–0.48
		Mean ± SD	0.96 ± 0.25	0.49 ± 0.27	0.9 ± 0.13	0.38±0.06
Zn	2.0	Min-Max	0.16–0.76	0.085–1.53	0.18–0.91	0.26–0.86
		Mean ± SD	0.29 ± 0.12	0.68 ± 0.36	0.30 ± 0.12	0.56 ± 0.17

[a] FAO guidelines [38,41,65]
[b] n = number of samples;
[c] BDL = below the LoD. The LoD values can be found in Table S3.

3.3. The efficiency of the water treatment processes

Different water treatment methods (Table 1) were evaluated by testing their performances in the removal of pollutants from SBGW. We focused on inexpensive and effective systems (filtration through various filter media, clarification with iron(III) chloride etc.) that are suitable for meeting the minimum requirements of reclaimed water reuse regulations and can be operated in households and small communities. In this context, it needs to be emphasized that the nutrient content of BWGs is relatively small and the use of biological or natural methods for the treatment of these fractions is difficult and uneconomical. In contrast, physico-chemical methods have been proven to satisfy the general expectations. The biggest financial advantage of filtering through granular media is the possibility to use locally available inexpensive materials [22,64].

Several studies have reported GW treatment methods applying filtration through granular filter bed (quartz sand, lava rock and gravel). Most of them used a single-media filter in test experiments, but some recent studies have investigated the potential effectiveness of multimedia filters [9,22,54,55].

In this study, we investigated quartz sand and natural zeolite as inexpensive filter media, as well as their combinations. Typically, 10 times 5 L SBWG was filtered on one load of filtering medium. The filter media were characterized by SEM before and after use (Figs. 2 and 3).

An inspection of Fig. 2 and Fig. 3 reveals the appearance of shiny spots on the surface of the filter media that is attributed to the deposition of the organic pollutants on the surface. In case of zeolite, the porosity increased, and the particle size decreased during the filtration process. Using the spectra from EDX analysis, we also determined the elemental composition of samples, which is summarized in Table 4. The device determines the number of atoms of individual elements, and then calculates their partial proportions. Even a small change in % of atoms provides important information.

The EDX analysis was suitable for looking at the changes that occurred in the filter media by examining the average percentage elemental composition before and after filtration, so we can perform a semi-quantitative test. It can be established that the dominance of Si and O decreased in the case of quartz sand after filtration, and the percentage of Al, Ca, K, Mg and Na increased, i.e. the proportion of elements unequivocally changed. Using natural zeolite as a filter medium, the composition of filter medium surface was not changed significantly after the treatment.

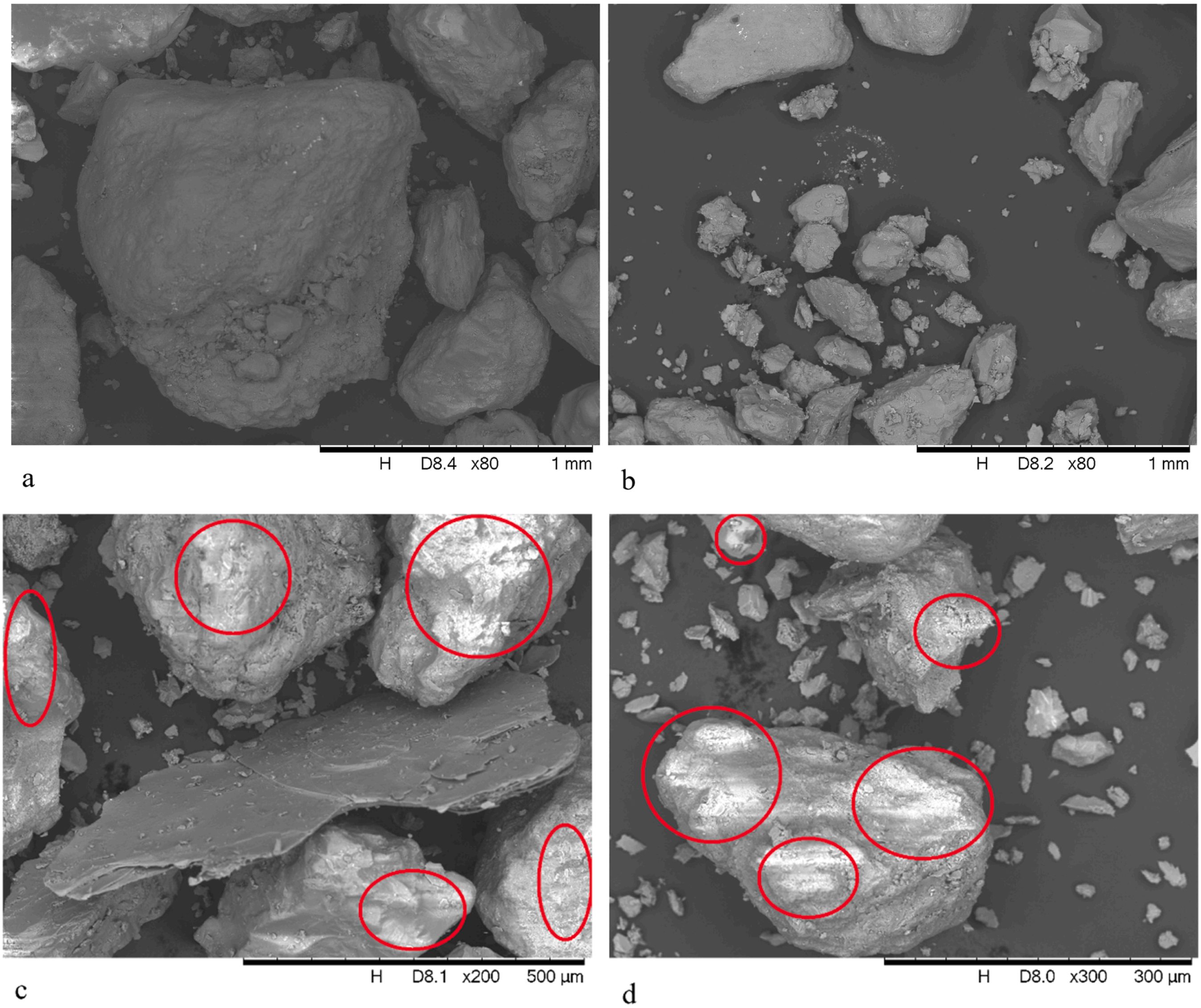


Fig. 2. SEM images of quartz sand filter medium at different magnifications before (a, b) and after (c, d) filtration. (The red circles indicate the organic matter content of the filter media.).

