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Sustainable water resources management attracts considerable attention in today's world. Recycling and reuse of both wastewater and greywater are becoming more attractive. The strategy is to protect ecosystem services by balancing the withdrawal of water and the disposal of wastewater. In the present study, a timely and novel synthetic greywater composition has been proposed with respect of the composition of heavy metals, nutrients and organic matter. The change in water quality of the synthetic greywater due to increasing storage time was monitored to evaluate the stability of the proposed chemical formula. The new greywater is prepared artificially using analytical grade chemicals to simulate either low (LC) or high (HC) pollutant concentrations. The characteristics of the synthetic greywater were tested (just before starting the experiment, after two days and a week of storage under real weather conditions) and compared to those reported for real greywater. Test results for both synthetic greywater types showed great similarities with the physiochemical properties of published findings concerning real greywater. Furthermore, the synthetic greywater is relatively stable in terms of its characteristics for different storage periods. However, there was a significant ($p<0.05$) reduction in 5-day biochemical oxygen demand (BOD_5) for both low (LC) and high (HC) concentrations of greywater after two days of storage with reductions of 62% and 55%, respectively. A significant ($p<0.05$) change was also noted for the reduction (70%) of nitrate–nitrogen (NO_3–N) concerning HC greywater after seven days of storage.

Keywords: Sustainability; Ecosystem; Greywater; Synthetic greywater; Contamination

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Introduction

Background

Researchers estimate that one-third of the world population could have insufficient water resources by 2025 [1]. Therefore, recycling of wastewater for non-portable purposes has been considered as a new strategy to conserve conventional water resources [2]. The most common practises of recycling treated wastewater and greywater can be found in the agricultural, industrial, urban and environmental sectors [3].

Greywater is a major proportion of domestic wastewater (around 50 to 80%) [4], which is generated from all household wastewater streams, except toilet discharge [2,4,5]. However, some literature has excluded the flow contributions of kitchen sinks, garbage disposal units and/or dishwashers from greywater [6,7,8,9]. High fluctuations in quality and a considerable overlap in characteristics between black and grey wastewater have been reported [4]. The compounds present in greywater vary from source to source, and depend on different lifestyles, customs and installations as well as on the use of chemical household products [6]. Furthermore, there could be chemical and biological degradation of the chemical compounds within the transportation network and during storage affecting physical and chemical parameters [4,10,11].

Reported physiochemical parameters of particular relevance for greywater are summarized in Table 1. Food particles and raw animal fluids from kitchen sinks, soil particles as well as hair and fibres from laundry wastewater are examples of sources of solid material in greywater [4]. High temperatures may be unfavourable since they enhance microbial growth and could induce precipitation in supersaturated solutions [7].

Measurements of turbidity and suspended solids provide some information concerning the overall content of particles and colloids that could induce clogging of installations such as the piping used for greywater transportation as well as sand filters and constructed wetlands used for subsequent treatment [4]. Measurements of the traditional wastewater parameters 5-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD) and nutrients such as nitrogen (N) and phosphorus (P) in form of ammonia–nitrogen (NH_4-N), nitrate–nitrogen (NO_3-N) and ortho-phosphate-

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phosphorus (PO_4-P) also give valuable information about the chemistry of greywater [18]. Ramona et al. [14] argued that wastewater would be better classified as a function of pollution load rather than origin, and hence suggesting the notion of low (bath, shower and washbasin) and high (kitchen, washing machine and dishwasher) strength greywater.

A major difficulty when treating greywater is the considerable variation in its composition. Reported mean values of, for example, COD and BOD_5, vary from 40 to 371 mg/l and from 33 to 466 mg/l, respectively, between sites and with similar variations arising at an individual site [4,6,14,20]. This has been attributed to changes arising in the quantity and type of detergent products employed during washing. Moreover, significant chemical changes may take place over time periods of only a few hours [2]. Among other pollutants, trace elements and heavy metals have been reported as important components to take into consideration for treatment, storage and recycling purposes as indicated in Tables 2 and 3 [16,19].

Storage of greywater

The BOD_5 and dissolved oxygen (DO) concentrations decrease during the sedimentation period when greywater is stored. Evidence has shown that 50% removal of BOD_5 could be achieved when greywater is stored over a four-hour-period [2]. However, extended storage may lead to the risk of odour increases and possibly health issues due to enhanced microorganism growth [22]. Furthermore, the BOD_5 concentration in, for example, greywater washing hand basins has been reported as being slightly lower than the one generated from mixed resources as well it varies with different discharge patterns [6].

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There has been considerable research into the quality processes of raw greywater occurring during the storage stage [23]. For example, Dixon et al [24] indicated improvements in greywater quality during complex storage processes.

Reported synthetic greywater

In general, recycling of greywater is widely accepted compared to blackwater due to the lack of urine and faeces in the former [25]. So, the pathogens and nutrients occurring in greywater are present in much lower concentrations than in blackwater [4].

Greywater does not contain the right nutrient and trace element ratio required for standard biological treatment or advanced treatment by membrane bioreactor [6,10,22]. Furthermore, low concentrations of trace elements have been linked to greywater [4]. Some synthetic greywaters have been created by mixing different recipes of chemical products that household use and/or analytical grade chemicals known to be present in real greywater. Consequently, these chemicals are expected to control the characteristics of the generated greywater in terms of water quality [26].

Nghiem et al. [17] investigated the feasibility of submerged ultrafiltration technology applied for greywater recycling. The synthetic greywater solution contained kaolin, cellulose, humic acid, sodium hypochlorite, calcium chloride electrolyte and a sodium bicarbonate buffer. These materials were also used in combination with sodium dodecyl sulphate to represent synthetic greywater proposed by Schäfer et al. [26].

Nazim and Meera [27] studied the treatment ability of a synthetic greywater by adding different concentrations of an enzyme protein solution to examine the reduction of chemical variables including nutrients. The mixture of synthetic greywater contained glucose, sodium acetate trihydrate, ammonium chloride, disodium hydrogen phosphate, potassium dihydrogen phosphate, magnesium sulphate and cow dung.

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Diaper et al. [28] introduced a synthetic greywater recipe to simulate combined laundry and bathroom greywater from an Australian residential dwelling. The constituents of the greywater included a variety of personal hygiene and household products, some laboratory grade chemicals (sodium dodecyl sulphate, sodium hydro carbonate, sodium phosphate, boric acid, and lactic acid), and secondary sewage effluent sourced from a local wastewater treatment plant.

Fenner and Komvuschara [29] described a new approach to model the effect of factors influencing ultraviolet disinfection efficiency of real and synthetic greywaters. A range of synthetic greywater recipes has been developed for both soft and hard waters to ensure they were representative of the properties of real greywater samples. A typical synthetic greywater recipe comprised dextrin, ammonia chloride (NH_3Cl), yeast extract, soluble starch, sodium carbonate (Na_2CO_3), monosodium phosphate (NaH_2PO_4), potassium phosphate (K_2PO_4) and an *Escherichia coli* culture mixed with distilled water.

Surendran and Wheatley [3] proposed a biological treatment process for greywater obtained from large buildings. The synthetic greywater used comprised a known amount of soap, detergent, starch yeast extract and cooking oil. Settled sewage was also added to provide appropriate bacteria counts.

Jefferson et al. [22] dosed synthetic and real greywater with nutrient supplements. The synthetic greywater recipe comprised synthetic soap, hair shampoo, sunflower oil and tertiary effluent.

Gross et al. [30] have developed a new small-scale vertical-flow constructed wetland for decentralized treatment of greywater. The removal of indicator and pathogenic microorganisms was investigated to assess the reuse of treated greywater for irrigation purposes. The focus was on the removal dynamics of *Escherichia coli*,

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Staphylococcus aureus and *Pseudomonas aeruginosa* in three different synthetic greywaters.

Each greywater was made by combining three waste stocks representing laundry, bath and kitchen wastes [30]. The composition of synthetic greywater for each stock contained laundry soap, shampoo, cooking oil, and kitchen effluent (comprising one egg and one tomato). All greywater types were supplemented with raw sink effluent from a large dining room. This effluent, which contained an inoculum of *E. coli* and other bacteria, was added in a small enough volume not to affect the composition of the synthetic greywater [31].

In a controlled study, a recirculating vertical-flow constructed wetland has been investigated to assess the effect of irrigation with treated greywater on soil properties [32]. The greywater was prepared according to a similar recipe used by Gross et al. [31]. However, pulverized bar soap was applied instead of shampoo in the synthetic greywater.

Gross et al. [20] developed an economically sound, low-tech and easily maintainable combined vertical-flow constructed wetland and trickling filter system for greywater treatment and subsequent recycling. The greywater was prepared artificially by mixing laundry detergent, boric acid and raw kitchen effluents into tap water.

Comino et al. [33] proposed a functional hybrid phytoremediation pilot platform for the treatment of greywater. The pilot plant was tested with and without vegetation for different design specifications as well as for various organic and hydraulic loads of synthetic greywater. This study by Comino et al. [33] followed one by Gross et al. [20] in terms of preparation of artificial greywater.

Glasshouse experiments were conducted by Pinto et al. [34] to understand the effects of greywater reuse for irrigation of plants. Changes in soil pH, electric

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conductivity and nutrient content (total nitrogen and total phosphorus) due to greywater irrigation were assessed. Synthetic greywater was prepared by mixing a commonly available local detergent with potable water.

Winward et al. [35] evaluated the three treatment technologies constructed wetlands, membrane bioreactors and membrane chemical reactors for indicator microbial removal and greywater reuse potential under conditions of low and high strength greywater influents. A high strength supplementary solution together with real greywater was pumped to the treatment systems. Real greywater was referred to as low or high strength solution based on a mixture of locally sourced shampoo diluted by tap water.

Chemicals used in greywater simulation

The increased focus on the treatment and reuse of highly variable real greywater has driven some researchers to create greywater with stable properties artificially as indicated in Table 4a [36]. The concentrations of the corresponding greywater pollutants (e.g., organic strength, nitrogen, phosphorus, surfactants and metals) as a result of mixing the ingredients listed have been published in the references shown in Table 4a. Table 4b shows the corresponding water quality. However, most recipes cannot be reproduced accurately, because the environmental boundary conditions are variable or unreported. Moreover, some ingredients such as cow dung, shampoo and kitchen effluent is unspecified. A reproduction of the published water quality data is therefore of little use to the readers of this paper. Nevertheless, a review of the most common chemicals used for artificial greywater recipes is summarized below.

Kaolin is a common clay mineral composed of alternating sheets of aluminium hydroxide and silicate [38]. It is frequently selected as an artificial greywater

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component to represent suspended organic and inorganic solids in greywater, which may originate from natural clay containing various mineral components. These solids are often generated from kitchen and laundry effluents [4]. Kaolin is also used in synthetic wastewater recipes [17,26,39,40].

Cellulose is the principal structural component of plant cells and leaves. Furthermore, the majority of the carbohydrates found in soils are derived from cellulose, which is one of many polymers found in nature [38]. Cellulose is frequently chosen to mimic organic fibres in greywater, since kitchen sinks and dishwashers are common sources of organic fibres [17,26].

