Environmental Engineering and Management Journal
November 2014, Vol.13, No. 11, 2717-2724
http://omicron.ch.tuiasi.ro/EEMJ/

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QUALITATIVE CHARACTERIZATION OF HOUSEHOLD GREYWATER IN THE NORTHERN GREAT PLAIN REGION OF HUNGARY

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Abstract

Greywater (GW) has attracted global attention as an alternative water source over the last few decades. GW treatment and reliable reuse require the overall qualitative characterization of samples from different sources. This paper represents an investigation of household-generated GW in the Northern Great Plain Region of Hungary. Modern and reliable analytical techniques and instruments (ion chromatography, microwave plasma atomic emission spectrometry, Zetasizer Nano Z analysis, etc.) were applied for the determination of the main pollutants and the preparation and specification of the potential treatment methods for indoor or outdoor GW reuse. It was shown that the shower/bathtub fraction must be collected separately from other sources based on its low organic matter (DOC<87.76 mg L^{-1} and BOD_5<250.33 mg L^{-1}, MBAS<2.92 mg L^{-1}), solids (TS<804 mg L^{-1}), salt (EC<610 μS cm^{-1}), nutrients (NO_3-N<1.15 mg L^{-1}, NH_4-N<4.80 mg L^{-1}) and microelement (Fe<0.01 mg L^{-1}, Zn<0.01 mg L^{-1}, Cu<0.15 mg L^{-1}, Ba<0.38 mg L^{-1}) concentrations. In particular, laundry and kitchen sink or dishwasher GW were the most loaded streams. The current study demonstrated that there are no significant limitations for implementing GW reuse systems in Hungarian households but that treatment is necessary before reuse. Further research is needed to adapt treatment methods for the specifics of Hungary.

Key words: greywater, ion chromatography, microelements, reuse, zeta potential

Received: February, 2014; Revised final: October, 2014; Accepted: October, 2014

1. Introduction

In recent years, an outstanding research aim has been to achieve near-zero water requirements for buildings in addition to near-zero energy needs. Water is strategically as important as energy; therefore, reducing water consumption and reusing water would be appropriate in this field as well. In the European Union (EU), the EU 20-20-20 Climate and Energy Package (EC Directive, 2009) was laid down to draw up the main objectives for the member states regarding energy efficiency expectations by 2020.

Household greywater (GW), comprising wastewater from bathing (light GW) as well as that from laundry and cooking (dark GW), excluding wastewater from toilets, is not waste but an alternative water source, as has been slowly realized around the world over the last few decades. In the literature, several continents are utilizing GW reuse approaches for a variety of GW sources for use both indoors and outdoors. In a number of known domestic activities (toilet flushing, soaking, window cleaning or car washing, irrigation etc.), the use of potable water is not necessary. According to these applications and rising household water charges, the utilization of GW or rainwater significantly decreases the potable water consumption and the amount of black water produced. Because the availability of harvested rainwater is not regular and is suffering

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from anthropogenic effects and because of the various problems related to climate change, the various GW sources around a building, even those of low quality, can be valuable (Antonopoulou et al., 2013; Boyjoo et al., 2013; Ghaitidak and Yadav, 2013; Matos et al., 2013; WHO, 2006).

An average person typically produces 150-250 liters of domestic wastewater per day, and GW accounts for up to 75% of household wastewater and over 90% if vacuum toilets are installed (Ghaitidak and Yadav, 2013). In Europe, the GW production is 35-150 L person^{-1} d^{-1} (Boyjoo et al., 2013). Some research has shown that onsite GW reuse for toilet flushing could reduce daily household water consumption by 10-29% and that the reuse of light GW for garden irrigation could further reduce the daily water demand for an overall reduction of 41% (Penn et al., 2013).

