

A state-of-the-art-review on grey water management: a survey from 2000 to 2020s

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ABSTRACT

Water reuse can contribute to reducing pressures on water resources, as an important approach and practice, reducing the demand for potable water for purposes not requiring high quality water. With water resources being depleted and the demand for water increased, grey water reuse becomes more popular in order to preserve water worldwide. This paper presents a comprehensive review of all significant research and reviews existing case studies to review the present knowledge with respect to the characteristics of grey water. The main summary table covers 63 works that focus on the application of these methods to different fields of sustainable building design. Key fields are reviewed in detail: grey water, including water reuse; grey water recycling; water sustainability; building design optimization; and wastewater of several areas simultaneously, with particular focus on buildings. This research aims to introduce the review of the research that covered the grey water management. Various engineering databases, international journals, and conference proceedings were searched. International journals were searched for relevant research papers. This paper provides perspectives on grey water context in order to frame the breadth and multiple dimensions it encompasses, to summarize recent activities on selected relevant topics, and to highlight possible future directions in research and implementations.

Key words | green building, grey water, grey water recycling, wastewater, water reuse, water sustainability

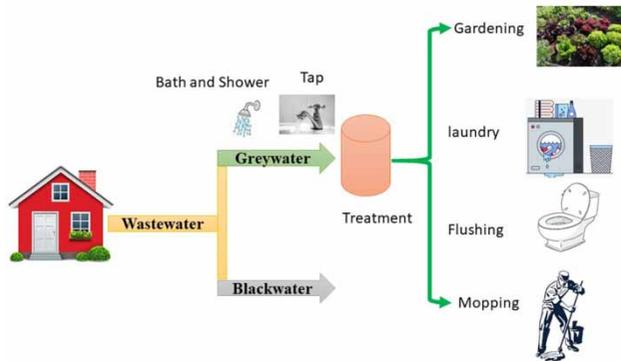
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HIGHLIGHTS

- Review of grey water generation, quality and treatment.
- Feasibility analysis of grey water treatment.
- Insights on grey water and water reuse issues.
- Case studies of reclaiming and reusing grey water.
- Challenges and obstacles of implementing grey water recycling.

GRAPHICAL ABSTRACT



INTRODUCTION

Integrated water management aims to promote water supply not only from conventional sources but also from wastewater reuse in part to address issues such as water scarcity. The positive input from collection and reuse of water for household purposes has not often seen assessments of the impact of climatic change, water resource availability and water deprivation in several countries. If the source water comes from a clean water source and was first used to wash or bathe it is commonly referred to as 'greywater'. Grey water is an abundant resource generated throughout the life of people. Grey water can be used for domestic cleaning, flushing toilets, washing vehicles, washing kitchen gardens, clothes washing and washing before rinsing, as shown in Table 1. Consequently, if grey water is to be used widely, there is considerable theoretical

potential to increase total water resources availability. Locally treated grey water reduces the demands of the distribution system, reduces building effort and cost and minimizes the related carbon footprint wherever possible. Such locally processed grey water offers important practical opportunities to increase total local water resources. A major action to mitigate the reduction in clean water supplies in certain areas and the anticipated mitigation required in the future is in keeping with the aspirations of the WHO/UNICEF. In water stressed countries, the concept of grey water recycling and reuse gradually becomes one of the main strategies. Grey water reuse is a potential way of reducing the consumption of potable water in buildings and, hence, of reducing wastewater discharged into public sewage and treatment facilities, as shown in Figure 1. This approach has significant environmental and economic benefits. However, these reliability, safety and cost criteria should be met by the grey water treatment system. Utilizing sustainable alternatives, such as water efficient showerheads, aerated faucets, dual flush/waterless toilets, water conserving dishwashers and steam washing machines opposed to standard devices, has the ability to optimize water efficiency and reduce living expenses, while helping conserve this natural resource (Tam *et al.* 2019). An online survey of users of BASIX in the construction industry revealed that the tool had played a significant role in providing a guideline for the sustainability performance of a proposed development and lifting the standard of design practices. The tool had led to better thermal comfort for users and reduced water and energy consumption by all new residential developments in New South Wales, Australia. However successful this had been,