All natural waters contain humic [38] constituents as the result of biodegradation of animal and plant matter or might form in situ due to the presence of soils, nutrients, and cellulosic substrates for microbial action in the waste [41]. Humic acid is often used to represent dissolved organic matter in greywater [17,26].

Boric acid is frequently applied to represent boron ions in greywater. One source of boron is natural and the other is a result of human activities (e.g., extraction plant, industry and detergent containing sodium perborate). It follows that many water sources and wastewaters may contain boron in variable concentrations [20,28].

The following salts have been previously suggested as possible ingredients in synthetic greywater: Sodium chloride (dissolved monovalent salt) is found as a common ingredient of soap solutions and dyes [42,43]. Sodium hydrogen carbonate (natural buffer) and sodium dodecyl sulphate are mainly used for the manufacture of detergents. Their greatest cleaning application is as filler in powdered home laundry detergents [43,44]. Sodium hydrogen carbonate, sodium dodecyl sulphate and sodium phosphate are important in the manufacture of textiles by reducing negative charges on fibres, so

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that dyes can penetrate evenly [45]. Some of these salts have previously been used in synthetic grey and municipal wastewater recipes [3,17,26,28,37,40].

Calcium nitrate and calcium chloride have been suggested as components in synthetic greywater. Calcium salts are chosen to provide calcium ions to artificial greywater. Previous research used calcium salts in synthetic greywater [17,26]. Laboratory grade chemicals such as potassium nitrate, mono-potassium phosphate and magnesium sulphate have been chosen in previous studies [27,37] to resemble real greywater in terms of nutrients and macronutrients generated from laundry and kitchen effluents. Low suspended solids and turbidity linked to greywater indicates that a large proportion of pollutants are dissolved. Although organics present in greywater are relatively similar to domestic greywater, their chemical natures are quite different. So, the deficiency of nutrients and low values of biodegradable organic matter are limiting the effectiveness of biological treatment of greywater [6].

Iron(III) chloride, manganese(II) chloride, chromium(III) nitrate, zinc sulphate, copper sulphate, cadmium oxide, nickel oxide, and lead(II) oxide are commonly selected to provide heavy metals to artificial greywater, as discussed in publications reported in Table 3. Sources of heavy metals in real greywater may be from cosmetics [16], other products such as skin emulsions (creams, lotion and jelly), soap, shampoo, hair cream, henna dye [46,47] and from body parts such as hair, nails and died skin cells [4,48].

Ammonium molybdate tetrahydrate is used to provide molybdenum in artificial greywater. Molybdate is also known to enhance the biological treatment of wastewater [22]. Sodium hydroxide and hydrochloride acid are widely used as buffers to adjust the pH value of a chemical solution.

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Small quantities of secondary or tertiary effluent obtained from predominantly domestic wastewater treatment plants is frequently recommended as an additive to synthetic greywater to provide a source of pathogens and microorganisms in general [28,31,36,37,40]. However, the addition of microbes might not be necessary for experiments in non-sterile environments such as outdoor trials where a microbial population adjusted to the system tested will establish naturally eventually. One target of this study is to evaluate the stability of chemical compositions of artificial greywater through specific storage time experiments, without the contribution of biological treatment, which is offered by micro-organism. There are numerous papers in the peer-reviewed literature indicating greywater recipes that have no artificially introduced micro-organism in the list of ingredients [17,26].

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Rationale, aim, objectives and scope

There is a need to develop standard synthetic greywater recipes to allow for the easy comparison of similar experiments in the future. Original experiments and a detailed literature review have been performed to support the development of reasonably stable generic synthetic greywater recipes for both low and high concentrations.

The aim of this article is to propose practical recipes to be used for the simulation of greywater, which can be used with confidence to assess different treatment technologies. The objectives are (a) to review previous greywater recipes and corresponding components, (b) to evaluate the quality of the new synthetic greywater and compare it with recipes found in the literature, (c) to examine the stability of synthetic greywater as a function of time, and (d) to show that water quality changes are not caused by internal reactions of used chemicals.

The scope of this paper is limited to weak and strong standard synthetic greywater recipe proposals being prepared under non-sterile conditions. It follows that specific greywater types, which are often a function of geographical region, cultural and religious practices as well as guidelines and legislation, are beyond the scope of this article.

Materials and methods

Synthetic greywater

Household greywater was created artificially by using analytical grade chemicals (Table 5) purchased from Fisher Scientific Co. Ltd. (Bishop Meadow Road, Loughborough, UK). The synthetic greywater was prepared under non-sterile conditions as a stock solution by mixing the selected chemicals with de-chlorinated public mains tap water at a temperature of around 25°C. The following water quality parameters of greywater were simulated: biochemical oxygen demand, chemical oxygen demand, ammonia-nitrogen, nitrate-nitrogen, ortho-phosphate-phosphorus, pH, redox potential, turbidity, total suspension solids and electronic conductivity. The resultant key pollutants of the proposed recipes are summarised in Table 6.

Two stock solutions were mixed separately to represent low (LC) and high (HC) greywater strengths, and stirred by a magnetic stirrer (3.0 cm long and 0.5 cm wide) with rounded edges for one hour at 1200 rpm [26]. The two solutions were stored overnight at 4°C, and stirred for a further 30 minutes before the start of subsequent experiments. The concentration levels of the proposed synthetic greywater are shown in Table 6. These concentrations were subject to environmental conditions typical for Greater Manchester (temperate and oceanic climate) between November and May.

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Sodium hydroxide (NaOH) and hydrochloride acid (HCl) were used to adjust the pH value of the solution [17]. A wide range for pH values for real greywater has been reported in literature (Table 1). However, in this experiment, the pH values for both low and high strength greywaters were adjusted at pH ranges of around 5 to 7 and 7 to10, respectively.

Experimental set-up

The set-up design includes two groups of black plastic buckets (volumes of 14 litres each) selected to store 10 litres of the prepared greywater for two days and seven days residence storage times. The storage times selected represent typical ones reported in literature (Tables 1 to 4). Moreover, there are rather practical considerations of regular feeding of experimental set-ups avoiding weekends. Each group has two bucket replicates; the first group was used for storing low concentration greywater and the second for keeping high strength greywater.

The buckets were subjected to real weather conditions at a quiescent place on University grounds from 1st of November 2014 to 30th of April 2015. Samples were collected manually after the specific storage time (2 and 7 days) to conduct several analytical tests as outlined in the next section.

Water quality

Water quality sampling was carried out according to APHA [49], unless stated otherwise, to monitor the properties of synthetic greywater. The spectrophotometer DR 2800 (Hach Lange, Rechnungen, Germany) was used for standard water quality analysis concerning variables including chemical oxygen demand (COD, mg/l), ammonia-nitrogen (NH_4-N, mg/l), nitrate-nitrogen (NO_3-N, mg/l), ortho-phosphate-phosphorus (PO_4-P, mg/l), total suspension solids (TSS, mg/l) and colour (Pa/Co).

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The 5-day biochemical oxygen demand (BOD_5, mg/l) was determined in all water samples with the OxiTop IS 12-6 system, a mono-metric measurement device, supplied by the Wissenschaftlich–Technische Werkstätten (Weilheim, Germany). Turbidity was measured with a Turbicheck Turbidity Meter (Lovibond Water Testing, Tintometer Group, Dortmund, Germany). The redox potential (redox) was measured with a sensION+benchtop multi-parameter meter (Hach Lange, Düsseldorf, Germany). The electric conductivity (EC, µs/cm) was determined by a conductivity Meter entitled METTLER TOLEDO FIVE GOTM (Keison Products, Chelmsford, Essex, England, UK). Dissolved oxygen (DO, mg/l) for all samples was measured by an HQ30d Flexi meter (Hach Lange, Düsseldorf, Germany).

Data analysis

Microsoft Excel has been used for the general data analysis (e.g., mean, standard deviation, minimum and maximum values). The non-parametric Mann–Whitney test was computed using IBM SPSS Statistics Version 20 and applied to compare the variance in test results of two (unmatched) independent samples. Since, all sample data were not normally distributed.

Results and discussion

Synthetic greywater characteristics

The inflow water parameters in Table 6 refer to characteristics of prepared synthetic greywater just before utilisation in the experiment. These parameters were compared and discussed with published results of real greywater constituents obtained from previous research studies (Table 1).

The figures shown in Table 6 are based on outside (greywater systems exposed

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to the elements) experiments. The data variability is therefore high, resulting in some unexpected findings, which are, however, not statistically ($p>0.05$) significant. For example, the mean COD of inflow (LC greywater) was 25.2 mg/l. After two days of storage, the average outflow COD was 27.9 mg/l. Furthermore, the corresponding standard deviations are relatively high and the sample numbers of both data sets are different.

There are very few reported data regarding colour of real greywater. The test results of synthetic greywater have shown ranges of colour from 26.0 to 332.0 Pa/Co and from 787.0 to 2499.0 Pa/Co for LC and HC greywater concentrations, respectively. The temperature was around 6.5–37.0°C for both types of proposed greywater, which was similar to figures reported by Eriksson et al. [4] and Christova-Boal et al. [7]. Depending on the sources of greywater, there is a wide range of pH for real greywater. Most of these waters were simulated by using LC synthetic greywater with a pH between 6.0 and7.9, while the pH values for HC greywater were between 5.4 and 11.5, representing those real discharges, which were commonly generated from laundries [4,7,10,17].

The reported ranges for turbidity and total suspended solids (TSS) as shown in Table 1 were successfully simulated particularly by the ingredient kaolin (Table 5) for both greywater strengths (Table 6). Those values for simulated HC greywater (mean of 318 mg/l and range between 190 mg/l and 473 mg/l; Table 6) are particularly represented by the solids in the discharges from laundry, kitchen and mixed greywater sources as shown in Table 1 [4,7,10,12], while the simulated LC greywater (mean of 40 mg/l and range between 10 mg/l and 87 mg/l; Table 6) is linked to waters from hand basins, showers and similar mixed greywater sources as indicated in Table 1 [6,13,14,15,16]. Electric conductivity data for real greywater in literature have

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demonstrated high levels for laundry and mixed greywater sources [4,7,14,18]. In contrast, low values are linked to bathroom fluxes [4,7,12,19]. The DO was around the reported upper limits, especially in the absence of significant numbers of microorganism in the synthetic greywater.

Numerous water quality parameters of the proposed greywaters (Table 6) have similar values in terms of averages, or are at least within the published ranges (Tables 1 to 3). Although the concentrations of BOD_5 in low strength greywater, in particular, are less than some of the reported values for real greywater, but they agree with those indicated by Eriksson et al. [16] and Winward et al. [35].