In Hungary, the average water consumption is currently 100-110 L person^{-1} d^{-1}: 120-130 L person^{-1} d^{-1} in large cities and as little as 50-70 L person^{-1} d^{-1} in small villages. In the last decades, the water charges have increased dramatically (HITA, 2013; Hungarian Central Statistical Office, 2013). Of all water used, 34% is used for toilet flushing, 38% for bathing (washing hands, showering, filling a bathtub), 14% for washing, 7% for washing up and 2% for drinking. The remaining 5% goes to cleaning and other purposes, such as car-washing or irrigation (Böse, 2008). Thus, the average GW production in Hungary is 60-65 L person^{-1} d^{-1}. In Hungary, the quality of water resources (groundwater or riverbank-filtered wells) is currently satisfactory, but these sources may be contaminated by human activities and climate changes (e.g., droughts or floods) (HITA, 2013). Furthermore, precipitation also shows large temporal and spatial variability, and the average annual rainfall has decreased in the last several decades (Forian and Tamas, 2013). Based on these facts, GW utilization in Hungarian households can help reduce domestic water charges and the production of wastewater, allowing water to be reused locally.

The quality of GW depends on the type of the source, the quality of the water supply, the type of distribution system, household occupancy and the occupants' genders, age distribution and activities. The analysis of the quality of GW streams originating from different sources is essential before reuse. The concentrations of organic compounds, solids, salts, pathogens, phosphorus and nitrogen forms in GW vary widely by source and depend significantly on the volume of water used (Boyjoo et al., 2013; Ghaitidak and Yadav, 2013). Modern analytical techniques can be used to assist the identification of the different pollutants in water samples (Broekaert and Siemens, 2004; Jackson, 2000). Several studies consider the chemical and physical characterization of domestic GW, while fewer papers about the ionic or microelement contents of effluents are available (Braga and Varesche, 2014; Hernández Leal et al., 2012).

Greywater treatment systems of varying complexities are being used around the world. The most popular treatment methods are physical (filtration, sedimentation), biological (aerobic and anaerobic methods), chemical (coagulation, adsorption and oxidative processes) and natural systems or a combination thereof. It is very difficult to identify the "best" GW treatment system, as each has its own advantages and disadvantages, and each country has its own preferences and specialization (Boyjoo et al., 2013; Ghaitidak and Yadav, 2013).

Based on the different pollutants in GW, guidelines are needed to control GW reuse to establish the extent of treatment and reduce health risks from exposure. A general report referring to the reuse of wastewater is given by the EPA (EPA, 2012). The standard aims to ensure the aesthetic (BOD, COD, turbidity), hygienic (total coliforms, FC) and technical (suspended solids) quality of GW (Boyjoo et al., 2013; Oron et al., 2014). European Council Directive 91/271/EEC states that "treated wastewater shall be reused whenever appropriate"; however, the level and method of treatment is ambiguous (Oron et al., 2014; Somogyi et al., 2009). According to the literature, the structure of Hungarian settlements accentuates the importance of on-site wastewater treatment. In Hungary, the reuse of GW is not regulated. Irrigation water quality criteria were set forth by Government Regulation No. 90/2008 (VII.18) (GR, 2008). Thus, a gap remains in the European and Hungarian legislation concerning the quality criteria of GW for non-potable use (Somogyi et al., 2009).

In this study, the qualitative characterization of household-generated GW streams of the Northern Great Plain Region (NGPR) of Hungary was reported. Our aim was to delimit adequate analytical methods and measuring parameters for the design and the control of the potential on-site treatment methods for GW reuse. Modern and reliable analytical techniques were applied for the identification of the main pollutants in GW. To our best knowledge, the literature contains no scientific publications on GW reuse for this region and Hungary. Only a few relevant Hungarian patents could be found (e.g., Ökrös, 2004), which applied simple treatment methods and lacked scientific examinations into the qualitative characterization of GW fractions. This scientific paper and similar ones are also expected to help develop national guidelines based on the international and EU directives.

2. Material and methods

2.1. The studied area and households

This study was carried out around the city of Debrecen, the center of the Northern Great Plain Region (NGPR) of Hungary. This area is situated in the eastern part of Hungary. Thirty households (flats, houses and terraced houses with areas of <44 m^2 to >250 m^2 and with 1 to 6 inhabitants) located around

Debrecen were systematically analyzed between January and April of 2014. The selection of households was random, and they represent the profile of a typical Hungarian household structure. The total number of inhabitants in these households was 96 (41 men, 39 women and 16 children under 14 years of age). The mean age of the inhabitants living in the analyzed households was 35 years. Based on the water consumption and distribution, the average GW production in the analyzed households was 60 L person^{-1} d^{-1}.