Table 1 | Grey water sources and their composition

Grey water source	Constituents
Bathroom	Shampoo, soap, toothpaste lint, traces of urine, body care products, hairs, skin, hair oil, body fats, hot water and sand/clay particles
Hand basin	Toothpaste, soaps, body care products, shaving waste, hairs and skin cells
Kitchen	Dish washing detergents, oil and fats, food residue, hot water, raw meat washing, fruit and vegetable peels, tea or coffee, traces of food preservatives, sand and clay particles
Laundry	Chemicals from detergents, oils, solvents, bleaches, paints, hot water, nonbiodegradable fibres from clothing

(Sources: Eriksson *et al.* 2002; Noah 2002; Babaei *et al.* 2019).

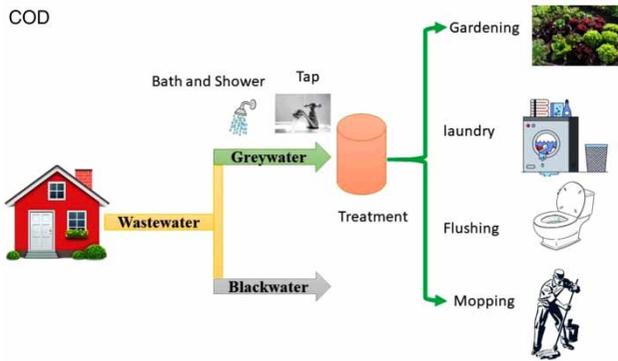


Figure 1 | Shown the process of the wastewater and grey water.

there is more to be done such as control of waste and energy usage in the manufacturing of building materials (Ding 2010).

DATA COLLECTION

Various engineering databases, international journals, and conference proceedings were searched. International journals were searched for relevant research papers. This review is based on articles retrieved from well-acknowledged academic journals up to the end of June 2020 (2000–2020) within the domain of the grey water management. The selected journals have significant impacts on the grey water and are included in the Science Citation Index Expanded database or Engineering Index database. SCOPUS, Google Scholar, and Web of Science were used as the paper search engines, and two search rounds were conducted. In the first search round, the articles were searched using a diverse combination of key phrases, including grey water, buildings design optimization, green building, water sustainability, wastewater, civil engineering, and environmental engineering. Based on the findings of the first search round, a second search round was conducted by manually filtering the papers related to grey water management in the buildings to remove irrelevant papers. The authors to ensure that the application of the paper is within the sustainability and green buildings read the abstract of each paper. After two rounds of filtering, 63 journal papers were selected and classified into six categories, namely: (1) review of grey water generation, quality and treatment, (2) review on grey water disinfection technology, (3) feasibility analysis of grey water treatment, (4) insights on grey water and water reuse issues, (5) case studies of reclaiming and reusing grey water, and (6) challenges and obstacles of implementing grey water recycling. A total of 26 journals are involved in this review, which

covers a broad scope of research fields – most of them related to grey water and green buildings.