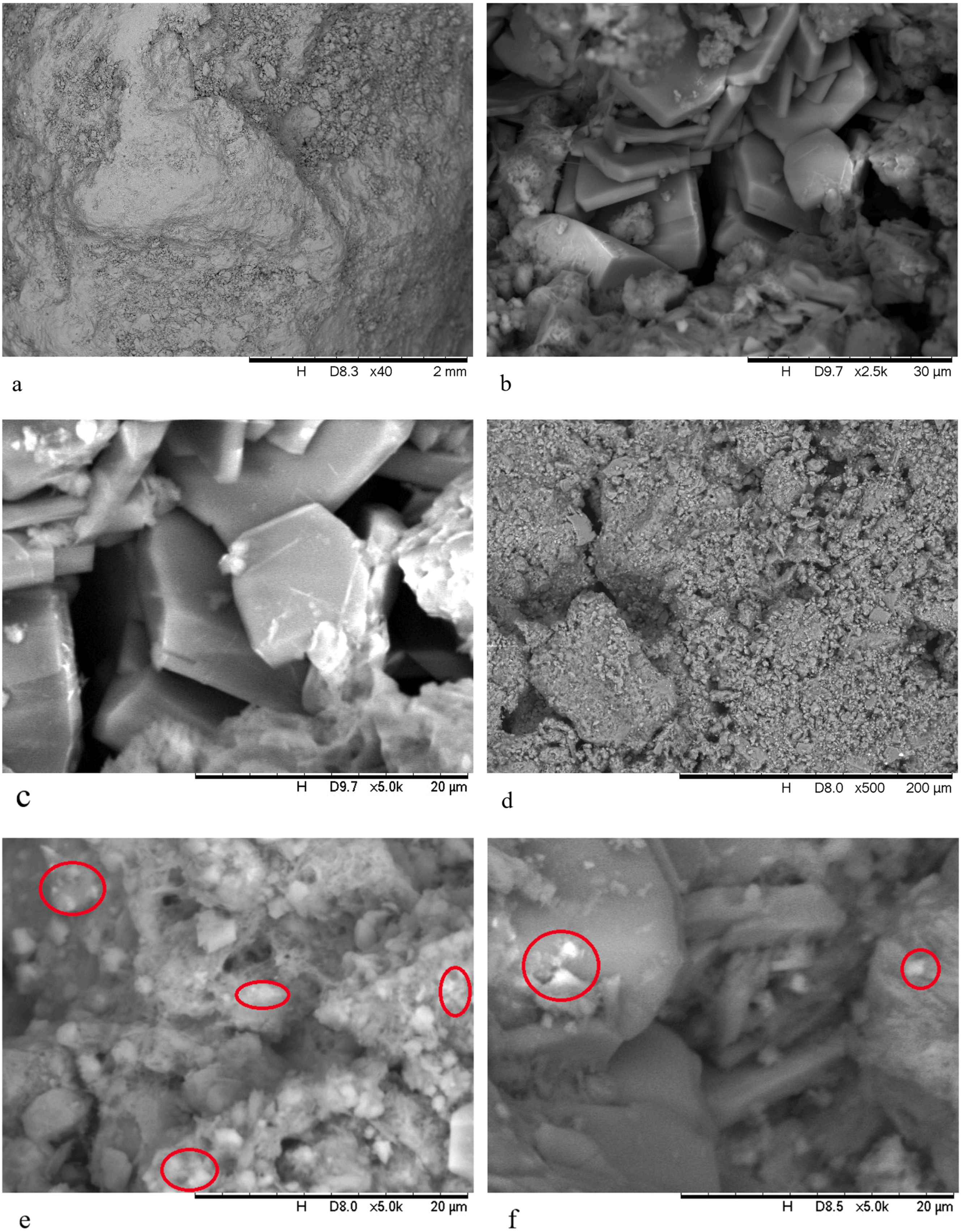


Fig. 3. SEM images of zeolite filter medium at different magnifications before (a, b, c) and after (d, e, f) filtration. (The red circles indicate the organic matter content of the filter media.).

Table 4
Elemental composition (% of atom) of sand and natural zeolite filter media by SEM-EDX before and after filtration.

	Sand before the filtration		Sand after the filtration		Zeolite before the filtration		Zeolite after the filtration	
	Mean	SE	Mean	Error	Mean	SE	Mean	SE
Unit	%	%	%	%	%	%	%	%
Elements								
Al	3.6	0.3	6.7	0.7	6.5	0.1	7.4	0.2
Ca	0.2	0.1	0.6	0.2	1.7	0.1	1.7	0.1
Fe	2.9	0.5	4.5	0.9	1.3	0.1	1.5	0.2
K	0.9	0.1	1.6	0.2	4.0	0.1	3.8	0.2
Mg	0.6	0.1	1.1	0.1	0.5	0.1	0.6	0.0[a]
Na	0.7	0.1	2.0	0.6	0.3	0.1	0.3	0.0[a]
O	56.2	0.2	54.6	0.6	54.5	0.5	50.2	1.2
Si	34.6	0.7	28.7	1.0	31.4	0.4	34.6	0.9
Ti	0.2	0.1	0.2	0.0[a]	-[b]		-[b]	

[a] <0.05 % of Standard error (SE).

[b] Not detected.

When we compare the quartz sand and zeolite filter layers compositions, it can be concluded that the zeolite has a higher percentage of Ca, Fe, K, which are exchangeable cations, thus playing an important role in the ion exchange capacity of the medium [66]. The cation exchange property of the zeolite was not significant, because the ion exchange requires usually a longer contact time [67]. In our case, the contact time is equivalent to the filtration time. It was established that the filtration rates are not affected by the volume of the filtrated SBGW, and the fastest filtration was observed in S2, which are shown in Fig. 4. However, it needs to be emphasized that the quality of the treated SBGW is the key issue when the performance of different filtration processes is compared.

GWs are colloid systems, and their stability is characterized by their resistance to flaking. The typical particle size in WW and GW is in the range of 10–100 µm [68] and the surface charge has a pivotal role in the transport of the particles during the filtration process. The colloidal particles in aqueous suspensions are negatively charged because they mainly adsorb anions, i.e. the colloids are stabilized by the repulsion between the particles. However, the negatively charged colloidal surface attracts positively charged ions and various coagulants, most often iron or aluminum salts or polyelectrolytes, are administered to neutralize the surface charge. The prerequisite of coagulation is the elimination of repulsive forces between the colloid particles. The stability of colloidal systems can be estimated on the basis of the electrokinetic potential (zeta potential, ZP), which is a measure of the charge on the surface of a particle. The Doppler effect electrophoresis method was used to measure the ZP of the samples. During coagulation, the isoelectric point (IEP) of an analyzed sample is reached, which is the pH at which the ZP is 0 mV. This implies no electric charge on the surface of a particle [22,46,69]. The ZP at the particle-solution interface, is a key indicator of particle stability and the probability of successful coagulation. The variation of ZP as a function of the amount of added coagulant makes it possible to predict the optimum conditions for coagulation and problems associated with under- or overdosing can be eliminated [27,28,58].

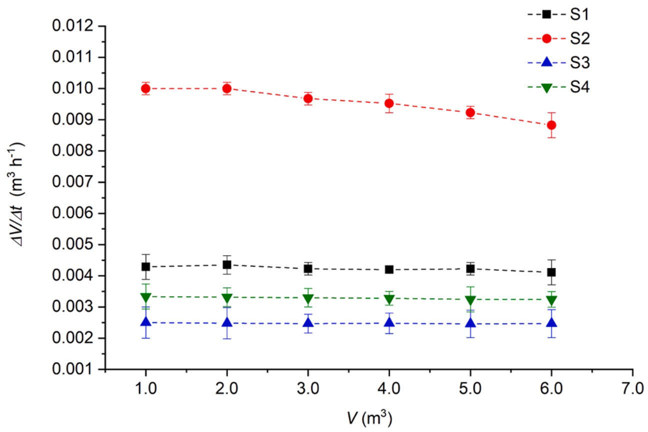


Fig. 4. The filtration rate as a function of the volume of filtrated SBGW. Filtration systems S1, S2, S3 and S4.