2.2. Sample handling and preparation of domestic greywater

Samples were collected from the shower or bathtub, the laundry (from the manual washing area and the washing machine) and from the kitchen sink or dishwasher. The control samples were the tap water used for drinking at the sampling spots. In this study, 120 samples were collected and analyzed. The samples were collected in acid-rinsed 1-L glass containers and 2-L plastic containers. Samples were transferred to the laboratory in an ice-chest and cooled to 4°C.

Most of the water samples for analysis required no pretreatment, but the samples were acidified with nitric acid (65% m/m, analaR, VWR) for elemental analysis and preserved with chloroform for the determination of methylene blue active substances (MBAS). GW samples and standard solutions for the analytical methods were diluted and filtrated (0.45-μm membrane filters) for certain tests, while the control tap water sample was only filtrated. Samples were analyzed within 24 h after the sampling.

2.3. Analytical methods

For the qualitative characterization of GW samples, several physical, chemical and biological techniques were applied. The pH and conductivity were measured by a Multiline P4 meter (WTW GmbH, Weilheim, Germany). The total solids (TS), total suspended solids (TSS) and total dissolved solids (TDS) were measured by gravimetry (EPA, 1975). Turbidity (NTU) was measured with a Turb 555 IR turbidimeter (WTW GmbH, Weilheim, Germany). The zeta potential (ζ) was determined using a Zetasizer Nano Z instrument (Malvern Instruments Ltd, Malvern, UK). The organic content of the samples was evaluated by the following methods and expressed in mg L^{-1}: BOD (biochemical oxygen demand) was determined using the 5-day procedure (incubation at 20 °C) with OxiTop manometric equipment (WTW GmbH, Weilheim, Germany), while DOC (dissolved organic carbon) was determined using a Shimadzu TOC-Vcpn total organic carbon analyzer (Shimadzu Europe GmbH, Duisburg, Germany). The determination of different anions and cations in GW samples was achieved using a suppressed Dionex ICS 3000 ion chromatography (IC) system (Thermo Fisher Scientific Inc., Olten, Switzerland), which included a Dionex IonPac AS14A column for anion separation and a Dionex IonPac CS12 column for cation separation. All separations were conducted at 30 °C. The sodium adsorption ratio (SAR) was determined from IC data (Eq. 1) (Kariuki et al., 2012).

$$SAR = \frac{[Na^{+}]}{\sqrt{([Ca^{2+}]+[Mg^{2+}])}} \qquad (1)$$

where [Na^{+}], [Ca^{2+}] and [Mg^{2+}] are concentrations in mmol L^{-1}.

The microelement concentration of GW samples was determined by microwave plasma atomic emission spectrometry (MP-AES) method, MP-AES 4100, (Agilent Technologies, Inc., Santa Clara, United States). MBAS values were determined by photometric method (Chitikela et al., 1995) by Nanocolor Linus photometer (WTW GmbH, Weilheim, Germany). Hygiene Monitor test kits (Transia GmbH, Ober-Mörlem, Germany) were used for characterization of the microbiological load of GW samples. These test kits are suitable for hygiene control according to DIN 10113-3 and EU Hygiene regulation (No. 852/2004) (REU, 2004). Two types of contact slides (TTC total count/total coliforms and CHROMagar *E. coli*/coliforms) were used simultaneously via the dipping method.

Statistical analysis was carried out using the IBM SPSS 22.0 software package. The elemental concentration of GW samples was compared by ANOVA, and canonical discriminant analysis (CDA) was used to further evaluate the results.

3. Results and discussion

This section presents a comprehensive qualitative characterization of different GW samples from the NGPR of Hungary. Based on the measurement systems used to investigate the samples, non-specific and specific parameters were determined to represent the regional characteristics of GW streams, and drinking water samples were applied as control samples.