The review on chemical oxygen demand (COD) concentrations in literature reveals that there is a wide variation of greywater types and compositions (Table 1). This can be explained by a great variety of household chemicals used causing a high degree of fluctuation from sample to sample [4,6,16]. Comparted with those obtained from the analysis of synthetic greywater (Table 6), the LC greywater COD concentrations were similar to the lower limits of reported studies. Furthermore, the test results for synthetic greywater (Table 6) have shown appropriate simulations for reported values of ammonia-nitrogen (NH_4-N), nitrate-nitrogen (NO_3-N) and ortho-phosphate-phosphorus PO_4-P, in terms of mixed greywater regardless the sources of origin [4,13,14,16].

In the literature, various recipes for synthetic greywater, which was utilized for different treatment technologies, have been proposed (Table 4a). This study illustrates how to choose analytical grade chemicals to create two strength solutions of synthetic greywater (Table 5). Organic and inorganic matter, dissolved and suspended solids, nutrients and macronutrients, trace elements and microorganisms were resembled carefully to simulate real greywater components and associated properties. Depending

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on data shown in Table 2 and 3, synthetic greywater solutions represent reality reasonably well. The recipe was based on the molar weight of the chemical composition multiplied by the percentage of the specific element in that chemical. For example, 100 mg of Iron (III) chloride provides 34 mg/l of iron (Table 5).

Stability of synthetic greywater

Table 6 shows all water quality results of LC and HC synthetic greywaters after two and seven days of storage. For LC greywater, the pH has increased from 6.9 to 7.2 for a two-day storage period. There was no significant ($p>0.05$) change after seven days of storage. However, data show a reduction in colour, turbidity and total suspended solids for the outflow of two-day storage experiments by 22.0%, 5.5% and 23.4%, respectively. The percentages concerning the outflow for the seven-day storage experiments were 14.2%, 11.1%, and 22.9%, respectively. The number of colloids and particles is likely to reduce over time as physical (e.g., coagulation and flocculation) processes reduce turbidity and suspended solids. However, biochemical processes such as biodegradation will lead to an increase in microorganisms and debris contributing to an increase in turbidity and fine material [4,7,10,20,24,30].

A statistical analysis has shown no significant ($p>0.05$) changes in colour, pH, turbidity and total suspended solids, when both synthetic greywaters are stored for two or seven days. This confirms previous findings [28,36] showing that suspended solids and insoluble particle concentrations of chemical greywaters are highly stability, possibly, because they originate from inert materials.

Figure 1(a) and (b) illustrate the variations in BOD_5 concentrations for both LC and HC synthetic greywater, respectively. The values for LC greywater have shown significant ($p<0.05$) reductions in the averages from 15.2 mg/l to 5.7 mg/l and to 7.0 at

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two and seven days of storage time, respectively (Table 6 and Figure 2(a)). While for HC greywater, the biochemical oxygen demand has dropped significantly ($p<0.05$) form 32.3 mg/l to 14.5 mg/l after two days of storage with a reduction of 55.2%, and it was stable at around 14.7 mg/l for outflow water after seven days (Table 6, Figure 2(a)). This change has been confirmed by comparing available data evidence, which was reported by Jefferson et al. [2]. Microbial contamination is the likely reason for the drop in organic strength [50,51].

The chemical oxygen demand in the LC greywater increased from 25.2 mg/l to 27.9 mg/l (not statistically significant ($p>0.05$); see also above) for the two-day storage time experiment. However, it decreased to 19.6 mg/l for the seven-day storage time test (Figure 2(b)). In contrast, the chemical oxygen demand for HC greywater dropped from 115.4mg/l to 110.7m/l (reduction by 4.1%) and to 108.3 mg/l (reduction by 6.2%) for two-day and seven-day storage times, respectively. The variations in test results are shown in Figures 1(c) and (d) in that order. Some of the COD data variations can be attributed to both experimental variability (see discussion in the previous section) and biodegradation of the fraction of the COD, which is biodegradable [29,38].

For HC greywater, the averages of ammonia-nitrogen show a stable behaviour with values of around 0.4 mg/l without change through storage (Figures 1(e) and (f)). The corresponding values for LC greywater have decreased from 0.2 m/l to 0.1 mg/l after two days of storage. The results show no change for seven days outflow (Figure 2(c)). The measured values for ammonia-nitrogen are close to the detection limit. Therefore, the transformation of ammonia to nitrite and subsequently to nitrate cannot be evidence in this experiment [38].

A considerable change was observed for the average values of nitrate-nitrogen after both storage times. The values dropped from 9.2 mg/l to 6.2 mg/l and 2.8mg/l after

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storage times of tow and seven days, respectively (Table 6, Figure 1(h)). However, a significant ($p<0.05$) reduction was noted for two days of storage regarding HC synthetic greywater. In contrast, the nitrate-nitrogen values of LC greywater decreased slightly from 1.4 mg/l to 1.3 and to 1.1 mg/l after two and seven days of storage time in this order (Figures 1(g) and 2(d)). The reduction of nitrate-nitrogen can be explained by denitrification [38].

Also, there are no significant ($p>0.05$) changes in the reduction of ortho-phosphate-phosphorus for both storage times (Figures 1(i) and (j)). They decreased from 50.6 mg/l to 46.5 mg/l (reduction of 8.2%) for two-day storage, and decreased to 45.8 mg/l (reduction of 26.4%) for seven-day storage of HC greywater. The ortho-phosphate-phosphorus concentrations also decreased from 6.3 mg/l to 5.6 mg/l for two-day storage experiments, and to 8.2 mg/l for seven-day storage of LC greywater (Figure 2(e)). Phosphorus is likely to be taken up by microbes developing in the outside systems [51]. However, considering that microbes were not deliberately added to the greywater recipe, microbial biomass development is rather slow. Therefore, changes in phosphorus concentrations were small.

Conclusions and recommendations

The proposed new synthetic greywater recipes mimic real greywater well in both composition and properties. Furthermore, they provide a good matrix for microorganisms to survive and contain compounds in detectable concentrations identified as having a potentially detrimental environmental impact.

The suggested recipes for LC and HC greywater loadings are easy to prepare and replicate by others in the future. All selected materials were of chemical analytical

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grade. High quantity stock solutions can be prepared and stored at 4°C without major concern.

Throughout monitoring of the synthetic greywater properties during storage, the water quality parameters concerning their average values are chemically relatively stable. It has been noticed that only significant ($p<0.05$) fluctuations in the BOD_5 for both greywater concentrations may occur. In addition, it is not recommended to store the synthetic greywater for more than two days to avoid depletion of dissolved oxygen due to development of microorganisms. Furthermore, significant changes in nitrate-nitrogen content might be noticed after two days of storage.

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Figure 1. Effect of storage time on the variation of (a) five-day biochemical oxygen demand (BOD_5) of low concentration synthetic greywater (LC), (b) BOD_5 of high concentration synthetic greywater (HC), (c) chemical oxygen demand (COD) of LC, (d) COD of HC, (e) ammonia-nitrogen (NH_4–N) of LC, (f) NH_4–N of HC, (g) nitrate-nitrogen (NO_3–N) of LC, (h) NO_3–N of HC, (i) ortho-phosphate-phosphorus (PO_4–P) of LC, and (j) PO_4–P of HC greywater.

Figure 2. Effect of storage time on the synthetic greywater characteristics (a) five-day biochemical oxygen demand, (b) chemical oxygen demand, (c) ammonia-nitrogen, (d) nitrate-nitrogen, and (e) ortho-phosphate-phosphorus.

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Table 1. Characteristics of real greywater (GW).

Table 2. Trace element concentrations (mg/l) of real greywater (GW).

Table 3. Heavy metal concentrations (mg/l) of real greywater (GW).

Table 4a. Recipes reported for different synthetic greywater.

Table 4b. Characteristics of different synthetic greywaters proposed in Table 4a.

Table 5. Proposed ingredients for low and high strength synthetic greywaters.

Table 6. Water quality parameters after two and seven days of storage time.

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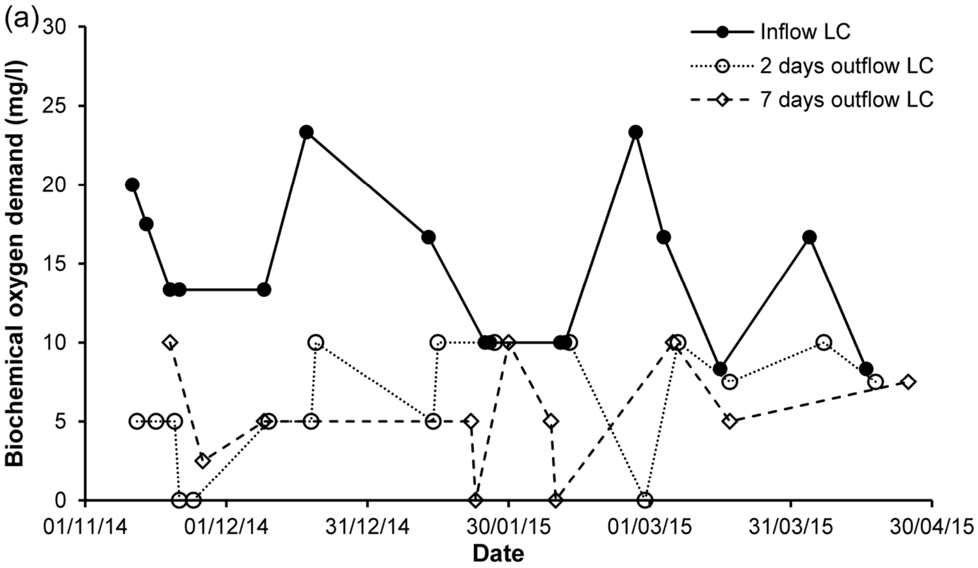

Effect of storage time on the variation of five-day biochemical oxygen demand (BOD5) of low concentration synthetic greywater (LC).
85x49mm (600 x 600 DPI)

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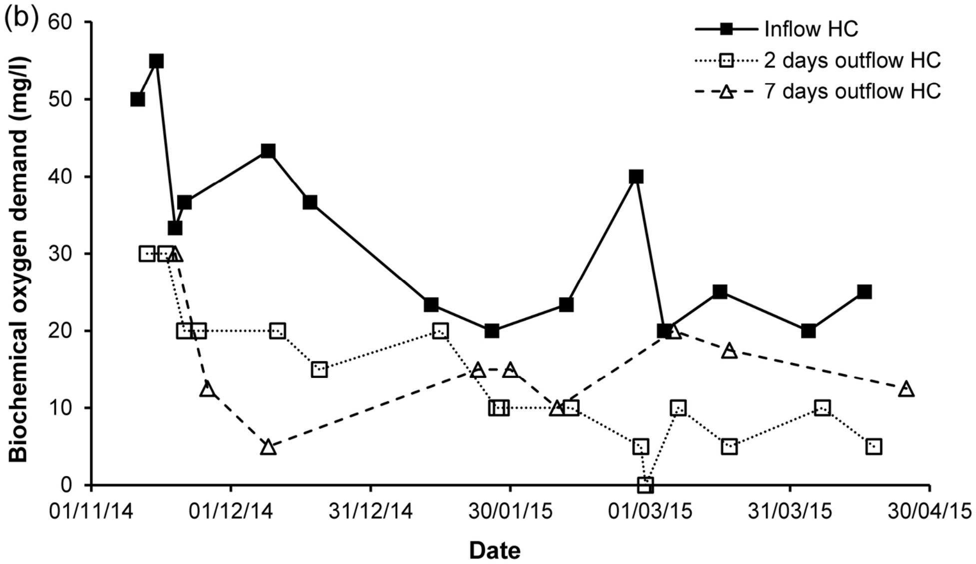