REVIEW OF GREY WATER GENERATION, QUALITY AND TREATMENT

In determining the treatment system and the reuse option, it is important to ensure reliable data on grey water generation and quality features. Nine hundred different xenobiotic organic compounds (XOCs) were identified as potentially present in grey wastewater by the use of tables of contents of household chemical products (Eriksson *et al.* 2002). An evaluation of the potential for the availability of grey water and the various components that constitute grey water sources in Amman has been investigated; the various parameters of the water quality of grey water have been investigated in order to assess its potential for reuse (Jamrah *et al.* 2006). Two types of grey water systems, commercial and custom-constructed, have been reported. Commercial systems for grey water treatment are costly for small amounts. Therefore, the aim was to gather, treat and reuse wastewater from small to medium-sized mosques using a cost-effective low maintenance treatment system (Ahmed *et al.* 2008). The long-term performance of three pilot-scale grey water treatment systems was analyzed. The analysis was performed by employing novel statistical methods. Special attention was given to the input–output deviation statistics, which are very important where on-site reuse (short reuse cycle) is considered (Aizenchtadt *et al.* 2009). Two separate up-flow anaerobic sludge blanket reactors were used as a primary treatment step. Constructed wetland was used for the treatment of black water and grey water separately. The overall removal of the key constituents represented by chemical oxygen demand, biological oxygen demand and total suspended solids (TSS) in the final effluent was 87.7, 89.5 and 94% for grey water and 94.2, 95.6 and 94.9% for black water. It was recommended that the combination of up-flows anaerobic sludge blankets and constructed wetlands is an effective system (Abdel-Shafy *et al.* 2009). A study was presented to design, realize and analyze a functional hybrid phytoremediation pilot platform. The pilot plant was tested with and without vegetation at the design specifications. The vegetated system was able to handle the chemical oxygen demand (COD) reduction of an organic loading rate (OLR) that at the beginning of the treatment stage had a value of about 31 g COD/m²/d, equal to a triple charge of pollutants. The results obtained were always positive (in

terms of COD reduction) when the tests with vegetation presence were started inside the pilot platform, says the study (Comino *et al.* 2013). Performance of the slanted soil system for grey water was evaluated in light of required water quality for irrigation reuse. Only fine soil (1–4 mm) performed reductions of *Escherichia coli* and MS2 phage, while coarse soil could not remove those pathogens. Clogging was observed in fine soil after 3–5 weeks' operation; however, combination of coarse soil chamber and fine soil chamber could extend it to 8 weeks (Ushijima *et al.* 2013). Sand filter was used as a secondary treatment step for the treatment of the primary sedimented effluent. During the study period, gravel filter down flow and gravel filter up flow were operated with an influent flow rate of $173 \text{ m}^3/\text{m}^2/\text{d}$. The final effluent of gravel filter followed by sand filter and horizontal flow sand filter were found to be complying with the National Regulatory Standards for the treated effluent reuse in irrigation (Abdel-Shafy *et al.* 2014). Aspects relating to the reuse of grey water were discussed at airports in various regions and a case study on the airport in Brazil was presented. An anaerobic filter system was evaluated, followed by ultraviolet disinfection (Couto *et al.* 2014). The efficiencies of simplified treatments for grey water reuse using slow sand and slow slate waste filtration were studied. The system monitoring was conducted over 28 weeks, using analyses of the following parameters: pH, turbidity, apparent color, biochemical oxygen demand (BOD), COD and surfactants. The average removal efficiencies with regard to the turbidity, apparent color, chemical oxygen demand and biochemical oxygen demand were 61, 54, 56, and 56%, respectively, for the sand filter. Both systems showed good efficiencies in removing surfactants, around 70%, while the pH reached values of around 7.80. The statistical analysis found no significant differences between the responses of the two systems (Zipf *et al.* 2016). An eco-efficiency analysis framework was developed with the integration of life-cycle assessment and economic analysis for the evaluation of different water systems in Hong Kong. Results reveal the anaerobic fluidized bed membrane bioreactor grey water reuse scenario to be the most eco-efficient option. The system is capable of energy recovery, recycling of water resource and reduction of sewage treatment loadings (Lam *et al.* 2017). Precipitated sludge (ochre) was considered as an adsorbent substance for pollutants. Ochre is relatively free from problematic levels of toxic elements. Artificially created ochre pellets were utilized to remediate either high or low contaminated synthetic grey water in mesoconsumer scale stabilization ponds in Salford (Abed *et al.* 2017).