3.1. Non-specific physical and chemical parameters

Several non-specific physical and chemical parameters of different GW sources were determined to indicate a given property of a group of substances (Table 1). The pH values are determined by the characteristics of the water supply. The mean pH ranged from 6.77 to 8.06 for drinking water, while the pH values of GW sources for the shower/bathtub, laundry and kitchen sink or dishwasher ranged from 6.73 to 7.95, from 7.27 to 10.15 and from 6.80 to 7.82, respectively. The pH of the drinking water control sample was similar to that of the shower/bathtub GW, greater than or equal to that of the kitchen sink and dishwasher GW, but significantly lower than that of laundry GW, which contains several surfactants/detergents. The average total alkalinity was also the highest for the laundry GW samples (12.40±7.34 mmol L^{-1}), as evidenced by the pH.

According to the measured TS concentrations, the kitchen GW is the most contaminated fraction of household GW as a result of the presence of food particles, with an average TS value of 2205.25±905.43 mg L^{-1}. The TS concentration of the laundry GW is lower, while that of the shower/bathtub samples is lowest. The measured TS values for Hungarian households are similar to those reported in the literature (Antonopoulou et al., 2013; Couto et al., 2013; Eriksson et al., 2002). The EC and TDS concentrations represent the concentrations of dissolved components in the GW samples, while the TSS and turbidity characterize the insoluble fractions of the GW samples. Relative to the drinking water values, the EC and TDS values of the GW samples may be elevated by anthropogenic effects (detergents, body care products, bleaches, oils, paints, solvents, traces of urine, dissolved elements from old plumbing and piping systems). The TSS originates from body care products, toothpaste, shaving waste, foam, skin, hair and body fats in shower/bathtub GW; food particles, bacteria, foam and high amounts of oil, fat and sand in kitchen GW; and from foam, oils, hair, fibers and sand particles in laundry GW (Boyjoo et al., 2013; Ghaitidak and Yadav, 2013).

The results showed that the shower/bathtub GW presents lower EC, TDS and TSS concentrations and turbidity than drinking water. These values were higher for the laundry and kitchen GW. It was shown that the EC and TDS values as well as the TSS and turbidity values of different sources were well correlated. Ghaitidak and Yadav (2013) cited occasionally higher TS and turbidity values for laundry GW than kitchen GW, which supports the variety of particles found in GW samples.

According to the literature, the priority pollutants in the GW are organic components, which represent approximately 40% of the total constituents and primarily originate from detergents and surfactant products. Various concentrations of these contaminants are toxic to plants and aquatic animals (Boyjoo et al., 2013). It was found that the GW fractions from the examined households contain different concentrations of organic matter: the average BOD_5 and DOC concentrations were, respectively, 111.85±73.84 mg L^{-1} and 39.57±19.38 mg L^{-1} for shower/bathtub GW, 635.64±336.22 mg L^{-1} and 256.82±125.64 mg L^{-1} for laundry GW and 827.14±198.25 mg L^{-1} and 335.13±155.16 mg L^{-1} for kitchen sink or dishwasher GW, the highest among the sources studied. These values correlated well with the TS values. The MBAS values were also analyzed for different GW sources to map the detergent concentration as a part of the organic content.

According to the literature, MBAS values range from 0.01 to 118.30 mg L^{-1} (Boyjoo et al., 2013; Ghaitidak and Yadav, 2013). The detergent concentrations were higher for GW originating from laundry (37.60±17.37 mg L^{-1}) than that from the kitchen sink or dishwasher (2.61±1.54 mg $^{-1}$) or the shower/bathtub (1.60±1.32 mg L^{-1}).

The assessment of these non-specific parameters revealed that there are more insoluble particles in kitchen sink or dishwasher GW and more soluble components in laundry GW.

3.2. Ionic concentrations

An efficient IC method was applied for the analysis of ionic solutes in different GW samples to determine the specific chemical factors in the qualitative characterization. Dual IC was applied, meaning two distinct chromatographic systems (for the determination of anions and cations) comprised one instrument and were used them simultaneously to increase productivity. The IC results for different anions (chloride, bromide, nitrate, phosphate, sulfate), cations (sodium, ammonium, potassium, magnesium, calcium) and calculated parameters are presented in Table 2.