In tests, iron(III) chloride was used for the treatment of SBGW. Coagulation and flocculation is due to the partial hydrolysis of $FeCl_3$. The positively charged hydroxide species bind to the colloid particles and may also interact with the dissolved pollutants thus transferring them into insoluble sediments. The insoluble pollutants can physically be separated from the treated water by filtration or sedimentation [29,32,70].

In the coagulation-flocculation treatment process, the ideal zeta potential is 0 mV that corresponds to the isoelectric point (IEP) of the colloid. Practically ZP should fall in the range of 0 ± 5 mV [71]. Under such conditions, the repulsion between the particles is at minimum, the van der Waals forces and the chemical binding forces become dominant and the colloid system becomes unstable. According to our experimental results, the zeta potential somewhat increases with simple filtration, but it does not reach 0 ± 5 mV. Therefore, the use of appropriate chemical agent cannot be avoided by using a simple physical method for the treatment of SBGW.

To establish the optimum dose of $FeCl_3$ for setting ZP = 0 mV, we have tested 16 individual SBGW samples. The measured zeta potential is plotted as a function of coagulant dose in Fig. 5 and Figure S1. The data were fitted to a quadratic polynomial and the results are shown in Table S4 and Table S5. According to these measurements, the optimum dose of the coagulant is in the range of 74 – 99 mgL^{-1} for Fe^{3+}, which corresponds to 215 – 288 mgL^{-1} for $FeCl_3$ (Table S5). Furthermore, the experimental data from 16 series of measurements were fitted to a quadratic polynomial of concatenated data, the result of which is shown in Fig. 5. It was concluded that the optimal dose for Fe^{3+} is in the range of 74–95 mgL^{-1}.

The pH, EC, TURB and TOC were determined at 3 doses of the coagulant (min, max, and average) and were also analyzed as the functions of ZP. As shown in Fig. 6a, the pH of SBGW decreased upon increasing the coagulant dose as a consequence of the hydrolytic reactions of $FeCl_3$. The pH dropped below the lower limit recommended for the reuse of GWs (pH = 6 – 9) in many samples [37,40,59,72]. This strongly suggests that the pH needs to be strictly controlled in the treatment of RBGWs. Dosing an ionic compound ($FeCl_3$) to SBGW increased the EC values by an average of 17 % for Dose 1, 20 % for Dose

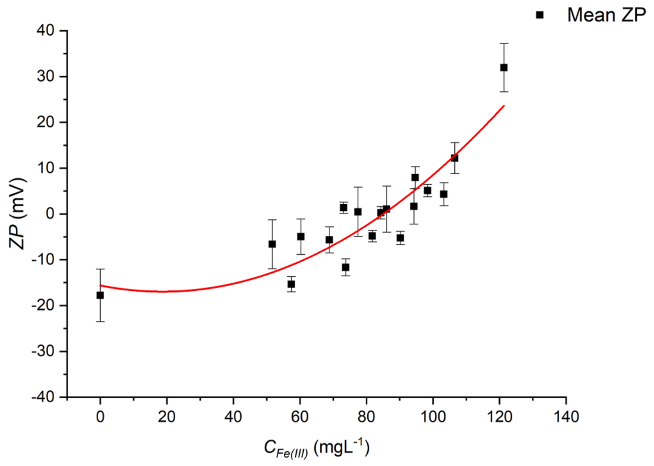


Fig. 5. The measured ZP values (■) as a function of coagulant dose. Solid line: fit of the concatenated data to a quadratic polynomial. (ZP = A + B x ($C_{Fe(III)}$) + C x $(C_{Fe(III)})^2$, A = −15.62 ± 5.1, B = −0.145 ± 0.14, C = 0.0039 ± 0.001).

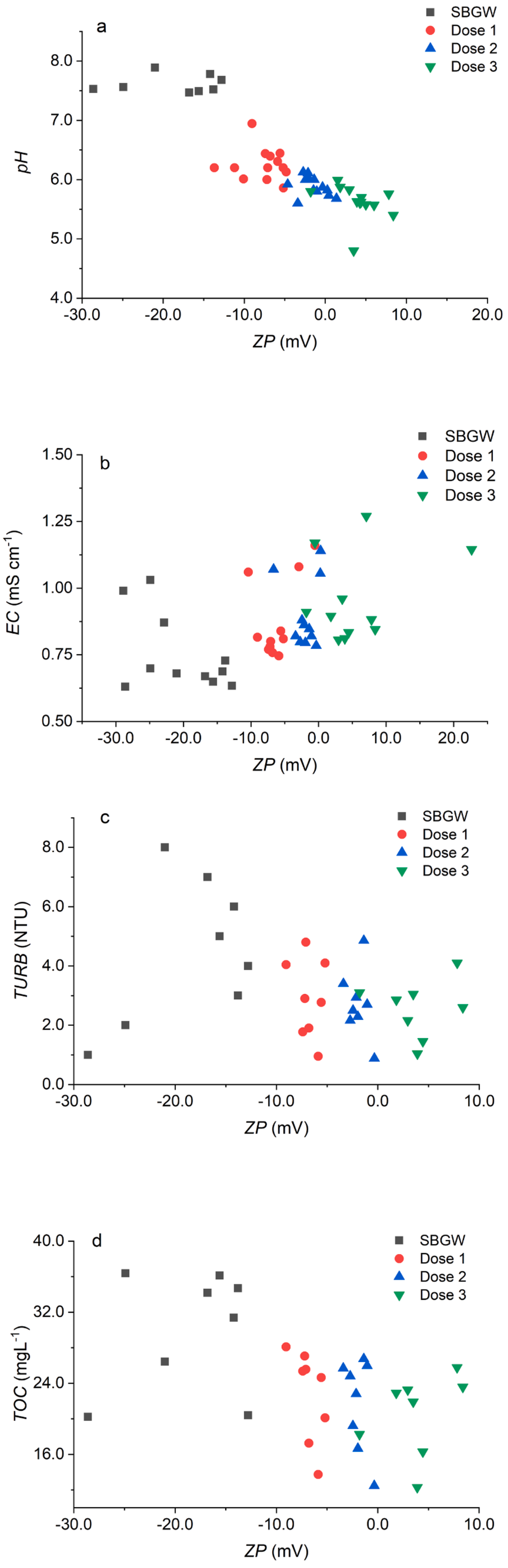


Fig. 6. The pH (a), EC (b), TURB (c) and TOC (d) as a function of ZP at three different doses of the coagulant: Dose 1: 200 mgL^{-1} $FeCl_3$; Dose 2: 250 mgL^{-1} $FeCl_3$; Dose 3: 300 mgL^{-1} $FeCl_3$. For comparison, the results are also shown for the untreated SBGW.

2, and 28 % for Dose 3 (Fig. 6b). The addition of the coagulant immensely reduced the turbidity of the treated water even when the smallest dose was applied (Fig. 6c). In contrast, only a minor decrease was observed in TOC. (Fig. 6d).

After the characterization of the filter systems and optimization of the coagulation, the SBGW samples were treated with 7 different treatment procedures. Our aim was to investigate whether the SBGW modelling the NGPR-generated bathwater can be treated using single methods to achieve the reuse requirements for GW. Table 5 summarizes the characteristic quality parameters for SBGW without treatment and after treatment using the methods listed in Table 1.