Untreated grey water quality was monitored from two full-scale grey water recycling systems. The study assessed the performance of a decentralized hybrid rainwater-grey water treatment system. The pilot-scale hybrid treatment system featured a multimedia filter (MMF), a granular activated carbon filter (GAC), and ozone disinfection. It exceeded the allowable Malaysian limits for both recreational waters with body contact (Class IIB) and irrigation waters (Class IV) for total coliforms. It was found that untreated grey water was frequently contaminated with faeces (20/32 samples tested positive for *Escherichia coli*) (Leong *et al.* 2018). The quantity and quality of combined grey water from houses with in house water supply and houses that rely on external sources of a peri urban area in a developing country were determined. The results indicate that, average water consumption from households with in-house access was $82.51 \pm 12.21 \text{ Lc-1d-1}$ (Oteng-Peprah *et al.* 2018). Proposed approach was tested in the Rio Mannu Basin (Sardinia, Italy) for durum wheat production. The fraction of nutrients flowing into the river and groundwater was evaluated using the Soil and Water Assessment Tool model. The uncertainty was found to be relevant for both dissolved inorganic nitrogen (60%) and total phosphorus (TP) (18%) The environmental sustainability of durum wheat production was assessed throughout the basin (De Girolamo *et al.* 2019). Grey water naturally was treated using ornamental plant species that can be integrated vertically into green building structures. Various regional ornamental plants and growing media were tested in column experiments. Media selection was found to be a much more dominant factor than plant selection for treatment performance. The removal rates of hydrophilic and hydrophobic organics were also analyzed and effluent specific ultraviolet (UV) absorbance measurements demonstrated that more compounds that are toxic were successfully removed from the system (Pradhan *et al.* 2019). Treatment of light grey water with *Chlorella* variables was investigated. Microalgae was cultivated in raw grey water and 30% diluted (with tap water) samples. After 19 days of cultivation, the microalgae had been removed from the media by centrifugation. The removal efficiencies of COD, BOD5, TP and TP were calculated. Results showed a maximum of 92.3% chemical oxygen demand, 91.9% BOD5, 85.6% total nitrogen (TN) and >97% TP remediation. Furthermore, the findings of microbiological analysis showed that toilet flushing can take place in this water (Oktor & Çelik 2019). The potential to save drinking water through the modelling of a system, which combines rainwater and grey water in a house, was evaluated. The

potential was assessed. The system was to wash clothes using rainwater, and then to reuse the effluent. Using the Netuno computer program the potential of potable water savings and rain-water tank storages were estimated (Rosa & Ghisi 2020).

REVIEW ON GREY WATER DISINFECTION TECHNOLOGY

A formulate model synthetic grey water in order to evaluated and compared the performances of several recycling processes on a reproducible effluent. The formulated synthetic grey water was composed of septic effluent to provide indicators of faecal contamination, and technical quality chemical products to simulate organic pollution of grey water. The performance of a direct nano filtration process with a concentration factor of 87.5% at 35 bar, then tested on both real grey water and synthetic grey water (Hourlier *et al.* 2010). A study on a low cost and easy maintenance experimental system for grey water reuse with a collection tank and a treatment system composed of a pump, filter and UV disinfection was presented. Raw grey water was collected from washing basins of public and exclusive access toilets as well as from showers of a changing room (Santos *et al.* 2012). The evaluation of potential opportunities for prioritizing grey water systems to support water reuse takes into account the availability of water resources, water use indicators and published estimates. Resource strategies for grey water reuse have the potential to consistently improve water efficiency and availability in water impoverished and water stressed regions of Ghana and West Africa (Hyde 2013). A hybrid wetland concept for the first time in a water-stressed region was showed in the coldest capital in the world. The system was based on storing water during the winter freezing period as an ice block, and then starting treatment during the summer. Results showed that the maximum removal rates of COD, NH₄, NO₂, TSS, PO₄, and *Escherichia coli* were up to 100%. The system has proven potential from a technical point of view and can be scaled up to community or cluster levels (Uddin *et al.* 2016). GAC-MI-ME was developed to attain multi-grade effluents for versatile reuse of grey water. It consists of a matrix of treatment trains including coarse filtration, microfiltration, activated carbon, ultrafiltration and ultraviolet. The contaminant load distributions of GAC-MI-ME system were observed with an average of 90.4% turbidity and 53.2% of BOD₅ as the pre-filtration (Kant *et al.* 2018). Design possibility was explored for

improvising approach to treating grey water sewage in the context of depleting water resources and emerging conurbations. Study looked at Membrane Bio reactor Sewage Treatment Plant at Indian Institute of Science, Bangalore. The model was designed to maximize its potential for self-sustaining efficiency and smart management of existing water resources. The study was based on a gate-to-gate Life-cycle assessment study focusing on use-phase (Ashok *et al.* 2018).