Table 1. Non-specific physical and chemical parameters of greywater from different sources in the NGPR of Hungary

		Drinking water (n=30)	***Shower/ Bathtub (n=30)***	***Laundry (n=30)***	***Kitchen sink/ Dishwasher (n=30)***
Parameter	Unit	*Mean±SD*	*Mean±SD*	*Mean±SD*	*Mean±SD*
pH	-	7.43±0.37	7.45±0.32	8.40±1.05	7.40±0.22
EC	µS cm^{-1}	527.79±47.71	544.35±44.78	1275.73±938.71	827.00±198.25
TDS	mg L^{-1}	377.34±36.83	412.57±66.20	1232.14±507.41	1095.25±484.23
TS	mg L^{-1}	379.34±31.34	470.32±142.71	1683.93±879.90	2205.25±905.43
TSS*	mg L^{-1}	13.67±3.21	67.79±64.58	181.2±80.79	840.63±743.15
Turbidity	NTU	0.66±0.75	25.45±22.68	218.67±125.83	357.39±216.47
Alkalinity	mmol L^{-1}	5.85±0.86	5.47±0.72	12.40±7.34	7.15±3.13
BOD_5	mg L^{-1}	1.98±0.88	111.85±73.84	635.64±336.22	827.14±198.25
DOC	mg L^{-1}	2.28±0.77	39.57±19.38	265.82±125.64	335.13±155.16
MBAS	mg L^{-1}	-	1.60±1.32	37.60±17.37	2.61±1.54

*Notes: n: number of samples; SD: standard deviation; *Values calculated by TS-TDS*

Table 2. Ion chromatography results for different anions and cations and calculated parameters from IC data for greywater from different sources (conditions: anionic eluent concentration of 8 mM L^{-1} Na_2CO_3 and 1 mM L^{-1} $NaHCO_3$, cationic eluent concentration of 11 mM L^{-1} H_2SO_4)

			Drinking water (n=30)	***Shower/ Bathtub (n=30)***	***Laundry (n=30)***	***Kitchen sink/ Dishwasher (n=30)***
	Ionic components	Unit	*Mean±SD*	*Mean±SD*	*Mean±SD*	*Mean±SD*
ANIONS	Chloride, Cl^-	mg L^{-1}	9.81±12.35	22.71±10.35	60.95±3.23	197.50±465.94
	Bromide, Br^-	mg L^{-1}	0.03±0.01	1.38±0.44	5.08±3.23	1.44±0.49
	Nitrate, NO_3^-	mg L^{-1}	3.83±0.19	3.77±0.39	4.35±1.17	3.59±1.26
	NO_3-N*	mg L^{-1}	0.86±0.04	0.85±0.09	0.98±0.26	0.81±0.28
	Phosphate, PO_4^{3-}	mg L^{-1}	0.25±0.10	11.84±16.95	7.89±4.08	10.65±7.50
	PO_4-P*	mg L^{-1}	0.08±0.03	3.86±5.53	2.56±1.33	3.47±2.45
	Sulfate, SO_4^{2-}	mg L^{-1}	8.56±8.52	15.70±2.79	69.30±77.79	19.47±8.96
CATIONS	Sodium, Na^+	mg L^{-1}	27.10±5.64	37.51±7.18	376.8±374.73	85.94±28.52
	Potassium, K^+	mg L^{-1}	1.83±0.21	6.40±3.13	13.38±4.02	12.10±6.90
	Calcium, Ca^{2+}	mg L^{-1}	73.74±12.79	91.07±30.50	70.93±20.10	80.45±8.91
	Magnesium, Mg^{2+}	mg L^{-1}	17.53±2.18	19.16±3.05	18.83±5.77	19.23±3.49
	Ammonium, NH_4^+	mg L^{-1}	0.47±0.10	2.03±1.36	13.28±6.52	4.03±3.97
	NH_4-N*	mg L^{-1}	0.38±0.09	1.67±1.12	10.92±5.36	3.31±3.26
	SAR**	-	0.74±0.14	0.94±0.19	10.97±10.34	2.24±5.41

*Notes: n: number of samples, SD: standard deviation, *values calculated from raw IC data; **values calculated from raw IC data using Eq. 1*

Compared to the drinking water, all GW sources presented higher anionic concentrations. Among the GW sources, the anionic contents of the shower/bathtub GW were lowest, except for phosphate ion concentration, for which kitchen sink or dishwasher GW has a slightly lower value. Among the anionic components, chloride and sulfate ions can be detected in higher concentrations than in the control samples. It was shown that all sources present higher cationic concentrations than the control samples. The calcium and magnesium content in GW originated from drinking water, but the correlation between sodium content and chloride and sulfate contents indicate the use of dishwashing or laundry detergents and body care products in households.

