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Research article

Greywater characterization and loadings – Physicochemical treatment to promote onsite reuse

C. Noutsopoulos*, A. Andreadakis, N. Kouris, D. Charchousi, P. Mendrinou, A. Galani, I. Mantziaras, E. Koumaki

Sanitary Engineering Laboratory, Department of Water Resources and Environmental Engineering, School of Civil Engineering, National Technical University of Athens, Iroon Polytechniou 9, Zografou, 15780, Athens, Greece

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ABSTRACT

Greywater is the wastewater produced in bathtubs, showers, hand basins, kitchen sinks, dishwashers and laundry machines. Segregation of greywater and blackwater and on site greywater treatment in order to promote its reuse for toilet flushing and/or garden irrigation is an interesting option especially in water deficient areas. The objective of this study was to characterize the different greywater sources in Greek households and to evaluate the performance of alternative physicochemical treatment systems to treat several types of greywater. Based on the results average daily greywater production was equal to 98 L per person per day and accounts for approximately 70–75% of the total household wastewater production (135 L per person per day). Among the different sources, laundry and kitchen sink are the main contributors to the total greywater load of organic carbon, suspended solids and surfactants, whereas dishwasher and bathroom greywater are the main sources of phosphorus and endocrine disrupting chemicals respectively. Depending on sources, greywater accounts for as low as 15% of the total wastewater load of organic carbon (in the case of light greywater sources), to as high as 74% of the total load organic load (in the case of the heavy greywater sources). On the other hand, the nutrients load of greywater is limited. The application of a physical treatment system consisting of coagulation, sedimentation, sand filtration, granular activated carbon filtration and disinfection can provide for a final effluent with high quality characteristics for onsite reuse, especially when treating light greywater.

1. Introduction

Household wastewater consists of greywater and blackwater. Greywater is the wastewater produced in bathtubs, showers, hand basins, kitchen sinks, dishwashers and laundry machines and blackwater is the wastewater which comes from toilets (Eriksson et al., 2002; Friedler and Hadari, 2006), although wastewater originated from kitchen sinks is very often regarded as blackwater. Several studies have shown that greywater accounts for around 70–75% of the total household wastewater production, while at the same time it concentrates a rather limited portion of the total pollutional load of wastewater (Friedler, 2004; Jefferson et al., 2004; Li et al., 2009; Donner et al., 2010; Antonopoulou et al., 2013). Qualitative greywater characterization studies have been conducted and several pollutants have been identified in greywater samples such as organic carbon (in terms of COD, BOD_5 or TOC), total and volatile solids (TS and VS), total and volatile suspended solids TSS and VSS), nutrients (nitrogen, phosphorus, sulfur), surfactants, heavy metals and emerging contaminants (Eriksson et al., 2002; Hernández Leal et al., 2007; Eriksson and Donner, 2009). However the physicochemical characteristics of the alternative greywater sources reported by several studies along with the contribution of each source to the total greywater pollutional load are rather controversial (Christova – Boal et al., 1996; Almeida et al., 1999; Nolde, 2000; Palmquist and Hanæus, 2005; Hernández Leal et al., 2007; Eriksson and Donner, 2009). These differences could be attributed to several parameters such as the quality of water supply, the piping material, the lifestyle and the activities of the residents, the products used and many others. Another crucial parameter is the sampling protocol applied in each study.

Separation of greywater from blackwater and on site greywater treatment for toilet flushing and/or garden irrigation is an interesting option especially in areas facing water shortage problems. A

* Corresponding author.
E-mail address: cnoutso@central.ntua.gr (C. Noutsopoulos).

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recent study of European Commission states that the promotion of greywater reuse and rainwater harvesting could result to a noticeable reduction of potable water use to the order of 5% by 2050 (Bio, 2012). To apply such a reuse option, greywater needs to be treated. The intensity and type of treatment varies with the characteristics of greywater. Several greywater treatment systems have been tested in a high number of studies including physical, chemical and biological systems, producing effluents with different quality characteristics (Pidou et al., 2008; Li et al., 2009; Ghunmi et al., 2011; Ghaitidak and Yadav, 2013; Boyjoo et al., 2013). Based on experimental results, it is anticipated that besides their satisfactory performance, biological greywater treatment systems are in some cases exhibiting several operating deficiencies on a household level due to i) nutrients deficiency of greywater, ii) the periodic greywater-wastewater production in residencies of temporary use and iii) the need for sewage sludge handling. On the other hand, physicochemical greywater systems often present many drawbacks such as non-satisfactory performance or increased cost for chemicals. However the performance of each treatment system is highly dependent on the type and the characteristics of the greywater being treated.

In view of the above, the objectives of this study were twofold. First to perform a comprehensive qualitative characterization of different greywater sources and secondly to evaluate the performance of alternative physicochemical treatment systems to treat several types of greywater.