FEASIBILITY ANALYSIS OF GREY WATER TREATMENT

The potential impacts in two communities, which envisage building additional water storage capacity, were identified at a large scale. A case study found possible reductions in the demand of existing water resources from grey water toilets (Glick *et al.* 2011). The quality of grey water produced in the airport environments and the reuse potential of such effluent was assed. Grey water reuse can meet the non-potable demand and provide great savings of water and financial resources, in addition to priceless environmental benefits. The study was developed in a mid-size airport in Brazil (Do Couto *et al.* 2013). In Falmouth, MA, researchers looked at how best to manage nitrogen in household wastewater. It was found that flush diversion toilets paired with conventional septic systems were the best option. Composting toilets were also attractive options in some cases. A centralized wastewater treatment plant was the most expensive and least cost-effective option in all cases (Wood *et al.* 2015). The use of rainwater and grey water in the urban Philippines during the rainy and dry seasons and socio-economic predictors were examined. Results of the domestic survey (N = 396) and the in-depth interviews (N = 18) suggest that, particularly in seasonal households with more members, less funding, and less access to utilities, rainwater and grey water are widespread (Mason *et al.* 2017). In the city of Atlanta, a hybrid system has been examined that combines a grey water recycling system with a central water system. Technological feasibility was simulated for nine residential areas of five single-family house zones and four multifamily building areas of 1,000 m² that vary according to land use and population densities (Jeong *et al.* 2018). The environmental benefit of using rainwater, grey water, water efficient appliances and their combinations in low-income houses was assessed, during the life cycle of the system in southern Brazil (Marinoski *et al.* 2018). A functional unit of 1 m³ of non-potable toilet flushing

and irrigation water for a project lifespan of 50 years was used. It was compared against a decentralized rainwater harvesting, grey water recycling and hybrid rainwater–grey water systems (Leong *et al.* 2019). A comparative life cycle assessment was presented and focused on global warming potential, eutrophication potential and human health – carcinogenic potential of decentralized grey water management systems at different scales for a hypothetical community in a cold (winter) region. To provide a comparison between nature-based and engineered grey water treatment solutions, constructed wetlands and membrane bioreactors were investigated (Kobayashi *et al.* 2020). Table 2 summarizes some recently published research.

INSIGHTS ON GREY WATER AND WATER REUSE ISSUES

A seven-year project to develop a grey water washing plant were described. The design of a 50-person residential college hall has been carried out with site surveys and laboratory research. A balancing tank (13:1 maximum to average capacitance), a moving bed bioreactor and a double filtration (reticulated foam) were included in the final design (Wheatley & Surendran 2008). Four different investigations where grey water was treated with low technology was presented. The technologies were compared in terms of robustness and effluent quality. The applications were perfectly suited to be operated in remote areas or small communities with tourist depending variation of discharged wastewater flows (Scheumann *et al.* 2009). Study examined people's views on a number of water issues and their motivation, practices and concerns about grey water reuse. Survey participants (275) from different socio-economic background from 125 suburbs in the Western Sydney region, Australia took part in the study. Majority of participants identified water quality as the most important and availability without water restriction as the least important. About half of the participants reused grey water regularly or at some time during the last few years (Pinto & Maheshwari 2010). A general overview of the survey-based part of a study concerning wastewater reuse was provided that carried out in the Kingdom of Saudi Arabia. Factor scale analysis identified three dimensions of wastewater reuse acceptability (Alataway *et al.* 2011). In Taiwan, the four-four-family unit was used to revise the zoning concepts in water use, with the addition of pipeline configurations, a water storage design and a filtering system to offer the customized interior grey water system based on the family unit