Effect of storage time on the variation of BOD5 of high concentration synthetic greywater (HC).
85x49mm (600 x 600 DPI)

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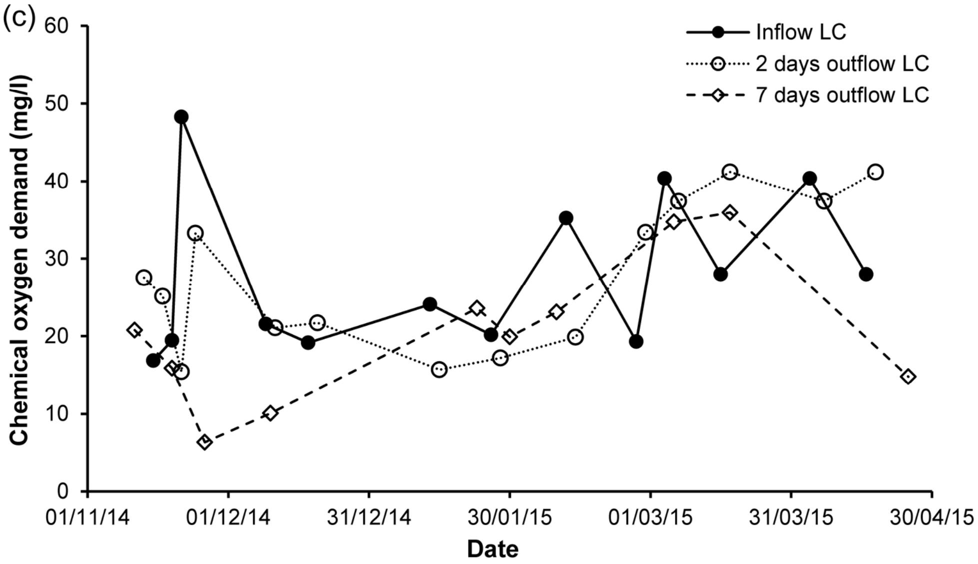

Effect of storage time on the variation of chemical oxygen demand (COD) of LC.
85x49mm (600 x 600 DPI)

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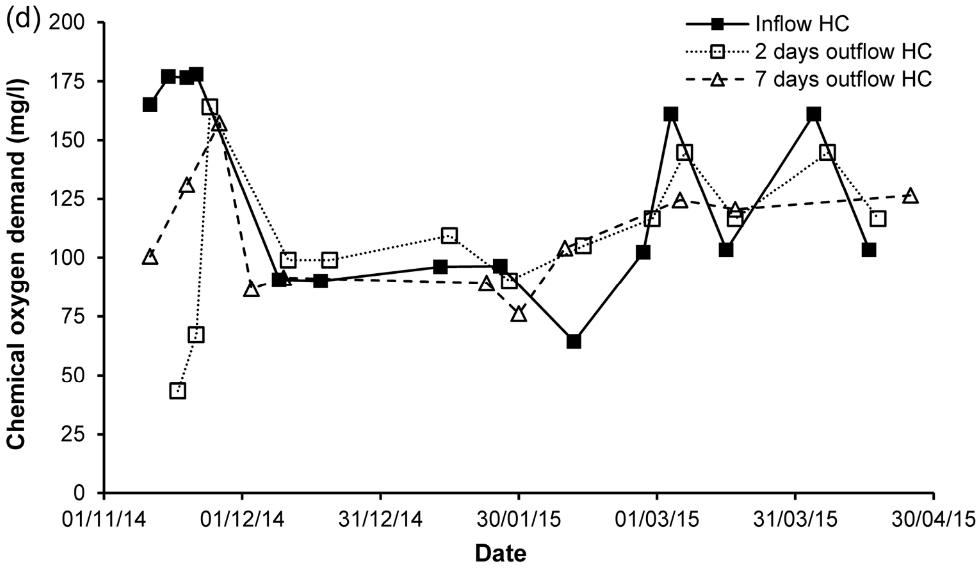

Effect of storage time on the variation of COD of HC.
85x49mm (600 x 600 DPI)

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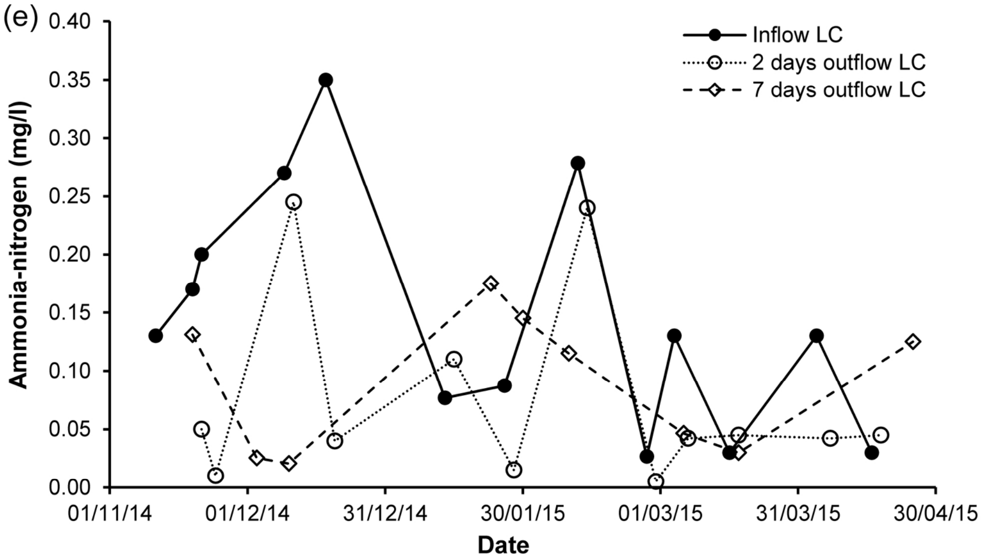

Effect of storage time on the variation of ammonia-nitrogen (NH4–N) of LC.
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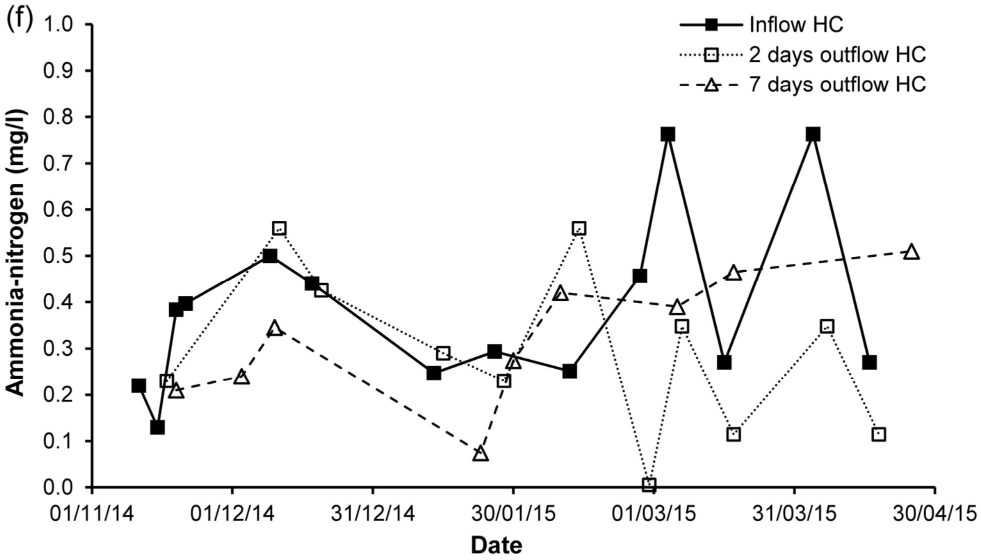

Effect of storage time on the variation of NH4–N of HC.
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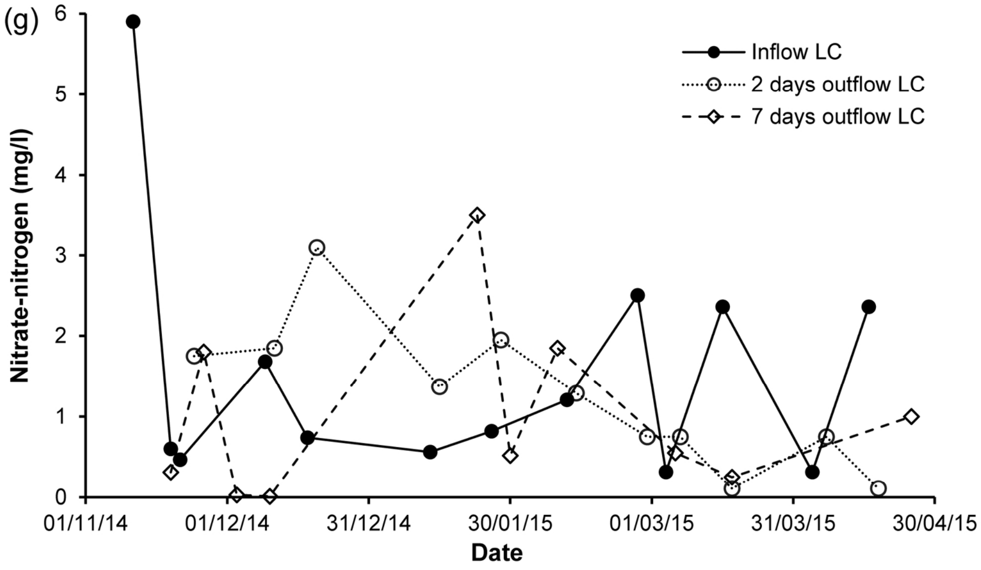