As expected, the physical treatments did not change the pH of the TSBGW samples. As discussed above, the use of $FeCl_3$ as coagulant decreased the pH to around 6. Interestingly, subsequent filtration through quartz sand compensated the pH effect of coagulation and the corresponding pH was 7.54 ± 0.29. Apparently, ZP will be a strongly negative value only in the case of filtration methods, which indicates that the filter layer does not retain the colloid-sized particles. Applying coagulation, we can remove colloidal components and ZP increases significantly.

As expected, the filtering procedures did not change the EC of the samples. Compared to the untreated SBGW, the conductivity was higher in all cases when the coagulant was used; the average increase was 36, 41 and 24 % in S5, S6 and S7, respectively. It is noteworthy that all EC values are below the regulation limit for drinking water (2500 μScm^{-1}) [61,73].

The turbidity provides information on the amount of insoluble components in a heterogeneous system. It is a non-specific parameter and does not directly give the concentration of the insoluble components in water, however, it is proportional to the amount of the suspended material and can be used for comparative purpose [74,75]. According to the related EU Directive on minimum requirements for reclaimed water for agricultural use, the average TURB value need to be below 5 NTU [43]. While filtration through zeolite and sedimentation alone were not suitable to meet the required conditions, the other methods were very efficient in reducing the TURB way below the allowed limit. The following removal efficiencies were obtained: S1: 95 %, S3: 95 %, S4: 94 %, S6: 94 %, and S7: 98 %.

On the basis of BOD_5 measurements, the following removal efficiencies were gained: 47 % (S1), 11 % (S2), 57 % (S3), 56 % (S4), 61 % (S5), 75 % (S6) and 87 % (S7). Thus, the best method for the removal of biodegradable organic components is S7 that is suitable to satisfy the 25 mgL^{-1} BOD_5 limit set for the irrigation reuse of GW by the relevant EU directive [43]. Based on the COD and TOC values, the organic matter removal efficiencies of the methods were as follows: 65, 50 % (S1); 25 %, 37 % (S2); 84 %, 64 % (S3); 82 %, 62 % (S4); 70 %, 45 % (S5); 89 %, 63 % (S6) and 93 %, 80 % (S7). All parameters confirm that S7, the combination of coagulation with $FeCl_3$ and the filtration on quartz sand, is the most efficient method for the removal of contaminants.

In earlier studies, various physical and physico-chemical methods were used for reducing the COD, BOD_5 and TOC values of the samples. In general, the removal efficiencies widely vary depending on the type of filter media used [54,76–79]. The results presented here are in line with earlier findings.

The ratio of COD/BOD provides information on the biodegradability of GW. In earlier studies, the COD/BOD ratio was typically between 2.9 – 3.6 for real greywater, which means low biodegradability, i.e., organic substances that are not biodegradable are present in relatively large concentrations in the studied waters [11,80]. According to our results (Table 6), the high COD/BOD ratio of SBGW was significantly reduced by the applied water treatment methods.

Furthermore, we examined TOC and TURB values vs. ZP values during the use of different treatment procedures (Fig S2), and we found that the greatest change was observed in case of method S7. Thus, the TOC value decreased to around 10 mg L^{-1}, while the TURB value was below 1 NTU, and the ZP value was −10 mV.

Table 5

Quality parameters for the SBGW and the TSBGWs after using various treatment methods (S1-S7).

	Unit		SBGW	S1	S2	S3	S4	S5[a]	S6[b]	S7[a]
n[c]			53	15	8	9	5	7	5	23
pH	-	Mean	7.82	7.93	7.99	7.95	8.05	5.84	5.93	7.54
		Δ[d]	-	0.11	0.17	0.13	0.23	−1.98	−1,89	−0,28
EC	μScm^{-1}	Mean	839	857	852	828	844	1138	1180	1036
		Δ[d]	-	19	13	−11	5	299	341	−197
ZP	mV	Mean	−27.5	−15.6	−24.8	−16.8	−16.9	−4.2	−0.62	−11.1
		Δ[d]	-	11.9	2.7	10.7	10.6	23.3	26.9	16.4
TURB	NTU	Mean	32.2	1.67	20.5	2.06	1.56	38.2	2.05	0.54
		Δ[d]	-	−30.5	−11.7	−30.1	−30.6	6	−30.2	−31.7
BOD_5	mgL^{-1}	Mean	160	75	143	70	69	63	39	21
		Δ[d]	-	−85	−17	−90	−91	−97	−121	−139
COD	mgL^{-1}	Mean	486	169	307	76	87	144	51	32
		Δ[d]	-	−317	−179	−410	−399	−342	−435	−454
TOC	mgL^{-1}	Mean	59.8	30.1	45.1	21.6	22.8	32.9	22.4	12.7
		Δ[d]	-	−29.7	−14.7	−38.2	−37	−32.9	−37.4	−47,1
COD/BOD_5 ratio	-	Mean	3.34	2.26	2.19	1.33	1.28	2.44	1.31	1.73
		Δ[d]	-	−1.08	−1.15	−2.01	−2.06	−0.90	−2.03	−1.61
COD/TOC ratio	-	Mean	8.55	5.63	6.83	3.47	3.83	4.36	2.38	2.76
		Δ[d]	-	−2.92	−1.72	−5.08	−4.72	4.19	−6.17	−5.79
TOC/BOD_5 ratio	-	Mean	0.38	0.40	0.32	0.39	0.33	0.56	0.60	0.66
		Δ[d]	-	0.02	−0.06	0.01	−0.05	0.18	0.22	0.28

[a] $FeCl_3$ of Dose was 250 mgL^{-1}.
[b] $FeCl_3$ of Dose was 200 mgL^{-1}.
[c] n is number of samples.
[d] The difference between the values of the treated and untreated samples, the rate of change.

Table 6

Elemental composition for SBGW samples, S1-S7 in mgL^{-1}.