Table 2 | Summary of earlier research in case studies of grey water

Authors & year	Description and contribution of the research
Jeong <i>et al.</i> (2018)	The grey water reclamation system reduces non-potable water demand in single-family house zones (by 17–49%) and multi-family apartment building zones (by 6–32%) while simultaneously reducing electricity consumption by 17–49% and 32–41% for single-family house zones and multi-family apartment building zones, respectively.
Marinoski <i>et al.</i> (2018)	Potential savings in potable water ran between 21.0% (grey water recycling) and 42.9% (combining water efficient equipment, rainwater collection and grey water recycling). With regard to the reduction in domestic water use, the grey water and water-efficient equipment with or without precipitation (36.8%) have been most severely reduced. Water efficient equipment installation showed potential for a 28.9% reduction in sewage.
Kobayashi <i>et al.</i> (2020)	In the membrane bioreactors scenarios, grey water reuse was considered for multiple non-potable applications due to its high-quality effluent. The constructed wetlands scenarios at community and neighborhood scales outperformed the membrane bioreactor scenarios.
Rosa & Ghisi (2020)	A financial analysis was performed. For a rainwater tank capacity equal to 5,000 liters, it was possible to obtain 51.6% potable water savings. The payback period was estimated as five years and three months.
Leong <i>et al.</i> (2019)	Hybrid rainwater-grey water systems had the highest mains water savings (55.3%) and lowest environmental impact scores. Domestic rainwater harvesting was the first system to become financially attractive at USD2.00/m ³ . Financial viability of decentralized rainwater. None of the systems were financially attractive otherwise at a discount rate of 6% for 50 years.

application (Juan *et al.* 2016). A field scale integrated onsite grey water treatment system (IOGTS) was constructed for hostel located in Sakharale, District Sangli (M.S.) India. The quality parameters used to assess feasibility of disposal for land application were COD, total Kjeldahl nitrogen (TKN), suspended solids, and pathogens. The effect of hydraulic loading rate (HLR), hydraulic retention time (HRT) and OLR on performance of the system was also studied. Overall performance of IOGTS was observed to be 70, 70 and 85%, respectively, for pathogen removal, COD and TKN removal. IOGTS can be considered to be

an appropriate treatment option to treat grey water to satisfy effluent standards for its reuse in land application (Patil & Munavalli 2016). Grey water was collected from a bathtub, shower and washing machine containing significant amounts of organic matter and pathogens. COD removal in the system was approximately 87%. The efficiency of the system to reduce anionic surfactants was about 80%. Overall, the treatment produces average effluent values that would satisfy international guidelines for indoor reuse applications such as toilet flushing (Fountoulakis *et al.* 2016). A decision tree for an optimized wastewater reuse was developed for the hotels in the Mediterranean region. The study suggested mixed domestic wastewater reuse might be the best suitable alternative for hotels, which have more than 250 rooms. For hotels, which were operated throughout the whole year, grey water reuse is seen as the best option (Hocaoglu 2017). The method of accounting multiple-pollutant grey water footprint with ecological perspective was developed. Original samples were taken from trout farms in the Kabkian River, southwestern Iran. It can provide a framework for considering Eutrophication, saline intrusions, minimum environmental flow and dissolved oxygen deficit of river, in addition to the risks of micropollutants in water footprint assessments. The proposed methodology can broaden the prospect of the application of grey water footprints and enhance the role of environmental capacity in this indicator (Jamshidi 2019). A model was integrated to minimize freshwater consumption and/or wastewater generation in addition to the fixed capital cost of installing the pipes and the variable operating cost of water pumping. A real-world case study was illustrated on a residential household with four occupants by combining engineering experience and physical insights to obtain a realistic model representation of the problem (Khor *et al.* 2020). A new multispectral optical sensor system has been designed and developed for measuring TSS concentration in polluted water. Sand-gravel media filters are particularly suitable for water with high suspended solid content. The study aims to measure the peak of optical properties at transmission and absorption intensities of irrigation water samples (Hassan *et al.* 2020). Table 3 summarizes some recently published research.