Effect of storage time on the variation of nitrate-nitrogen (NO3–N) of LC.
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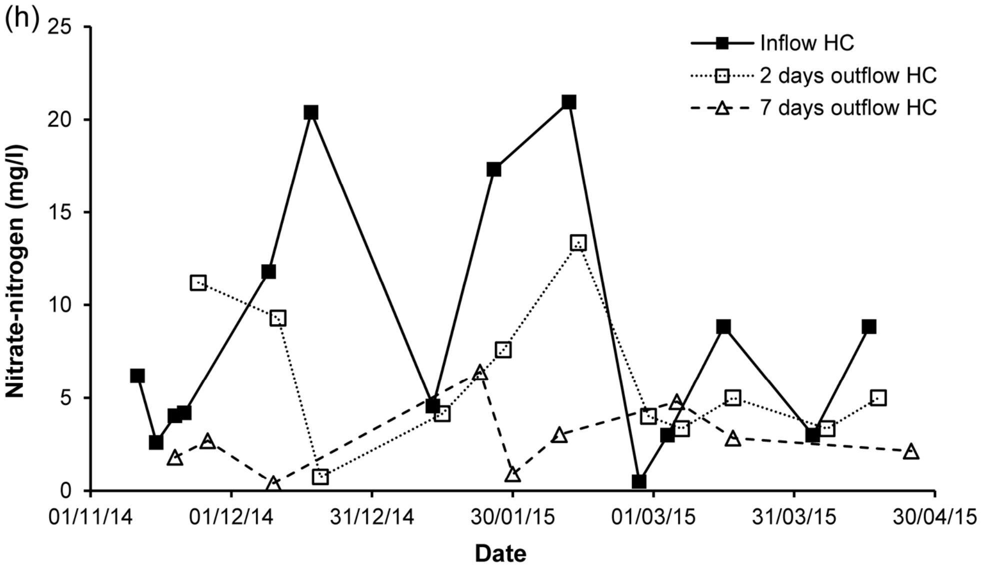

Effect of storage time on the variation of NO3–N of HC.
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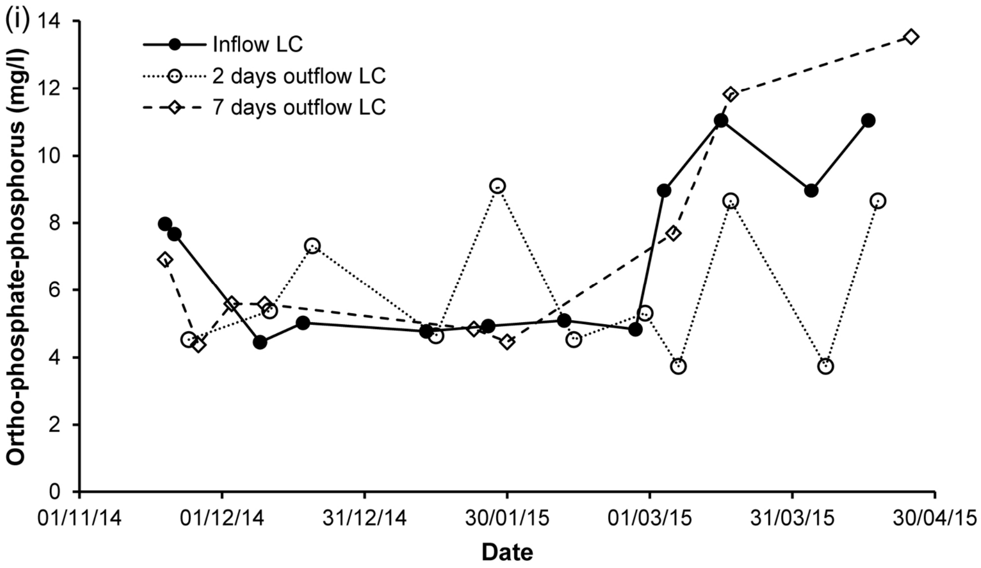

Effect of storage time on the variation of ortho-phosphate-phosphorus (PO4–P) of LC.
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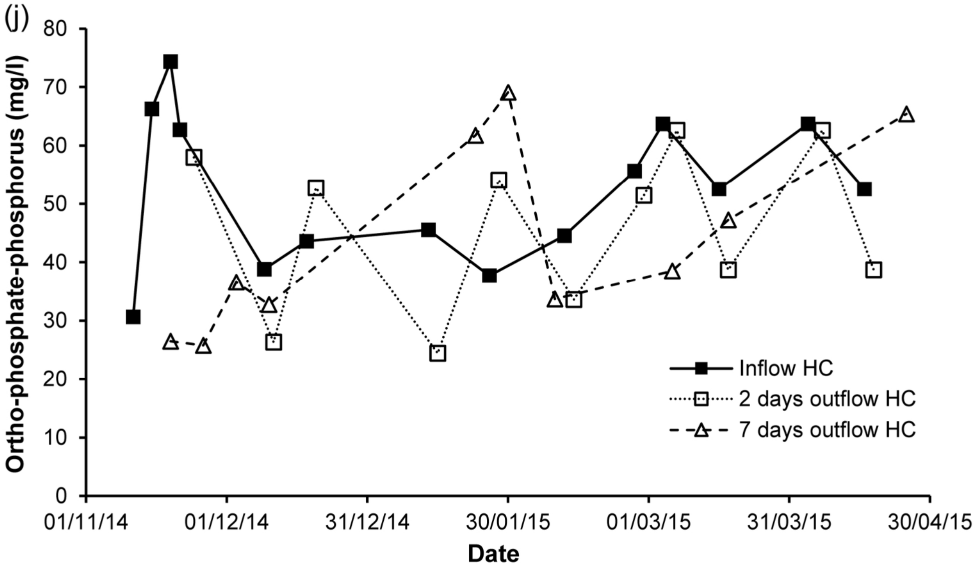
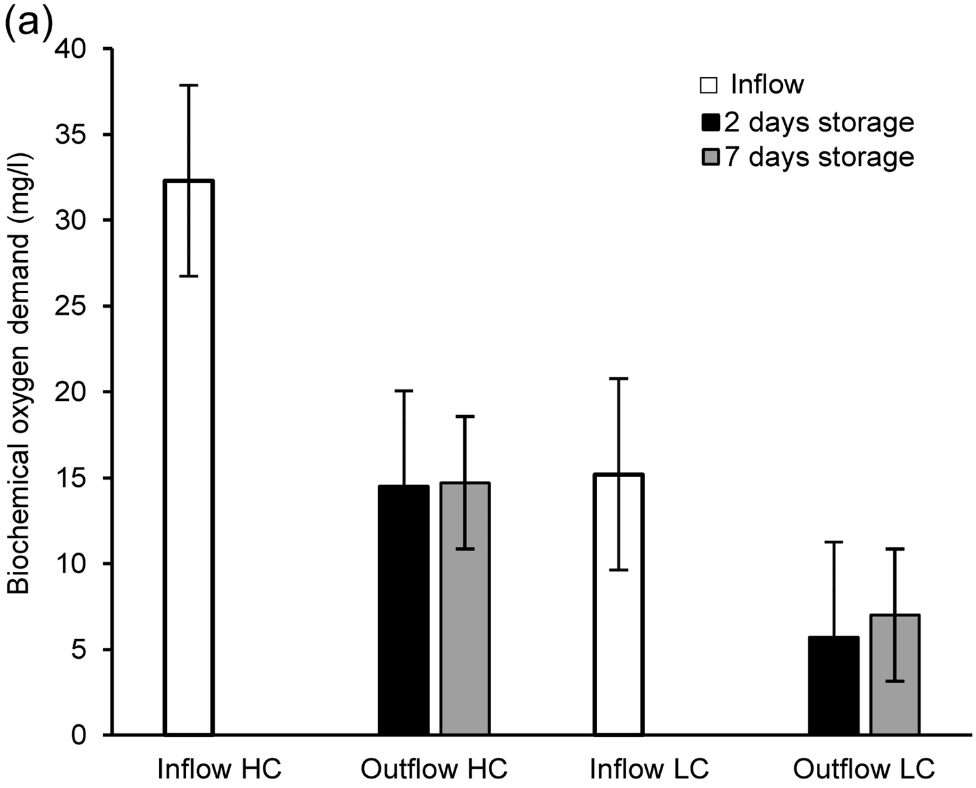


Effect of storage time on the variation of PO4–P of HC greywater.
85x49mm (600 x 600 DPI)

Review Only



Effect of storage time on the synthetic greywater characteristics five-day biochemical oxygen demand.
70x58mm (600 x 600 DPI)

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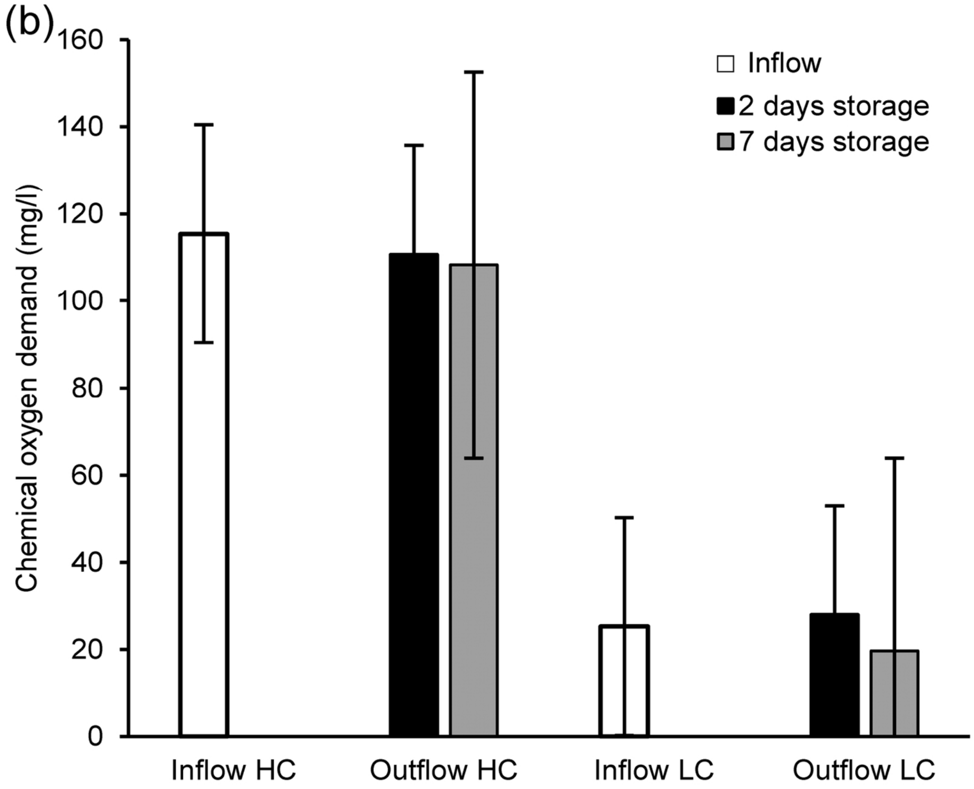