	FAO guidelines[a]		SBGW	S1	S2	S3	S4	S5	S6	S7
		n[b]	24	15	7	8	15	4	5	20
Macro elements										
Ca	-	Mean	76.7	78.7	78.00	79.5	75.5	78.9	74.7	80.5
		SD	10.5	7.3	5.53	8.4	8.5	0.6	6.9	11.0
Mg	-	Mean	15.9	14.5	12.8	13.1	12.4	12.4	15.0	14.7
		SD	1.1	2.0	0.7	1.0	0.8	0.4	3.6	1.8
K	-	Mean	4.8	4.4	9.6	7.4	10.9	4.38	3.9	3.1
		SD	1.9	2.9	2.3	2.6	3.5	0.07	0.8	0.8
Na	-	Mean	49.2	39.5	39.8	36.3	33.0	48.4	35.5	37.6
		SD	10.5	64	5.3	8.1	11.3	1.6	4.7	8.2
Micro elements										
Al	5.00	Mean	0.023	0.019	BDL[c]	0.024	BDL	0.016	0.021	0.024
		SD	0.015	0.007	-[d]	-[d]	-[d]	0.001	0.006	0.019
Ba	-	Mean	0.17	0.080	0.054	0.105	0.174	0.379	0.133	0.101
		SD	0.04	0.085	0.007	0.112	0.106	0.016	0.073	0.034
Cd	0.01	Mean	BDL[c]	0.026	0.026	0.026	0.027	0.029	0.024	BDL[c]
		SD	-	0.005	0.004	0.005	-[d]	-[d]	0.001	-[d]
Cr	0.10	Mean	0.009	0.0048	BDL[c]	BDL[c]	0.0015	BDL[c]	BDL[c]	BDL[c]
		SD	0.008	0.0017	-[d]	-[d]	0.0007	-[d]	0.0053	-[d]
Cu	0.20	Mean	0.048	0.026	0.038	0.040	0.060	0.037	0.014	0.014
		SD	0.018	0.013	0.009	0.014	0.05	0.011	0.014	0.007
Fe	5.00	Mean	0.034	0.065	0.022	0.052	0.325	0.038	0.159	0.028
		SD	0.008	0.050	-[d]	-[d]	0.226	0.003	0.114	0.0029
Li	2.5	Mean	0.01	0.0093	0.0107	0.011	0.010	0.0093	0.0094	BDL[c]
		SD	0.001	0.0029	0.0022	0.004	0.002	0.0010	0.0019	-[d]
Mn	0.2	Mean	0.005	0.315	0.0087	0.091	0.093	0.076	0.635	0.095
		SD	0.002	0.389	0.0044	0.105	0.187	0.020	0.557	0.199
Ni	0.2	Mean	0.003	0.0047	0.0030	0.0048	0.0030	0.0095	0.0073	BDL[c]
		SD	0.001	0.0041	-[d]	0.0068	0.0014	0.0070	0.0047	-[d]
Pb	5.0	Mean	0.011	0.0043	0.0038	0.0038	0.0020	0.0045	0.0060	BDL[c]
		SD	-[d]	0.006	0.003	0.0025	0.001	0.0064	0.0057	-[d]
Sr	-	Mean	0.384	0.324	0.238	0.254	0.256	0.304	0.325	0.517
		SD	0.061	0.0514	0.0140	0.0742	0.0709	0.028	0.046	0.108
Zn	2.0	Mean	0.557	0.421	0.431	0.322	0.218	0.307	0.489	0.0519
		SD	0.171	0.059	0.097	0.089	0.108	0.248	0.050	0.104

[a] FAO guidelines [38,41,65]
[b] n = number of samples.
[c] BDL = below the LoD value.
[d] Not calculable.

In our experiments, we examined how the ZP correlates with the measured turbidity and TOC values and found that the closer the measured ZP is to 0 mV, the smaller the measured turbidity and TOC are.

The macro and micro elemental compositions of the SBGWs before and after treatment are shown in Tables S6, and Table 6. In the case of macro elements (Table 6), when the filter system contained zeolite (S2, S3, and S4), the concentration of K increased, while the concentration of Mg decreased. We were able to reduce the Na content by all treatment methods, and the removal efficiencies were 23 %, 22 %, 29 %, 35 %, 55 %, 30 %, and 26 % for S1, S2, S3, S4, S5, S6, and S7 systems, respectively. The concentration of Sr decreased due to treatments S1 – S6, while an increase was observed for treatment S7, as it was also observed in connection a similar treatment procedure in case of other types of GW fraction [47].

It was shown that method S7, which comprises coagulation-–flocculation (applying iron(III) chloride) and quartz sand filtration, was the best and affordable treatment combination. It generates good-quality treated SBGW (TSBGW) samples for different non-potable proposes as proven by the comparison with the related limit values for reuse. The best advantage of iron(III) chloride is that it has low operating and disposal costs and generates more settleable flocs than those produced with PAC or PEs [29,31,33,34].

Overall, the element concentrations are affected by the composition of the filter media used, but none of the treatments leads to a significant increase in element concentration that would prevent the reuse of TSBGWs as irrigation water.

4. Discussion

The initial goal of our research was to create a model bathroom GW which represents the real BGW samples produced in households and can be effectively used in laboratory test experiments. It was experimentally and statistically proven that the applied SBGW composition adequately represents real BGW samples, not only in terms of general quality criteria, but also in terms of micro and macro elemental concentrations.

Based on the tested 7 treatment systems it was shown that coagulation–flocculation, with iron(III) chloride and quartz sand filtration (S7) was the most effective. The best and affordable treatment combination generates good-quality TSBGW (pH = 7.54 ± 0.29, TURB = 0.54 ± 0.49 NTU, $BOD_5 = 21 \pm 10\ mgL^{-1}$, COD= $32 \pm 11\ mgL^{-1}$, and TOC = $12.7 \pm 6.7\ mgL^{-1}$) for different non-potable purposes by satisfying the regulated limit values for reuse. In the studied systems, we found removal efficiencies 87 %, 93 %, 79 %, and 98 % for BOD5, COD, TOC and TURB, respectively. Earlier Singh et al. [81] reported 80.9 %; 82.6 % and 95.5 % for the removal of BOD_5, COD and TURB when mixed GW was treated with alum salt coagulant and filtered on sand layer. In another study, similar conditions were applied and removal efficiencies 99 %, 91 % and 94 % were established for TURB, BOD_5 and COD, respectively [82]. In many cases, the treatment efficiency of different filtration systems or coagulation processes was investigated, but these methods were not combined. The effect of the treatment on the composition of GW was not monitored in the earlier studies. In contrast, we determined the micro- and macro-elemental concentrations in the treated GW samples to confirm the compliance with FAO regulations. Considering other research results, in many cases it can be found that the treatment efficiency of different filtration systems or coagulation processes was investigated, but these methods were not combined. In most studies alum has been preferred, because it does not decrease the pH while iron salts slightly acidify the GWs. According to our results, post-filtration raises the pH back into an acceptable range (6.0 – 9.0) making iron(III) chloride suitable for the treatment of GWs. This offers several advantages because this compound has a disinfecting effect on real GWs, furthermore, it is environment friendly and inexpensive compared to other coagulants. The elemental analysis of raw, TSBGW and TW by MP-AES method provides further support that TSBGW is safe for recycling. According to the elemental analysis it was shown that there is no significant change in elemental concentrations due to the treatment.

5. Conclusion

Using synthetic SBGW for lab-scale analysis of treatment solution is great opportunity to create model GW of constant composition. In this study various a fit-for-purpose physico-chemical treatment procedures were tested by analyzing the general parameters and the micro and macro elemental composition of untreated and treated GW. Our experiments clarified important details of the selection, optimization and evaluation of BGW for reuse. It was shown that the most effective treatment method produced an effluent possessing low turbidity and BOD_5 values and micro elemental composition which conforms to the regulations and can be reused.

Using of treated greywater as an alternative water stream can effectively help the improvement of decentralized water reuse and source separation supporting the goals of circular economy.

The recycling of GW is of limited importance in the European Union (EU) and legal regulations are not available in many countries. This study provides novel support for regulating the reuse of water in Eastern European countries. To improve the spread of GW reuse perspectives, it is necessary to generate community consultation steps to assess the views of the various stakeholders on the proposed GW reuse-systems. In accordance with these perspectives, our goal is to use the TSBGW for plant cultivation experiments and to explore the applicability of this treated fraction in hydroponic systems. Bioaccumulation and biomagnification tests will be implemented to examine the applicability of selected plants for human consumption after irrigation with TBGW.

Author contributions

I.B. and I.F. were responsible for the conceptualization and methodology. A. SZ-I. took part in the visualization, review, editing, and experiments validation. I.B. and I.F. were responsible for the review, supervision, and project administration. All authors have read and agreed to the published version of the manuscript.

CRediT authorship contribution statement

Ildiko Bodnar: Writing – review & editing, Supervision, Project administration, Methodology. **Istvan Fabian**: Writing – review & editing, Supervision, Project administration, Methodology. **Andrea Szabolcsik-Izbeki**: Writing – review & editing, Writing – original draft, Visualization, Validation.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Istvan Fabian reports financial support was provided by National Research, Development and Innovation Found of Hungary. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Data availability

Data will be made available on request.