CASE STUDIES OF RECLAIMING AND REUSING GREY WATER

A pilot project to allow the poor to use untreated household grey water in house gardens was described in Tufileh,

Table 3 | Summary of earlier research in case studies of grey water

Authors & year	Description and contribution of the research
Santos <i>et al.</i> (2012)	The experimental treatment system showed potential for grey water recovery, because of the simple, low-cost and easy maintenance features, and because it provided high reduction of SS, chemical oxygen demand and BOD. No total or fecal coliforms were detected in all treated grey water samples.
Khor <i>et al.</i> (2020)	The proposed approach results in approximately 57% saving in freshwater as compared to the nominal requirement.
Wheatley & Surendran (2008)	The plant achieved a recycled water quality of 3 mg/L biochemical oxygen demand. Ultra violet disinfection was added to meet the UK guidelines of zero microbial indicator organisms. The demonstration trial lasted 5 years and users were unable to differentiate between the recycled water and mains water.
Aizenchtadt <i>et al.</i> (2009)	The results showed that the quality of the light grey water was far from being suitable for reuse, stressing the need for appropriate treatment. Raw grey water quality exhibited very high variability. The removal efficiency of the rotating biological contactor sand filter unit was high in respect of turbidity, biological oxygen demand and total suspended solid.
Pinto & Maheshwari (2010)	Grey water reuse is becoming increasingly common among households in Western Sydney. Most people (84%) were conscious of the local water and other environmental issues. The cost of plumbing and health risks to people, plants and soil were two the important issues.

Jordan. The quality of untreated grey water, and their negative impacts on soil and crops, have been shown in an environmental impact assessment. However, if larger volumes of grey water are used again, this could change (Faruqui & Al-Jayyousi 2002). The potential for potable water savings by using rainwater and grey water was evaluated in a multi-storey residential building composed of three blocks, located in Florianópolis, southern Brazil. The use of questionnaires and the measurement of water flow rates was estimated for water end use. The cost-effectiveness of rainwater and grey water use was evaluated either separately

or together through an economic analysis (Ghisi & Ferreira 2007). The current situation in Kuwait of grey water reuse was discussed and the potential for grey water reuse in Kuwait was described. Grey water reuse in Kuwait is insignificant. The economic and political considerations in this field may well lead to change if issues of oil reserve depletion and investments in a safe future could be linked to the facts of water shortages and real desalination costs (Abusam 2008). A study at Tianxiu Garden in Beijing, China, was investigated the potential and feasibility of water management based on a decentralized approach. A high degree of drinking water substitution (more than 25%) could not be attained by rainwater harvesting. Recycling of treated grey water for toilet flushing was shown to be an efficient method (Zhang *et al.* 2009). A capacity factor based classification for technologies using requirements analysis, and a matching policy for choosing technology options were developed. Capacity factor analysis was then applied in Cimahi, Indonesia as a form of validation. The findings were published in the International Journal of Water Economics (Henriques & Louis 2011). An artificial wetland and a commercial biofilter were proposed to treat grey water for toilet flushing in Sweida. The economic analyses of the two proposed systems showed that using treated grey water would save about 35% of the drinking water (Mourad *et al.* 2011). A proposed centralized grey water reuse system was presented for Daxing New City, Beijing. This system would use separate grey water and black-water discharge pipes in residences and public buildings. Water supply balance analysis showed that this system would conserve 28.5% of freshwater resources (Zeng *et al.* 2013). A grey water collection and treatment system for non-potable reuse was evaluated from washing machines, showers and washing machines. The pilot system used for the collection and characterization of grey water was implemented in a facility at the University of São Paulo (Chripim & Nolasco 2016). A method based on Life Cycle Analysis was presented and applied, which was used to assess the environmental performance of hybrid rainwater-grey water systems in residential buildings in southern Brazil (Marinoski & Ghisi 2019). The study quantifies China's final electricity demands' life-cycle impacts on water quality using the indicator Grey Water Footprint. Findings in the study were significant in helping policy-makers recognize and mitigate final power demands (Liao *et al.* 2019). A method for assessing the grey water footprint associated with winery wastewater co-treated with the municipal wastewater at municipal wastewater treatment plants was presented in a case study for the Niagara

Region of Ontario, Canada, and total grey water footprints of a treated winery (Johnson & Mehrvar 2019). Table 4 summarizes some recently published research.