Effect of storage time on the synthetic greywater characteristics chemical oxygen demand.
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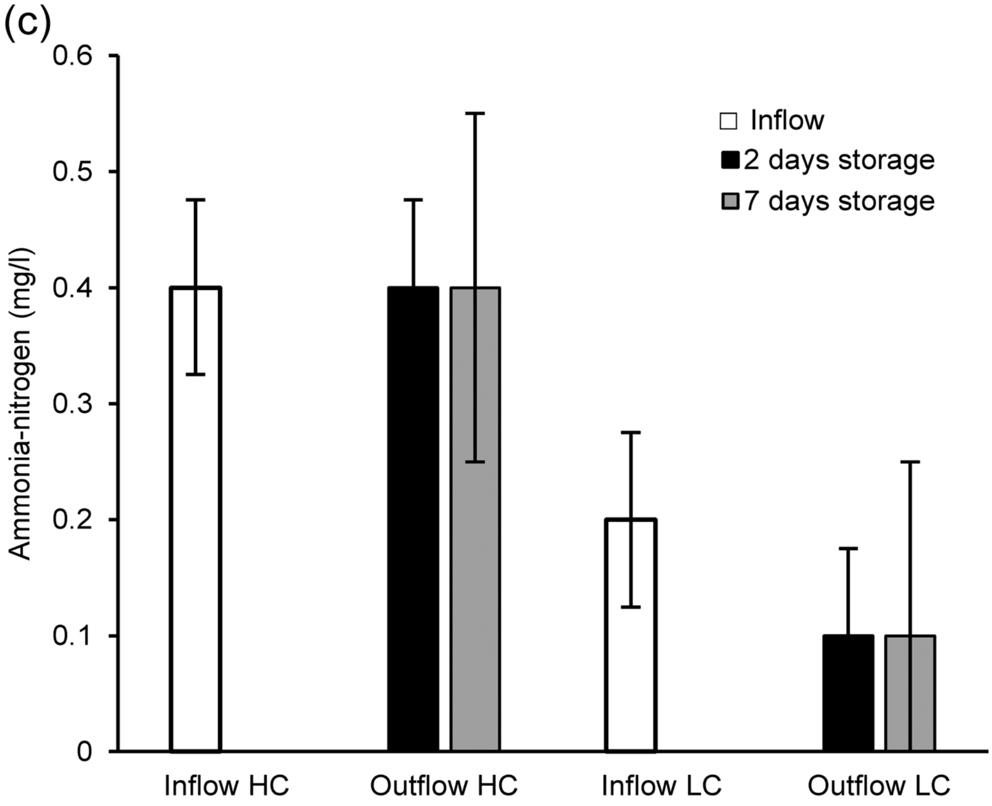

Effect of storage time on the synthetic greywater characteristics ammonia-nitrogen.
70x58mm (600 x 600 DPI)

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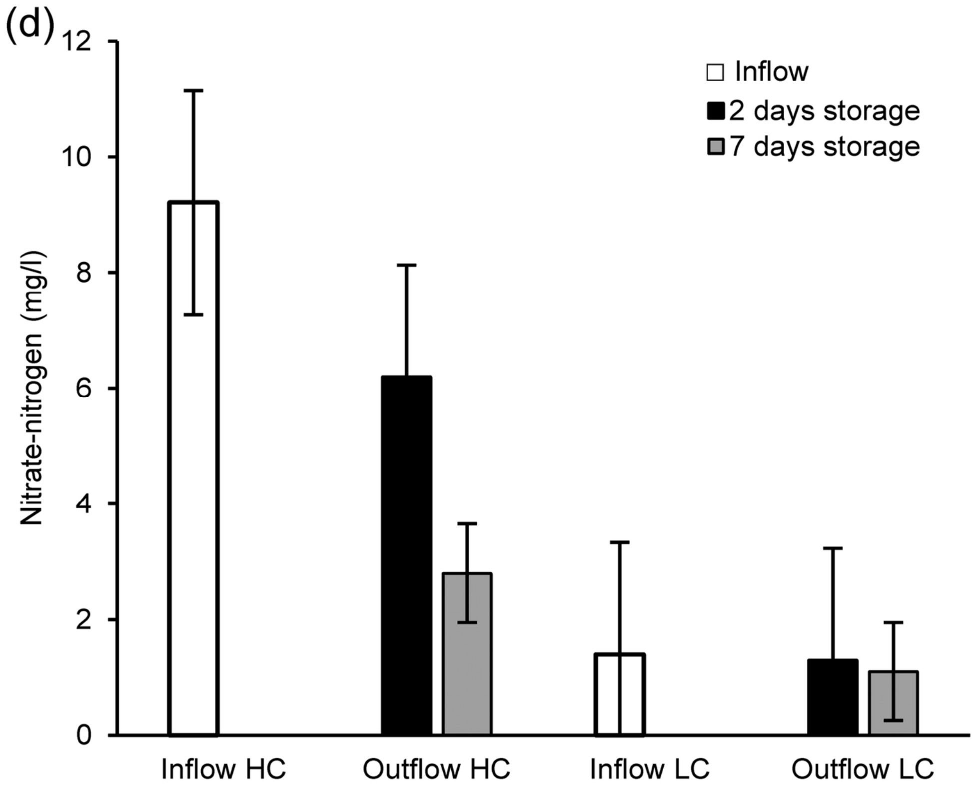

Effect of storage time on the synthetic greywater characteristics nitrate-nitrogen.
70x59mm (600 x 600 DPI)

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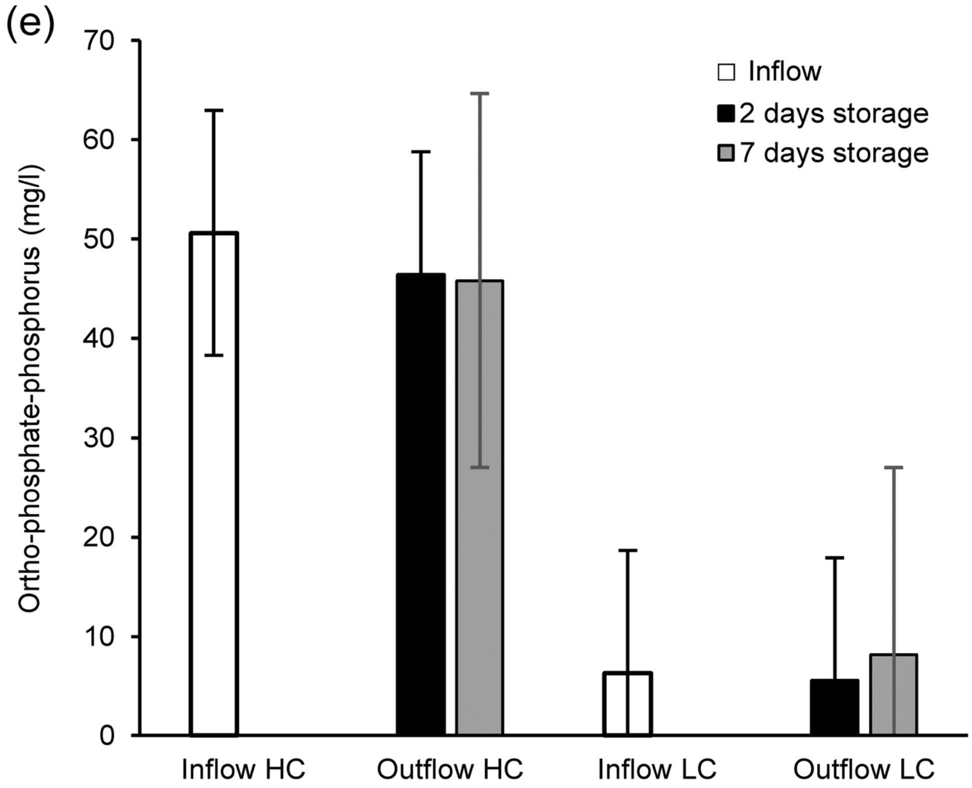

Effect of storage time on the synthetic greywater characteristics ortho-phosphate-phosphorus.
70x59mm (600 x 600 DPI)

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Table1. Characteristics of real greywater (GW).

Reference	Greywater source	Temp. (°C)	pH (–)	Turbidity (NTU)	TSS (mg/l)	EC (μS/cm)	DO (mg/l)	BOD$_5$ (mg/l)	COD (mg/l)	NH$_4$–N (mg/l)	NO$_3$–N (mg/l)	PO$_4$–P (mg/l)
Eriksson et al. [4]	Bathroom GW	29	6.4–8.1	60–240	54–200	82–250		76–200	100–633	≤0.1 to 15.0	0.28–6.30	0.94–48.80
	Laundry GW	28–32	8.1–10.0	14–296	120–280	190–1400		48–380	12.8–725.0	0.04–11.30	0.4–2.0	4–171
	Kitchen GW	27–38	6.3–7.4		235–720		2.2–5.8	1040–1460	3.8–1380	0.002–23.0	0.3–5.8	12.7–32.0
	Mixed GW	18–38	5.0–8.7	15.3 to ≥200.0		320–20000		90–360	13–549	0.03–25.40	0.0–4.9	4–68
Al-Jayyousi [6]	Hand basin							109	263	9.6		
	Combined			69				121	371	1		
	Single person			14				110	256			
	Single family			76.5						0.74		
	Block of flats			20				33	40	10		
	College			59				80	146	10		
	Large college			57				96	168	0.8		
Christova-Boal et al. [7]	Bathroom GW	25	6.4–8.1	60–240	48–120	82–250		76–200		≤0.1 to 15.0		
	Laundry GW	25	9.3–10.0	50–210	88–250	190–1400		48–290		≤0.1 to 1.9		
Li et al. [10]	Bathroom GW		6.4–8.1	44–375	7–505			50–300	100–633			
	Laundry GW		7.1–10.0	50–444	68–465			48–472	231–2950			
	Kitchen GW		5.9–7.4	298	134–1300			536–1460	26–2050			
	Mixed GW		6.3–8.1	29–375	25–183			47–466	100–700			
Al-Hamaiedeh and Bino [12]	Real GW range		6.9–7.8		23–358	157–200		110–1240	92–2263		0.44–0.93	
	Real GW average		7.2		275	183		942	1712		0.68	
Pidou et al. [13]	Mixed GW LC		6.6–7.6	35				39	144	0.7	3.9	0.5
	Shower GW HC		7.3–7.8	42				166	575	1	7.5	1.3
	Real Raw GW			46.6				205	791	1.2	6.7	1.66
Ramona et al. [14]	Shower GW1		7.5	23	29.8	1317		78	170	1.5–3.0	0.05–1.70	0.02–0.19
March et al. [15]	Raw GW		7.3–8.0	5–62					39–441			
Eriksson et al. [16]	Raw GW 1		7.7–8.1		51–135		2.5–4.5	18–68		0.36–4.40		0.02–2.20
	Raw GW 2		8.2–8.3		67–390		9.3–9.5	≤3		0.07–0.13		0.25–0.28
Nghiem et al. [17]	Real GW		5.0–10.9					33–1460	3.8–1380.0			
Houshia et al. [18]	Raw GW		6.1			1500		126.6			38	
Leal et al. [19]	Raw GW		7.24			74.4			1476		≤0.10	2.97

Notes: Temp. = temperature, NTU = nephelometric turbidity unit, TSS = total suspended solids, EC = electric conductivity, DO = dissolved oxygen, BOD$_5$ = 5-day biochemical oxygen demand, COD = chemical oxygen demand, NH$_4$–N = ammonia–nitrogen, NO$_3$–N = nitrate–nitrogen, and PO$_4$–P = ortho–phosphate–phosphorus.

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Table 2. Trace element concentrations (mg/l) of real greywater (GW).