Acknowledgments

We would like to thank the Partner Laboratory, Edina Baranyai and Zsófia Sajtos for the elemental analysis measurement and István Budai for the SEM measurement. This study was supported by the National

Research, Development and Innovation Found of Hungary under grant number OTKA-139140.

Conflicts of Interest

The authors declare no conflict of interest. The funder had no role in the design of the study; in the collection, analyzes, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jece.2024.114250.

References

[1] R.B. Johnston, Arsenic and the 2030 Agenda for sustainable development, 2016, Arsen. Res. Glob. Sustain. - Proc. 6th Int. Congr. Arsen. Environ. (2016) 12–14, https://doi.org/10.1201/b20466-7.
[2] D.E. McNabb, Glob. Pathways to Water Sustain, Glob. Pathw. Water Sustain. (2019) 1–303, https://doi.org/10.1007/978-3-030-04085-7.
[3] J. Müller, United Nations Millennium Declaration, Reform. U. Nations (2021) 209–218, https://doi.org/10.1163/9789004482012_014.
[4] A.G. Capodaglio, Taking the water out of "wastewater": An ineluctable oxymoron for urban water cycle sustainability, Water Environ. Res. 92 (2020) 2030–2040, https://doi.org/10.1002/wer.1373.
[5] A.G. Capodaglio, Urban wastewater mining for circular resource recovery: approaches and technology analysis, Water 15 (2023), https://doi.org/10.3390/w15223967.
[6] C.P. Kumar, Water security – challenges and needs, Int. Educ. Sci. Res. J. 4 (2018) 26–29.
[7] J. Rinaudo, Long-Term Water Demand Forecasting Long-Term Water Demand Forecasting, 2018. https://doi.org/10.1007/978-94-017-9801-3.
[8] G.M. Sanchez, A. Terando, J.W. Smith, A.M. García, C.R. Wagner, R. K. Meentemeyer, Forecasting water demand across a rapidly urbanizing region, Sci. Total Environ. 730 (2020), https://doi.org/10.1016/j.scitotenv.2020.139050.
[9] Y. Boyjoo, V.K. Pareek, M. Ang, A review of greywater characteristics and treatment processes, Water Sci. Technol. 67 (2013) 1403–1424, https://doi.org/10.2166/wst.2013.675.
[10] D.M. Ghaitidak, K.D. Yadav, Characteristics and treatment of greywater-a review, Environ. Sci. Pollut. Res. 20 (2013) 2795–2809, https://doi.org/10.1007/s11356-013-1533-0.
[11] A. Morel, S. Diener, Greywater Management in Low and Middle-Income Countries, 2006. ⟨https://www.ircwash.org/resources/greywater-management-low-and-middle-income-countries-review-different-treatment-systems⟩.
[12] A. Van de Walle, M. Kim, M.K. Alam, X. Wang, D. Wu, S.R. Dash, K. Rabaey, J. Kim, Greywater reuse as a key enabler for improving urban wastewater management, Environ. Sci. Ecotechnol, 16 (2023), https://doi.org/10.1016/j.ese.2023.100277.
[13] I.N. Shaikh, M.M. Ahammed, Quantity and quality characteristics of greywater: A review, J. Environ. Manag. 261 (2020) 110266, https://doi.org/10.1016/J.JENVMAN.2020.110266.
[14] M. Oteng-Peprah, M.A. Acheampong, N.K. deVries, Greywater characteristics, treatment systems, reuse strategies and user perception—a review, Water Air. Soil Pollut. 229 (2018), https://doi.org/10.1007/s11270-018-3909-8.
[15] H. Elhegazy, M.M.M. Eid, A state-of-the-art-review on grey water management: a survey from 2000 to 2020s, Water Sci. Technol. 82 (2020) 2786–2797, https://doi.org/10.2166/wst.2020.549.
[16] A.K. 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, https://doi.org/10.1007/s11157-018-9487-9.
[17] J. Anuja, B. Darshan, G. Saraswathi, N. Meyyappan, Study on reuse of grey water - a review, J. Phys. Conf. Ser. 1979 (2021), https://doi.org/10.1088/1742-6596/1979/1/012004.
[18] Z. He, Y. Li, B. Qi, Recent insights into greywater treatment: a comprehensive review on characteristics, treatment technologies, and pollutant removal mechanisms, Environ. Sci. Pollut. Res. 29 (2022) 54025–54044, https://doi.org/10.1007/s11356-022-21070-8.
[19] D.R. Samayamanthula, C. Sabarathinam, H. Bhandary, Treatment and effective utilization of greywater, Appl. Water Sci. 9 (2019) 1–12, https://doi.org/10.1007/s13201-019-0966-0.
[20] A.G. Capodaglio, Fit-for-purpose urban wastewater reuse: analysis of issues and available technologies for sustainable multiple barrier approaches, Crit. Rev. Environ. Sci. Technol. 0 (2020) 1–48, https://doi.org/10.1080/10643389.2020.1763231.
[21] V. Jegatheesan, L. Shu, L. Jegatheesan, Producing fit-for-purpose water and recovering resources from various sources: an overview, Environ. Qual. Manag. 31 (2021) 9–28, https://doi.org/10.1002/tqem.21780.
[22] I.N. Shaikh, M.M. Ahammed, Granular media filtration for on-site treatment of greywater: A review, Water Sci. Technol. 86 (2022) 992–1016, https://doi.org/10.2166/wst.2022.269.
[23] S. Rakesh, D.P. Ramesh, D.R. Murugaragavan, D.S. Avudainayagam, D. S. Karthikeyan, Characterization and treatment of grey water: a review, Int. J. Chem. Stud. 8 (2020) 34–40, https://doi.org/10.22271/chemi.2020.v8.i1a.8316.
[24] S. Nazif, S.T.O. Naeeni, Z. Akbari, S. Fateri, M.A. Moallemi, Development of data-driven models for the optimal design of multilayer sand filters for on-site treatment of greywater, J. Environ. Manag. 348 (2023) 119241, https://doi.org/10.1016/j.jenvman.2023.119241.
[25] I.N. Shaikh, M.Mansoor Ahammed, Comparative evaluation of different pre-treatment alternatives for granular media filters treating greywater and their ranking using analytical hierarchy process, Water Sci. Technol. 89 (2024) 2625–2645, https://doi.org/10.2166/wst.2024.155.
[26] G. Gupta, M. Mansoor Ahammed, I.N. Shaikh, Greywater treatment by zero-valent iron-modified sand filters: Performance and modelling using artificial neural network, Mater. Today Proc. 83 (2023) 24–32, https://doi.org/10.1016/j.matpr.2023.01.021.
[27] S. Barişçi, O. Turkay, Domestic greywater treatment by electrocoagulation using hybrid electrode combinations, J. Water Process Eng. 10 (2016) 56–66, https://doi.org/10.1016/j.jwpe.2016.01.015.
[28] M. Priyatharishini, N.M. Mokhtar, Study on the zeta potential effect of Artocarpus heterophyllus natural-based coagulant in wastewater treatment, IOP Conf. Ser. Mater. Sci. Eng. 991 (2020), https://doi.org/10.1088/1757-899X/991/1/012094.
[29] H.I. Abdel-Shafy, A.M. Al-Sulaiman, Assessment of physico-chemical processes for treatment and reuse of greywater 57 Egypt. J. Chem. , 2014, 215–231, 10.21608/ejchem.2014.1042.
[30] F. Nyström, K. Nordqvist, I. Herrmann, A. Hedström, M. Viklander, Laboratory scale evaluation of coagulants for treatment of stormwater, J. Water Process Eng. 36 (2020) 101271, https://doi.org/10.1016/j.jwpe.2020.101271.
[31] O. Ucevli, Y. Kaya, A comparative study of membrane filtration, electrocoagulation, chemical coagulation and their hybrid processes for greywater treatment, J. Environ. Chem. Eng. 9 (2021) 104946, https://doi.org/10.1016/J.JECE.2020.104946.
[32] E.M. Wilts, J. Herzberger, T.E. Long, Addressing water scarcity: cationic polyelectrolytes in water treatment and purification, Polym. Int. 67 (2018) 799–814, https://doi.org/10.1002/pi.5569.
[33] G. CEP, O. HA, A. AC, R. J, On the use of iron chloride and starch for clarification in drinking water treatment, Int. J. Water Wastewater Treat. 7 (2021) 1–10, https://doi.org/10.16966/2381-5299.178.
[34] L. Zaleschi, C. Teodosiu, I. Cretescu, M.A. Rodrigo, A comparative study of electrocoagulation and chemical coagulation processes applied for wastewater treatment, Environ. Eng. Manag. J. 11 (2012) 1517–1525, https://doi.org/10.30638/eemj.2012.190.
[35] D. Cecconet, A. Callegari, P. Hlavínek, A.G. Capodaglio, Membrane bioreactors for sustainable, fit-for-purpose greywater treatment: a critical review, Clean. Technol. Environ. Policy 21 (2019) 745–762, https://doi.org/10.1007/s10098-019-01679-z.
[36] D. Cecconet, S. Bolognesi, L. Piacentini, A. Callegari, A.G. Capodaglio, Bioelectrochemical greywater treatment for non-potable reuse and energy recovery, Water (Switz.) 13 (2021) 1–14, https://doi.org/10.3390/w13030295.
[37] F. Boano, A. Caruso, E. Costamagna, L. Ridolfi, S. Fiore, F. Demichelis, A. Galvão, J. Pisoeiro, A. Rizzo, F. Masi, A review of nature-based solutions for greywater treatment: Applications, hydraulic design, and environmental benefits, Sci. Total Environ. 711 (2020) 134731, https://doi.org/10.1016/j.scitotenv.2019.134731.
[38] R.S. Ayers, D.W. Westcot, Water quality evaluation, in: Water Qual. Agric., 29 Rev.1, FAO Irrigation and Drainage Paper, Rome, 1985.
[39] World Health Organization, Safe use of wastewater, excreta and greywater guidelines. Volume 4: Excreta and greywater use in agriculture 2 Wastewater Reuse Agric. , 2006, 182.
[40] E.P.Nancy Stoner, Lek Kadeli, EPA Guidlines for Water Reuse U.S. Environmental Protection Agency, Guidel. Water Reuse (2012) 643.
[41] A.F. Santos, P. Alvarenga, L.M. Gando-Ferreira, M.J. Quina, Urban wastewater as a source of reclaimed water for irrigation: barriers and future possibilities, Environ. - MDPI 10 (2023) 1–19, https://doi.org/10.3390/environments10020017.
[42] F. Shoushtarian, M. Negahban-Azar, World wide regulations and guidelines for agriculturalwater reuse: a critical review, Water (Switz.) (2020), https://doi.org/10.3390/W12040971.
[43] The European Parliament and the Council, Regulation EU 2020/741, Minimum requirements for water reuse Eur. Comm. , 2020, The European Parliament and the CouncilRegulation EU /741, Minimum requirements for water reuse, 20202019 (EU 2020/741).
[44] G. Oron, M. Adel, V. Agmon, E. Friedler, R. Halperin, E. Leshem, D. Weinberg, Greywater use in Israel and worldwide: standards and prospects, Water Res 58 (2014) 92–101, https://doi.org/10.1016/j.watres.2014.03.032.
[45] M. Mainardis, D. Cecconet, A. Moretti, A. Callegari, D. Goi, S. Freguia, A. G. Capodaglio, Wastewater fertigation in agriculture: issues and opportunities for improved water management and circular economy, Environ. Pollut. 296 (2022) 118755, https://doi.org/10.1016/j.envpol.2021.118755.
[46] I. Bodnar, A. Szabolcsik, E. Baranyai, A. Uveges, N. Boros, Qualitative characterization of household greywater in the northern great plain region of Hungary, Environ. Eng. Manag. J. 13 (2014) 2717–2724, https://doi.org/10.30638/eemj.2014.302.
[47] C.C.A. Cardoso, I. Bodnar, Modelling Treated Laundry Greywater Reuse for Irrigation Using an Affordable Treatment Method and Seed Germination Test, Sustain 14 (2022), https://doi.org/10.3390/su14031314.