SAR is an index of the ratio of the concentration of sodium (a detrimental element) to that of calcium and magnesium (beneficial elements). The SAR levels in GW are typically within the range of 2 to 10 depending on the source of GW. High SAR values (>6) reduce soil aeration and permeability (Kariuki et al., 2012). Due to its high sodium concentration, the SAR value of GW from laundry was significantly higher (10.97±10.34) than that of GW generated in the kitchen sink or dishwasher (2.24±5.41) and the shower/bathtub (0.94±0.19). Thus, the reuse of the laundry for irrigation is not recommended without treatment.

IC analysis helped us describe the nutrients in the GW samples. The concentrations of PO_4-P were found to be higher in the current study than those reported by Hernández Leal et al. (2012) and Antonopoulou et al. (2013) and lower than that reported by Friedler (2004), indicating the acceptable use of phosphate-containing detergents in Hungarian households, as the main sources of phosphate in GW are hygienic and cleaning products. The highest phosphate content (by a small amount) was detected in shower/bathtub GW, and laundry GW did not contain high phosphate ion concentrations. Based on the literature, the main source of nitrogen in wastewater is urine, but the main source in GW is food residue (Couto et al., 2013). Regarding NH_4-N and nitrate concentrations, the respective measured values ranged from 0.34 to 4.80 mg L^{-1} and 2.93 to 5.08 mg L^{-1} for the shower/bathtub, from 2.66 to 22.85 mg L^{-1} and 1.19 to 5.66 mg L^{-1} for laundry and 0.41 to 9.46 mg L^{-1} and 2.05 to 5.52 mg L^{-1} for kitchen sink or dishwasher. In the analyzed households, the nitrate concentrations do not deviate significantly between drinking water and GW based on the regional drinking water quality. The NH_4-N and nitrate concentrations determined in this survey were similar to those reported by Antonopoulou et al. (2013) and Couto et al. (2013) in scientific papers for shower/bathtub and kitchen sink GW. According to our results, the analyzed GW samples had low nutrient concentrations.

Using IC measurements, we could identify numerous ionic components simultaneously. The results showed that household-generated GW has higher ionic content than the control samples and that kitchen sink or dishwasher and laundry GW are the more polluted fractions.

3.3. Microelemental concentrations

In the literature, the GW characteristics investigated are mainly the organic content, nutrients and microorganisms. However, GW also contains different microelemental pollutants due to the detergents used in laundry, dishwashing and body care products (Kariuki et al., 2012). Reuse precepts must take into consideration these contaminants; thus, different microelements were analyzed to obtain a general picture of the regional characteristics of the GW studied. According to the concentrations of the measured elements, three canonical discriminant functions were used. The canonical discriminant functions were significant ($p<0.05$), and the canonical correlations of the functions were the following: 0.877 (I), 0.662 (II) and 0.469 (III). A significantly positive correlation was found between the first discriminant function and the concentrations of lead, nickel and iron. According to ANOVA, the levels of these elements increased significantly in samples originating from laundry and the kitchen sink or dishwasher ($p<0.05$). The second discriminant function was correlated negatively with the concentrations of aluminum and chromium and positively with those of strontium, barium, manganese and zinc. The concentrations of copper and cadmium were negatively correlated with the third discriminant function. The CDA plot (Fig. 1) shows a clear separation of samples collected from laundry and the kitchen sink or dishwasher, whereas the elemental concentrations of GW samples from the shower or bathtub did not differ significantly from those of drinking water.

A potential source of lead in samples originating from the kitchen sink or dishwasher is glazes on old ceramic dishes and porcelain as well as old lead piping in the water distribution system. Nickel and iron are commonly used alloys, and their presence may depend on the corrosiveness of water. Braga and Varesche (2014) investigated the chemical composition of commercial laundry water and found iron to be the most abundant metal. Similarly, in the current study, a significantly higher iron level was found in the GW samples compared to the drinking water. The significantly higher concentration of copper observed in the samples from laundry and the kitchen sink or dishwasher may originate from household detergents, such as soap powder (Eriksson et al., 2002).