Reference	Greywater Source	Aluminium	Boron	Calcium	Potassium	Magnesium	Sodium	Sulphur	Silicon	Phosphorus
Eriksson et al. [4]	Bathroom GW	≤0.1	≤0.1	3.5–7.9	1.5–5.2	1.4–2.3	7.4–18.0	1.2–3.3	3.2–4.1	
	Laundry GW	≤1.0–21	0.1–0.5	3.9–14.0	1.1–17.0	1.1–3.1	44–480	9.5–40.0	3.8–49.0	
	Kitchen GW	0.67–1.8		13–30	19–59	3.3–7.3	29–180			
	Mixed GW	0.10–3.55		11–35	6.6	1.5–19.0	21–230			
Christova-Boal et al. [7]	Bathroom GW	≤1.0		3.5–7.9	1.5–5.2	1.4–2.3	7.4–18.0	1.2–3.3	3.2–4.1	0.11–1.80
	Laundry GW	≤1.0–21.0		3.9–12.0	1.1–17.0	1.1–2.9	49–480	9.5–40.0	3.8–49.0	0.062–42.000
Li et al. [10]	Bathroom GW	2.44		33.8	8.1	5.74		23.7		
	Laundry GW	0.49		60.79	11.20–23.28	6.15		19		
	Kitchen GW	0.003		47.9	5.79	5.29		16.3		
Ramona et al. [14]	Shower GW	0.03	0.14	71.0–93.6	9.8–12.4	43.2–50.0	93.0–142.7			
Nghiem et al. [17]	Real GW			3.6–200.0						
Houshia et al. [18]	Raw GW			89.5	37.3	132.2				
Leal et al. [19]	Raw GW			42.8	14.5	11.6	128			
Kariuki et al. [21]	Kitchen GW1			4.9	23.4	4.8	15.38			
	Laundry GW1			1.3	26.9	2.54	39.23			
	Bath GW2			0.96	10	0.27	6.15			
	Kitchen GW2			0.93	16.9	0.28	9.89			
	Laundry GW2			0.32	31.8	1.14	35.38			
Jefferson et al. [22]	Real GW	0.003		47.9	5.79	5.29		16.3		

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Table 3. Heavy metal concentrations (mg/l) of real greywater (GW).

Reference	Greywater source	Cadmium	Chromium	Copper	Iron	Manganese	Nickel	Lead	Zinc	Molybdenum
Eriksson et al. [4]	Bathroom GW	0.00054–0.01000		0.06–0.12	0.34-1.10			0.003	0.059–6.300	
	Laundry GW	0.00036–0.03800	≤0.025	≤0.050–0.322	0.29-1.00	0.029	≤0.028	0.033 to ≤0.063	0.09–0.44	
	Kitchen GW	0.00052–0.00700	≤0.025–0.130	0.05–0.26	0.6-1.2	0.031–0.075	≤0.025	0.005–0.140	0.096–1.800	
	Mixed GW	≤0.006–0.030	≤0.01026–0.05000	0.018–0.230	<0.05-4.37	0.014–0.075	≤0.015–0.050	≤0.01–0.15	≤0.01–1.60	
Christova-Boal et al. [7]	Bathroom GW	≤0.01		0.06–0.12	0.34–1.10				0.2–6.3	
	Laundry GW	≤0.01		≤0.05–0.27	0.29–1.00				0.09–0.32	
Li et al. [10]	Bathroom GW			0.0618	0.36	0.0121			0.0644	
	Laundry GW			0.08	0.11	≤0.05			0.00	≤0.05
	Kitchen GW			0.006	0.017	0.04			0.03	0.00
Al-Hamaiedeh and Bino [12]	GW Range							1.00–1.31		
	GW Average	0.008						1.19		
Ramona et al. [14]	Shower GW 1	≤0.02	≤0.02	≤0.02	0.19	≤0.02	≤0.02	≤0.02	0.18	≤0.02
	Shower GW 2	≤0.02	≤0.02	≤0.02	0.06	≤0.02	≤0.02	≤0.02	0.03	≤0.02
Eriksson et al. [16]	Raw GW 1	0.0001		0.0087–0.0110			0.007–0.039	0.0025–0.0031		
	Raw GW 2	≤ 0.0001–0.0090		0.0085–0.0250			0.0055–0.0079	0.0018–0.0032		
Leal et al. [19]	Raw GW			0.0906	0.29			≤0.010		
Kariuki et al. [21]	Kitchen GW1	5.5	16.1	0.9	1.9	1.4		0.9	6.6	
	Laundry GW1	7	0.9	1	3.6	0.4		0.8	0.4	
	Bath GW2	10.7	11.1	2.6	3.8	0.3		0.2	0.2	
	Kitchen GW2	10	11.3	2.3	9.7	0.2		0.3	0.1	
	Laundry GW2	11.2	16.1	2.9	17.5	0.3		0.0	0.7	

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Table 4a. Recipes reported for different synthetic greywaters.

Reference	Surendran and Wheatley [3]	Diaper et al. [28]		Nazim and Meera [27]		Fenner and Komvuschara [37]	
Country	UK	Australia		India		UK	
Treatment approach	Multi-stage bio-filter	- Biological with suspended media - Chemical flocculants, ultraviolet disinfection and filtration - Settling, biological with fixed media		Using garbage enzyme after filtration		Ultraviolet disinfection system	
Dextrin	85 mg/l	Sunscreen or moisturiser	15 or 10 mg/l	Glucose	300 mg/l	Dextrin	85 mg/l
Ammonium chloride	75 mg/l	Toothpaste	32.5 mg/l	Sodium acetate trihydrate	400 mg/l	Ammonium chloride	75 mg/l
Yeast extract	70 mg/l	Deodorant	10 mg/l	Ammonium chloride	225 mg/l	Yeast extract	70 mg/l
Soluble starch	55 mg/l	Sodium sulphate	35 mg/l	Sodium dihydrogen phosphate	150 mg/l	Soluble starch	55 mg/l
Sodium carbonate	55 mg/l	Sodium hydrogen carbonate	25 mg/l	Potassium dihydrogen phosphate	75 mg/l	Sodium carbonate	55 mg/l
Washing powder	30 mg/l	Sodium phosphate	39 mg/l	Magnesium sulphate	50 mg/l	Sodium dihydrogen phosphate	11.5 mg/l
Sodium dihydrogen phosphate	11.5 mg/l	Clay (unimin)	50 mg/l	Cow dung	225 ml/l	Potassium phosphate	4.5 mg/l
Potassium sulphate	4.5 mg/l	Vegetable oil	0.7 mg/l			*Escherichia coli* culture	15 ml/l
Settled sewage	10 ml/l	Shampoo/hand wash	720 mg/l				
Shampoo	0.1 ml/l	Laundry	150 mg/l				
Cooking oil	0.1 ml/l	Boric acid	1.4 mg/l				
Biochemical oxygen demand	approx. 200 ml/l	Lactic acid	28 mg/l				
		Secondary effluent	20 ml/l				

Reference	Gross et al. [20]/Comino et al. [33]	Nghiem et al. [17]		Jefferson et al. [22]		Hourlier et al. [36]	
Country	Israel/Italy	Australia		UK		France	
Treatment Approach	Vertical-flow constructed wetland/ Hybrid constructed wetland	Submerged ultrafiltration membranes		Membrane bioreactors and activated sludge systems		Direct membrane nano-filtration	
Laundry detergent	20 g	Humic Acid	20 mg/l	Synthetic soap	0.64g	Lactic acid	100 mg/l
Boric acid	0.86 g	Kaolin	50 mg/l	Hair shampoo	8.0 ml	Cellulose	100 mg/l
Kitchen effluent	400 ml	Cellulose	50 mg/l	Sunflower oil	0.1 ml	Sodium dodecyl sulphate	50 mg/l
Tap water	150 l	Calcium chloride	0.5 mM	Tertiary effluent	24 ml	Glycerol	200 mg/l
		Sodium chloride	10 mM	Tap water	10 l	Sodium hydrogen carbonate	70 mg/l
		Sodium hydrogen carbonate	1 mM			Sodium sulphate	50 mg/l
						Septic effluent	10 mg/l

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Table 4b. Characteristics of different synthetic greywaters proposed in Table 4a.

Parameter	Unit	Surendran and Wheatley [3]	Diaper et al. [28]	Nazim and Meera [27]	Gross et al. [20]	Comino et al. [33]	Nghiem et al. [17]	Hourlier et al. [36]
Biochemical oxygen demand	mg/l	215	146.7	192	28.0–688			58–75
Chemical oxygen demand	mg/l		276.7	290	702–984	77.4		391–505
Ammonia-nitrogen	mg/l	11		9.6	0.1–0.5			
Nitrate-nitrogen	mg/l		<0.2		0.0–5.8			
Nitrite–nitrogen	mg/l		<0.003		0.0–1.0			
Total nitrogen	mg/l				25.0–45.2			
Ortho-phosphate-phosphorus	mg/l	4.9		110				
Total phosphorus	mg/l		17.8		17.2–27.0			
pH	–		7.4	6.16	6.3–7.0	7.3	7.5–8.0	6.29–7.29
Redox potential	mV							
Turbidity	NTU	72	52.1				140	4–42
Total dissolved solids	mg/l	12.3		563		247.4		
Total suspension solid	mg/l	196	59		85–285			41–87
Total organic carbon	mg/l	81.8	62.2					
Dissolved organic carbon	mg/l							106-149
Electronic conductivity	µs/cm		322.2		1000–1300	495.1		159–212
Dissolved oxygen	mg/l							
Aluminium	mg/l		1.6					
Boron	mg/l				1.4–1.7			
Calcium	mg/l		7.6					
Magnesium	mg/l		1.3					
Sodium	mg/l		65.3					
Surfactants	mg/l				4.7–15.6			33.5–69.8
Salinity	–					0.1		

Notes: NTU = nephelometric turbidity unit.

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Table 5. Proposed ingredients for low and high strength synthetic greywaters.