2. Materials and methods

2.1. Greywater quantity

In order to estimate the amount of greywater produced in Greek households, the average daily water consumption in three residences (H1, H2 and H3) with different characteristics (number and age of inhabitants, area) was recorded as the sum of wastewater produced in bathtubs, showers, hand basins, kitchen sinks, dishwashers, laundry machine and toilets. All residencies located in the city of Athens, Greece. Residence H1 was a one person (student) apartment, residence H2 was a two person (of middle age) apartment, while H3 was a family house (parents and two children). The estimation of the amount of greywater produced in bathtub/shower, hand basin and kitchen sink was achieved through the recording of the duration of the use of the corresponding tap by each resident and for each activity on a daily basis (e.g. cooking activities, hand cleaning, dish and glass washing, fruit and vegetables washing in the kitchen). As a result the amount of greywater produced from each resident and for each activity was calculated as the product of the duration of the use of each source tap and its flowrate which was measured at each source in each residence at least three times. In the case of the laundry, dishwasher and toilet, calculation of the amount of wastewater was based on the recording of the number of their uses per day and the amount of water consumption per use (based on measurements in the case of laundry and dishwasher and technical characteristics of the toilet flush). The aforementioned measurements were taking place, during November, for a week, in all residences in order to collect information of the average weekly habits of all the residents.

2.2. Greywater qualitative characterization

Based on the relative contribution of each activity and each resident to the production of each greywater source (e.g. hand cleaning, teeth cleaning, shaving), a sampling protocol was implemented to produce composite samples from the three residencies. For example, the composite hand basin greywater sample of residence H3 (four person house), was prepared by mixing the hand basin greywater samples of the four residents according to their relative contribution to the household's water consumption at hand basin. Moreover, the greywater hand basin sample for each resident was prepared by mixing the greywater samples of each activity taking place in hand basin by each resident (e.g. tooth cleaning, hand cleaning, shaving) according to the relative contribution of each activity to the total water consumption by each resident. According to the sampling protocol a total number of 60 samples were collected (3 residencies, 5 samples for each residence, 4 sampling campaigns). The duration of sampling procedure was four months (from January–April), with one sampling campaign taking place in each month (one in January, one in February, one in March and one in April). Samples were analyzed for the parameters detailed in Section 2.4.

2.3. Greywater treatment experiments

Greywater samples from the bathtub, the handbasin, the laundry and the kitchen were collected every two days and processed in the experimental units. Table 1 presents the contribution of each greywater fraction to the total untreated greywater being processed to each experimental system. Systems 1–2 consisted of a 10 L sedimentation tank, followed by a sand filter and a granular activated carbon (GAC) filter. Systems 3–5 were a modification of Systems 1–2 with the incorporation of a coagulation unit ahead of the sedimentation tank and the two filtering units (sand filter and GAC filter). System 6 consisted of a coagulation unit, the sand filter and the GAC filter. Every experimental system was operated for a period of 30–40 d.

Greywater retention time in sedimentation tank of all experimental systems (except System 6) was equal to 20 h. The supernatant of sedimentation tank was fed initially to sand filter (5 cm plexiglass column) and eventually passed through the GAC filter at a flowrate of 2.8 L/h and a filtering velocity of 1.4 m/h.

Before the beginning of the experiments, sand and activated carbon were washed with ultrapure water and dried at 105 °C for 24 h. GAC column was filled with Filtracarb CC60, bought from CHEMiTEC Inc. The physicochemical properties of the sorbent material are shown in Table S1 (Supplementary Material). At the bottom of the GAC column 4 to 5 pieces of glass wool were put to retain activated carbon inside the column. Both columns (sand and activated carbon columns) were operated continuously under pressure (with a hydraulic head of 60 cm). Based on the experimental protocol, when the hydraulic level above the sand filter exceeded the maximum allowable hydraulic head of 60 cm, the cleaning process was initiated by flushing upwards the filter with distilled water.

For the evaluation of the optimum coagulant dose ($Al_2(SO_4)_3 \times 14H_2O$) a series of jar tests were performed. According to the experimental protocol of the jar tests, after alum dosing, rapid mixing was taking place for 1 min at 200 rpm, followed by flocculation for 20 min at 70 rpm (for 7.5 min), 40 rpm (for 7.5 min) and 25 rpm (for 5 min) and sedimentation for 50 min.

Samples from the untreated greywater, the supernatant of the sedimentation tank and the effluent of the sand filter and the GAC unit were collected twice a week and subsequently analyzed for turbidity, TSS, VSS, CODt, CODs, surfactants and emerging contaminants.

2.4. Analytical methods

Greywater samples were analyzed for pH, conductivity, TS, TSS, VSS, total and soluble COD, BOD_5, surfactants in the form of Linear Alkylbenzene Sulfonate (LAS), NH_4–N, NO_3–N, NO_2–N, TKN, TN,