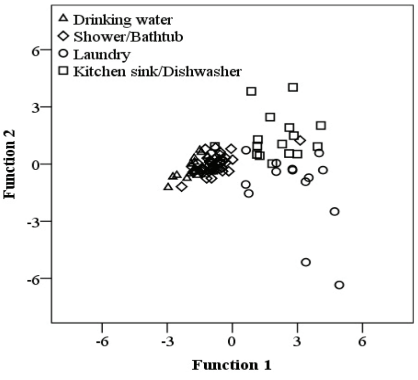

Fig. 1. Canonical discriminant analysis of the elemental concentration (mg L^{-1}) of greywater samples

Our results show that, based on the microelement concentration, samples from laundry and the kitchen sink or dishwasher contain a higher level of lead, manganese, nickel, copper, iron and chromium than drinking water or samples originating from shower/bath tubes. The metal load of the effluent produced by shower/bathtub use is lower and hence more desirable in terms of treatment and reuse.

3.4. Zeta potential

The zeta potential indicates the surface potential of a colloidal system and is commonly related to the stability of colloidal systems under a given set of water characteristics. A zeta potential near zero indicates minimal electrical repulsion and thus increases the likelihood of capture.

We analyzed the relationship between the zeta potential and EC values (Fig. 2) and the relationship between the zeta potential and turbidity (Fig. 3). The EC of drinking water samples ranged from 439 μS cm^{-1} to 631 μS cm^{-1}, while the zeta potential values were between 0 mV and - 7 mV. Of the various GW samples, the EC values of the shower/bathtub GW were similar to those of the drinking water samples (from 412 μS cm^{-1} to 610 μS cm^{-1}), while the zeta potential values for this GW source were significantly more negative than those of the control samples (from -3.54 mV to -32.1 mV). The high negative value of the ζ potential is due to the presence of colloidal particles in the water, the majority of which are contaminants enclosed in micelles or micelles formed from the tenzide molecules of personal hygiene materials. Both the zeta potential values and the conductivities of laundry and kitchen water are very similar. The high negative ζ values (e.g., - 42 mV) and high EC values (e.g., 3910 μS cm^{-1}) suggest that these types of water often contain large quantities of both floating particles and dissolved salts.

The ζ and turbidity values of the water samples are found to form three distinguishable groups. Drinking water samples have low ζ values and low turbidity, as expected. The turbidity of the bathwater samples is higher by an order of magnitude on average (from 2.3 to 84.0 NTU), while their zeta potential values, showing a wider distribution, become negative. The third group includes the turbidity of laundry and kitchen GW, the values of which – similarly to EC – are significantly similar to one another and are higher than that of bathwater. Turbidity is another sign of the presence of large quantities of colloidal particles in water.