Item	Chemical name	Chemical formula	Molar mass (g/mol)	Low concentration (mg/l)	High concentration (mg/l)	Composition percentages
1	Kaolin	$Al_2Si_2O_5(OH)_4$	258.16	15	100	Al (20.90%), H (1.56%), O (55.78%) and Si (21.76%)
2	Cellulose	$(C_6H_{10}O_5)_n$	162.14	15	100	C (44.45%), H (6.22%) and O (49.34%)
3	Humic acid	$C_{187}H_{186}O_{89}N_9S_1$	4015.55	5	20	C (55.90%), H (4.67%), O (35.46%), N (4.67%) and S (0.80%)
4	Sodium chloride	$NaCl$	58.44	10	120	Cl (60.66%) and Na (39.34%)
5	Sodium hydrogen carbonate	$NaHCO_3$	84.01	10	85	C (14.30%), H (1.20%), Na (27.37%) and O (57.14%)
6	Calcium chloride	$CaCl_2$	147.02	10	55	Ca (36.11%) and Cl (63.89%)
7	Potassium nitrate	KNO_3	101.10	0	90	K (38.67%), N (13.85%) and O (47.48%)
8	Calcium nitrate	$Ca(NO_3)_2$	164.09	0	150	Ca (24.43%), N (17.07%) and O (58.50%)
9	Magnesium sulphate	$MgSO_4$	120.37	2	240	Mg (20.19%), S (26.64%) and O (53.17%)
10	Monopotassium phosphate	KH_2PO_4	136.09	13	85	H (1.48%), K (28.73%), O (47.03%) and P (22.76%)
11	Iron(III)chloride	$FeCl_3$	162.20	0.3	50.0	Fe (34.43%) and Cl (65.57%)
12	Boric acid	H_3BO_3	61.83	0.6	3.0	H (4.89%), B (17.48%) and O (77.63%)
13	Manganese(II)chloride	$MnCl_2$	125.84	0.03	3.20	Cl (56.34%) and Mn (43.66%)
14	Zinc sulphate	$ZnSO_4$	161.44	0.25	15.00	O (39.64%), S (19.86%) and Zn (40.50%)
15	Copper sulphate	$CuSO_4$	159.61	0.025	7.000	Cu (39.81%), O (40.10%) and S (20.09%)
16	Ammonium molybdate tetrahydrate	$(NH_4)_6Mo_7O_{24}$	1163.94	0.35	0.35	H (2.08%), Mo (57.71%), N (7.22%) and O (32.99%)
17	Cadmium oxide	CdO	128.41	0.02	12.50	Cd (87.54%) and O (12.46%)
18	Nickel oxide	NiO	74.69	0.02	0.06	Ni (78.58%) and O (21.42%)
19	Chromium(III)nitrate	CrN_3O_9	99.99	0.045	70.000	Cr (21.85%), N (17.65%) and O (60.50%)
20	Sodium sulphate	Na_2SO_4	142.04	2.60	25.00	Na (32.37%), O (45.06%) and S (22.57%)
21	Sodium phosphate monobasic	H_2NaPO_4	119.98	0.00	250.00	H (1.68%), Na (19.16%), O (53.34%) and P (25.82%)
22	Lead(II)oxide	Pb_3O_4	685.60	0.16	1.40	Pb (90.67%) and O (9.33%)
23	Secondary treatment effluent with microbial content (ml/l)	–	–	20.00	100.00	–

Note: Al = aluminium, H = hydrogen, O = oxygen, Si = silicon, C = , N = nitrogen, S = sulphur, Cl = chlorine, Na = sodium, Ca = calcium, K = potassium, Mg = magnesium, P = phosphorus, Fe = iron, B = boron, Mn = manganese, Zn = zinc, Cu = copper, Mo = molybdenum, Cd = Cadmium, Ni = nickel, Cr = chromium, Pb = lead, and item 23 was not considered in this study.

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Table 6. Water quality parameters after two and seven days of storage time.

Parameter	Unit	Number	Mean	Standard deviation	Minimum	Maximum	Reduction (%)
Inflow (LC)							
Biochemical oxygen demand	mg/l	33	15.2	7.45	5.0	30.0	na
Chemical oxygen demand	mg/l	31	25.2	9.99	8.2	48.3	na
Ammonia-nitrogen	mg/l	30	0.2	0.11	0.0	0.5	na
Nitrate-nitrogen	mg/l	32	1.4	1.61	0.1	7.6	na
Ortho-phosphate-phosphorus	mg/l	31	6.3	2.35	3.8	12.0	na
pH	–	33	6.9	0.37	6.0	7.9	na
Redox potential	mV	33	15.7	53.07	-190.2	65.7	na
Turbidity	NTU	33	22.6	7.95	9.8	41.6	na
Total suspension solids	mg/l	33	40.2	18.70	10.0	87.0	na
Electronic conductivity	µs/cm	33	150.8	61.89	98.7	452.0	na
Dissolved oxygen	mg/l	33	10.1	1.53	7.7	12.2	na
Colour	Pa/Co	24	199.9	71.30	26.0	332.0	na
Temperature	°C	33	17.3	6.37	6.7	27.0	na
2-day outflow (LC)							
Biochemical oxygen demand	mg/l	21	5.7	3.96	0.0	10.0	62.3
Chemical oxygen demand	mg/l	21	27.9	10.26	2.7	41.9	-10.8
Ammonia-nitrogen	mg/l	19	0.1	0.09	0.0	0.3	45.2
Nitrate-nitrogen	mg/l	19	1.3	0.80	0.1	3.1	10.4
Ortho-phosphate-phosphorus	mg/l	19	5.6	2.04	3.5	10.9	11.4
pH	–	48	7.2	0.70	6.3	10.1	na
Redox potential	mV	48	17.5	30.68	-116.1	51.0	na
Turbidity	NTU	48	21.3	7.81	2.9	35.4	5.5
Total suspension solids	mg/l	48	30.8	12.92	13.0	76.0	23.4
Electronic conductivity	µs/cm	48	128.4	23.57	79.0	215.0	na
Dissolved oxygen	mg/l	48	10.7	0.94	8.8	12.6	-6.3
Colour	Pa/Co	36	156.0	51.13	34.0	265.0	22.0
Temperature	°C	48	16.0	4.85	5.3	21.8	na
7-day outflow (LC)							
Biochemical oxygen demand	mg/l	15	7.0	6.21	0.0	20.0	54.0
Chemical oxygen demand	mg/l	22	19.6	9.83	6.0	36.7	22.2
Ammonia-nitrogen	mg/l	18	0.1	0.07	0.0	0.3	45.2
Nitrate-nitrogen	mg/l	17	1.1	1.27	0.0	4.0	21.4
Ortho-phosphate-phosphorus	mg/l	17	8.2	6.03	2.6	25.7	-29.4
pH	–	44	7.2	0.60	6.4	8.9	na
Redox potential	mV	44	18.3	26.66	-56.4	53.2	na
Turbidity	NTU	44	20.1	5.71	12.6	34.1	11.1
Total suspension solids	mg/l	44	31.0	9.52	18.0	56.0	22.9
Electronic conductivity	µs/cm	48	143.0	38.83	97.7	263.0	na
Dissolved oxygen	mg/l	48	11.5	0.84	10.4	14.3	-13.9
Colour	Pa/Co	36	171.5	33.14	128.0	258.0	14.2
Temperature	°C	48	14.1	3.87	6.7	20.0	na
Inflow (HC)							
Biochemical oxygen demand	mg/l	33	32.3	12.81	10.0	60.0	na
Chemical oxygen demand	mg/l	30	115.4	39.57	63.9	189.0	na
Ammonia-nitrogen	mg/l	30	0.4	0.18	0.1	0.8	na
Nitrate-nitrogen	mg/l	32	9.2	7.81	0.2	29.8	na
Ortho-phosphate-phosphorus	mg/l	30	50.6	13.06	30.7	92.6	na
pH	–	33	8.1	1.93	5.4	11.5	na
Redox potential	mV	33	-29.3	89.61	-182.1	97.9	na
Turbidity	NTU	33	184.6	50.34	18.3	285.0	na
Total suspension solids	mg/l	33	317.5	54.73	190.0	473.0	na
Electronic conductivity	µs/cm	33	936.8	156.16	617.0	1180.0	na
Dissolved oxygen	mg/l	33	10.0	1.69	6.9	12.6	na
Colour	Pa/Co	27	1427.3	444.54	787.0	2499.0	na
Temperature	°C	33	17.6	6.58	6.5	27.8	na

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Table 6 (cont.)

2-day outflow (HC)							
Biochemical oxygen demand	mg/l	19	14.5	8.48	0.0	30.0	55.2
Chemical oxygen demand	mg/l	21	110.7	28.63	43.3	164.0	4.1
Ammonia-nitrogen	mg/l	19	0.4	0.26	0.0	0.9	6.8
Nitrate-nitrogen	mg/l	20	6.2	4.18	0.5	15.0	32.8
Ortho-phosphate-phosphorus	mg/l	20	46.5	14.37	23.7	70.1	8.2
pH	–	48	8.3	1.35	5.6	9.8	na
Redox potential	mV	48	-28.4	60.63	-107.6	88.6	na
Turbidity	NTU	48	215.7	49.45	111.0	341.0	-16.9
Total suspension solid	mg/l	48	345.0	48.49	229.0	447.0	-8.7
Electronic conductivity	µs/cm	48	948.3	105.86	627.0	1196.0	na
Dissolved oxygen	mg/l	48	10.3	0.78	9.0	12.1	-3.0
Colour	Pa/Co	36	1697.0	292.83	1121.0	2311.0	-18.9
Temperature	°C	48	17.0	4.94	6.0	21.5	na
7-day outflow (HC)							
Biochemical oxygen demand	mg/l	15	14.7	6.40	5.0	30.0	54.5
Chemical oxygen demand	mg/l	24	108.3	24.47	67.2	159.5	6.2
Ammonia-nitrogen	mg/l	16	0.4	0.19	0.0	0.8	0.01
Nitrate-nitrogen	mg/l	18	2.8	2.24	0.4	9.3	69.6
Ortho-phosphate-phosphorus	mg/l	17	45.8	18.23	20.3	79.4	9.5
pH	–	48	8.1	1.20	5.9	9.8	na
Redox potential	mV	48	-27.4	57.02	-108.3	78.1	na
Turbidity	NTU	48	209.3	38.14	122.0	281.0	-13.4
Total suspension solid	mg/l	48	322.5	73.45	3.1	434.0	-1.6
Electronic conductivity	µs/cm	48	1105.6	351.09	668.0	2460.0	na
Dissolved oxygen	mg/l	48	10.9	0.72	9.4	12.0	-9.0
Colour	Pa/Co	36	1882.8	409.34	1119.0	2889.0	-31.9
Temperature	°C	48	15.7	3.49	8.4	20.8	na

Notes: LC = low concentration synthetic greywater, NTU = nephelometric turbidity unit, na = not applicable, HC = high concentration synthetic greywater.

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Concentrations of Proposed Synthetic Greywater

Parameters	Unit	Synthetic greywater	
		Low: range (mean)	High: range (mean)
Biochemical oxygen demand	mg/l	5–30 (15.2)	10–60 (32.3)
Chemical oxygen demand	mg/l	8–48 (25.2)	64–189 (115.4)
Ammonia-nitrogen	mg/l	0.0–0.5 (0.2)	0.1–0.8 (0.4)
Nitrate-nitrogen	mg/l	0.1–7.6 (1.4)	0.2–29.8 (9.2)
Ortho-phosphate-phosphorus	mg/l	3.8–12.0 (6.3)	30–92 (50.6)
pH	–	6–8 (6.9)	5–12 (8.1)
Redox potential	mV	-190–66 (15.7)	-182–98 (-29.3)
Turbidity	NTU*	10–42 (22.6)	18–285 (184.6)
Total suspension solids	mg/l	10–87 (40.2)	190–473 (317.5)
Electronic conductivity	μs/cm	99–452 (150.8)	617–1180 (936.8)
Dissolved oxygen	mg/l	8–12 (10.1)	7–13 (10)
Colour	Pa/Co	26–332 (200)	787–2499 (1427.3)

*nephelometric turbidity unit.

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