[48] S.N. Abed, S.A. Almuktar, M. Scholz, Remediation of synthetic greywater in mesocosm—Scale floating treatment wetlands, Ecol. Eng. 102 (2017) 303–319, https://doi.org/10.1016/j.ecoleng.2017.01.043.

[49] S.N. Abed, S.A. Almuktar, M. Scholz, Impact of storage time on characteristics of synthetic greywater for two different pollutant strengths to be treated or recycled, Water Air. Soil Pollut. 231 (2020), https://doi.org/10.1007/s11270-020-04602-1.

[50] S. Pradhan, S.G. Al-Ghamdi, H.R. Mackey, Greywater treatment by ornamental plants and media for an integrated green wall system, Int. Biodeterior. Biodegrad. 145 (2019) 104792, https://doi.org/10.1016/j.ibiod.2019.104792.

[51] S.N. Abed, M. Scholz, Chemical simulation of greywater, Environ. Technol. (U. Kingd.) 37 (2016) 1631–1646, https://doi.org/10.1080/09593330.2015.1123301.

[52] E. Shahsavani, M.H. Ehrampoush, M.R. Samaei, E. Abouee Mehrizi, F. Madadizadeh, A. Abbasi, M. Shiranian, A. Mohammadpour, A.A. Ebrahimi, Real and synthetic greywater treatment by a combined process of ozonation, granular activated carbon, and ultrafiltration, Heal. Scope 11 (2022), https://doi.org/10.5812/jhealthscope-123644.

[53] K.A. Thompson, R.S. Summers, S.M. Cook, Development and experimental validation of the composition and treatability of a new synthetic bathroom greywater (SynGrey), Environ. Sci. Water Res. Technol. 3 (2017) 1120–1131, https://doi.org/10.1039/c7ew00304h.

[54] S.S. Dalahmeh, M. Pell, B. Vinnerås, L.D. Hylander, I. Öborn, H. Jönsson, Efficiency of bark, activated charcoal, foam and sand filters in reducing pollutants from greywater, Water Air. Soil Pollut. 223 (2012) 3657–3671, https://doi.org/10.1007/s11270-012-1139-z.

[55] S.S. Dalahmeh, M. Pell, L.D. Hylander, C. Lalander, B. Vinnerås, H. Jönsson, Effects of changing hydraulic and organic loading rates on pollutant reduction in bark, charcoal and sand filters treating greywater, J. Environ. Manag. 132 (2014) 338–345, https://doi.org/10.1016/j.jenvman.2013.11.005.