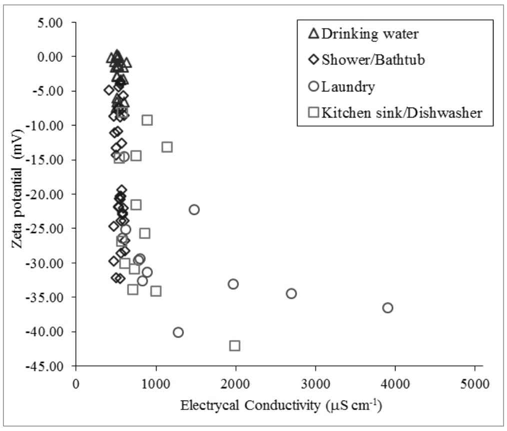

Fig. 2. Relationship between zeta potential and electrical conductivity

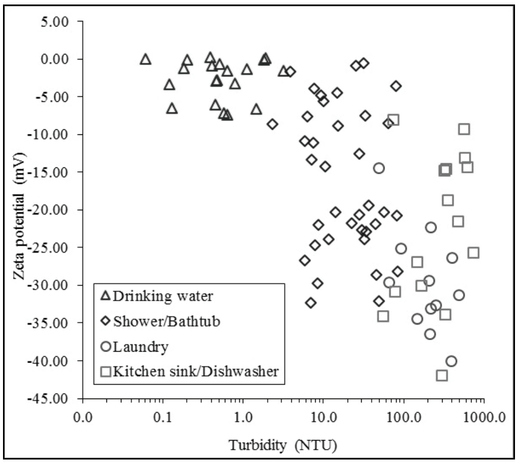

Fig. 3. Relationship between zeta potential and turbidity

3.5. Microbial quality parameters

To evaluate the microbial quality of different GW sources, the *Escherichia coli*, total coliform and total plate counts were determined. As Fig. 4 shows, the GW samples from different sources were highly contaminated by bacteria, with average total plate counts of 5 to 6 $\log_{10}$cfu mL^{-1}. There was no significant difference between the total plate counts of samples from the shower/bathtub and the kitchen sink or dishwasher (4.8 and 4.6 $\log_{10}$cfu mL^{-1}, respectively), but the GW samples from laundry were contaminated to a higher degree (5.5 $\log_{10}$cfu mL^{-1}). We detected some microbial content in not only the GW but also the drinking water samples. Greater variability was observed in terms of coliform bacteria contents. The drinking water samples showed only minimal contamination with coliform bacteria, whereas all GW samples were highly contaminated with coliforms. Among the three GW sources, the kitchen sink/dishwasher samples showed the lowest coliform content (3.3 $\log_{10}$cfu mL^{-1}) and the laundry samples the highest (4.1 $\log_{10}$cfu mL^{-1}).

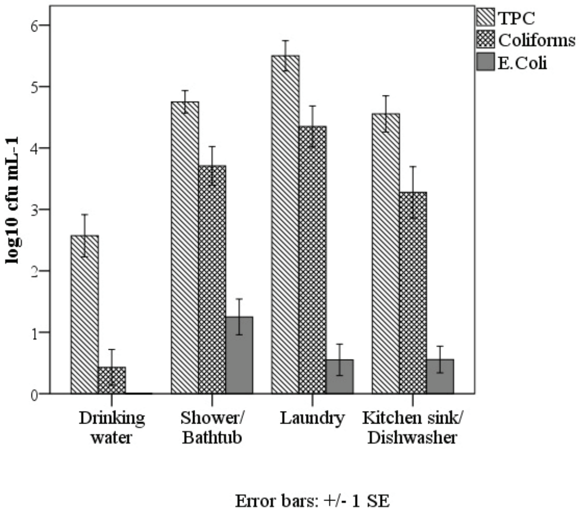

Fig. 4. Microbial quality of different greywater sources

The results of the survey to determine *E. coli* contamination showed that all GW sources can be contaminated with this fecal indicator bacterium. *E. coli* was not found in drinking water samples despite the detected coliform contamination (0.4 $\log_{10}$cfu mL^{-1}) of this source. The concentration of *E. coli* was the highest in GW samples from the shower/bathtub (1.3 $\log_{10}$cfu mL^{-1}). In all, 45.8 percent of the tested shower/bathtub samples presented *E. coli* (2-3 $\log_{10}$cfu mL^{-1}). *E. coli* contamination was also detected in GW samples from laundry and sink/dishwasher activities (0.5 and 0.6 $\log_{10}$cfu mL^{-1}, respectively). Our results confirm the findings of an earlier study (Winward et al., 2008) that fecal contamination of GW is a common occurrence, creating the risk of a range of fecally transmitted pathogens to be passed into GW.

4. Conclusions

In the present study, the overall qualitative characteristics of greywater for different sources were assessed by applying versatile modern analytical techniques. It was shown that the quality of regional (NGPR of Hungary) drinking water and that of the greywater samples showed high variability for the analyzed parameters.

The characteristics of the shower/bathtub effluent generally indicated low organic matter, salt and microelement concentrations; thus, this effluent must be collected separately from effluent from other loaded sources.

Safe and low-cost treatment methods should be developed to treat this effluent for financial gain and to achieve environmental goals for water usage.

Acknowledgments

The work is supported by the TÁMOP-4.2.2.A-11/1/KONV-2012-0041 project. The project is co-financed by the European Union and the European Social Fund.

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