[56] 2002, ISO 15705, Water Qual. Determ. Chem. Oxyg. Demand Index (ST-COD) Small-Scale sealed-Tube Method.

[57] A. Lakatos, A. Csik, A. Trnik, I. Budai, Effects of the heat treatment in the properties of fibrous aerogel thermal insulation, Energies 12 (2019) 1–12, https://doi.org/10.3390/en12102001.

[58] T. To Quoc, K. Bíró, Á. Pető, D. Kósa, D. Sinka, I. Lekli, A. Kiss-Szikszai, I. Budai, M. Béres, M. Vecsernyés, P. Fehér, I. Bácskay, Z. Ujhelyi, Development and evaluation of an FDM printed nasal device for CPZ solid nanoparticles, Molecules 28 (2023) 1–15, https://doi.org/10.3390/molecules28114406.

[59] O.M.S., Safe Use of Wastewater, Excreta and Greywater Guidelines for the Safe Use of, World Health II (2006) 204. ⟨http://whqlibdoc.who.int/publications/2006/9241546832_eng.pdf⟩.

[60] A. Szabolcsik, E. Baranyai, I. Bodnár, Utilization of modern analytical techniques for the analysis of household generated greywater samples, Int. Rev. Appl. Sci. Eng. 6 (2015) 47–53, https://doi.org/10.1556/1848.2015.6.1.7.

[61] 5/2023 (I. 12.) Government Regulation on the quality requirements for drinking water and the inspection procedure in Hungary, Budapest, Hungary, 2023. ⟨https://ampeid.org/documents/hungary/5-2023⟩-(i-12)-government-decree-on-the-quality-requirements-of-drinking-water-and-the-inspection-procedure/.

[62] F. Hourlier, A. Masse, P. Jaouen, A. Lakel, C. Gerente, C. Faur, P. Le Cloirec, Formulation of synthetic greywater as an evaluation tool for wastewater recycling technologies, Environ. Technol. 31 (2010) 215–223, https://doi.org/10.1080/09593330903431547.

[63] A.K. Salama, Assessment of metals in cosmetics commonly used in Saudi Arabia, Environ. Monit. Assess. 188 (2015), https://doi.org/10.1007/s10661-016-5550-6.

[64] A. Mahmoudi, S.A. Mousavi, P. Darvishi, Greywater as a sustainable source for development of green roofs: characteristics, treatment technologies, reuse, case studies and future developments, J. Environ. Manag. 295 (2021) 112991, https://doi.org/10.1016/j.jenvman.2021.112991.

[65] M.B. Pescod, 1992, , Wastewater treatment and use in agriculture - FAO irrigation and drainage.

[66] N. Widiastuti, H. Wu, H.M. Ang, D. Zhang, Removal of ammonium from greywater using natural zeolite, Desalination 277 (2011) 15–23, https://doi.org/10.1016/j.desal.2011.03.030.

[67] I. Szilágyi, Z. Czibulya, A. Csík, M. Braun, C. Hegedűs, Zeolit és magnéziummal ioncserélt zeolit in vitro összehasonlító vizsgálata, Fogorv. Sz. 114 (2021) 100–105, https://doi.org/10.33891/fsz.114.3.100-105.

[68] B. Jefferson, A. Palmer, P. Jeffrey, R. Stuetz, S. Judd, Grey water characterisation and its impact on the selection and operation of technologies for urban reuse, Water Sci. Technol. 50 (2004) 157–164, https://doi.org/10.2166/wst.2004.0113.

[69] A. Morfesis, A.M. Jacobson, R. Frollini, M. Helgeson, J. Billica, K.R. Gertig, Role of Zeta (ζ) potential in the optimization of water treatment facility operations, Ind. Eng. Chem. Res. 48 (2009) 2305–2308, https://doi.org/10.1021/ie800524x.

[70] C. Noutsopoulos, A. Andreadakis, N. Kouris, D. Charchousi, P. Mendrinou, A. Galani, I. Mantziaras, E. Koumaki, Greywater characterization and loadings – Physicochemical treatment to promote onsite reuse, J. Environ. Manag. 216 (2018) 337–346, https://doi.org/10.1016/j.jenvman.2017.05.094.

[71] E.L. Bean, S.J. Campbell, F.R. Anspach, Zeta potential measurements in the control of coagulation chemical doses, J. Am. Water Works Assoc. 56 (1964) 214–227, https://doi.org/10.1002/j.1551-8833.1964.tb01202.x.

[72] K.S. Oh, J.Y.C. Leong, P.E. Poh, M.N. Chong, E.Von Lau, A review of greywater recycling related issues: challenges and future prospects in Malaysia, J. Clean. Prod. 171 (2018) 17–29, https://doi.org/10.1016/j.jclepro.2017.09.267.

[73] European Union Council, Directive (EU) 2020/2184 of the European Parliment and of the Council of 16 December 2020 on the quality of water intended for human consumption, Off. J. Eur. Union 2019 (2020) 1–62.

[74] E. Popek, Practical Approach to Sampling. in: Sampl. Anal. Environ. Chem. Pollut., Elsevier, 2018, pp. 145–225, https://doi.org/10.1016/B978-0-12-803202-2.00004-5.

[75] L.L. Simon, E. Simone, K. Abbou Oucherif, Crystallization process monitoring and control using process analytical technology, Comput. Aided Chem. Eng. 41 (2018) 215–242, https://doi.org/10.1016/B978-0-444-63963-9.00009-9.

[76] F. Boano, A. Caruso, E. Costamagna, L. Ridolfi, S. Fiore, F. Demichelis, A. Galvão, J. Pisoeiro, A. Rizzo, F. Masi, A review of nature-based solutions for greywater treatment: applications, hydraulic design, and environmental benefits, Sci. Total Environ. 711 (2020) 134731, https://doi.org/10.1016/j.scitotenv.2019.134731.

[77] J.Y. Al-Zou'by, K.K. Al-Zboon, J.A. Al-Tabbal, Low-cost treatment of grey water and reuse for irrigation of home garden plants, Environ. Eng. Manag. J. 16 (2017) 351–359, https://doi.org/10.30638/eemj.2017.035.

[78] E. Friedler, Y. Alfiya, Physicochemical treatment of office and public buildings greywater, Water Sci. Technol. 62 (2010) 2357–2363, https://doi.org/10.2166/wst.2010.499.

[79] S. Finley, S. Barrington, D. Lyew, Reuse of domestic greywater for the irrigation of food crops, Water Air. Soil Pollut. 199 (2009) 235–245, https://doi.org/10.1007/s11270-008-9874-x.

[80] G.A. Edwin, P. Gopalsamy, N. Muthu, Characterization of domestic gray water from point source to determine the potential for urban residential reuse: a short review, Appl. Water Sci. 4 (2014) 39–49, https://doi.org/10.1007/s13201-013-0128-8.

[81] S. Singh, M.M. Ahammed, I.N. Shaikh, Combined coagulation and intermittent sand filtration for on-site treatment of greywater, IOP Conf. Ser. Mater. Sci. Eng. 1114 (2021) 012031, https://doi.org/10.1088/1757-899x/1114/1/012031.

[82] I. Shaikh, M.M. Ahammed, Coagulation followed by continuous sand filtration for treatment of graywater, J. Hazard. Toxic. Radioact. Waste 25 (2021) 267–277, https://doi.org/10.1061/(ASCE)HZ.2153-5515.0000640.