Table 4 | Summary of earlier research in case studies of grey water

Authors & year	Description and contribution of the research
Ghisi & Ferreira (2007)	It was conclusion that the three systems that were investigated are cost effective as the payback periods were lower than eight years, but the grey water system was the most cost effective one, followed closely by the rainwater one.
Marinoski & Ghisi (2019)	The average potential for potable water savings through the implementation of the hybrid rainwater-grey water system was 41.9%, the potential for domestic sewage reduction was 40% and the total energy consumption reduction in comparison to the conventional system scenario was 36.1%.
Chripim & Nolasco (2016)	The water from showers had the highest <i>E. coli</i> concentration while the lavatories water had the highest total coliforms concentration. The removal efficiencies of BOD and chemical oxygen demand were 59% and 70%, respectively.
Faruqui & Al-Jayyousi (2002)	Each family in the project area was able to reduce its food expenditures by consuming its garden produce. The average family saved or earned 10 percent of its income, while the poorest saved 44%.
Ahmed <i>et al.</i> (2008)	Both commercial and custom-made systems were capable of treating grey water to satisfy relevant government regulations. Internal rate of return (IRR) for custom-made and commercial systems for the mosques were 14.9 and 19.06%, respectively.
Zhang <i>et al.</i> (2009)	The exclusive connection of the roof surface of two residential buildings resulted in substitution of only 25.4% of toilet-flushing water in a building. Most (85%) rainfall in Beijing happens from June to September. The savings potential by using rainwater to flush toilets is not great enough.
Mourad <i>et al.</i> (2011)	Average total grey water production in a typical Syrian urban area was about 46% of the total water consumption. More than 10% of households are using untreated laundry water in irrigation and for house cleaning. For a block system consisting of one residential building (50 inhabitants) the saved drinking water may reach about 600 m ³ /year.

CHALLENGES AND OBSTACLES OF IMPLEMENTING GREY WATER

Grey water recycling can potentially save significant volumes of potable water, say researchers. The dominant removal process for a particular pollutant is heavily dependent on the physical, chemical and biological properties of that pollutant. The potential for the grey water treatment and reuse system to act as a pollutant emission barrier is highly substance dependent (Revitt *et al.* 2011). Simulation study evaluated the influence of onsite grey water reuse on domestic wastewater quality and quantity. Light grey water use reduced the daily household wastewater flows by 25–40%. These reductions mainly occurred during the morning and evening peak wastewater generation. The proportional concentration increase of most pollutants was lower than the decrease in wastewater discharge (Penn *et al.* 2012). The effects of grey water reuse and water-efficient toilets, positive and negative, were studied by modelling a representative urban sewer system. Grey water reuse scenarios were modelled and analyzed using the SIMBA simulation system. The results showed that, as expected, the flow, velocity and proportional depth decreased as grey water reuse increased. Nevertheless, the reduction was not evenly distributed throughout the day but mainly occurred during the morning and evening peaks. In some of the grey water reuse scenarios flows, velocities and proportional depths in the sewer were reduced. Sewage blockage rates are not expected to increase significantly, says the study. The results supported the option to construct new sewer systems with smaller pipe diameters (Penn *et al.* 2013). Determine, by epidemiological survey, the risk for gastroenteritis symptoms associated with grey water reuse. The survey comprised a weekly health questionnaire answered by both grey water users and non-grey water users. A Cox Proportional Hazards model indicated a somewhat higher health risk for the control group. There was practically no difference in the prevalence of water-related diseases between users of grey water and potable water, suggesting that quantitative microbial risk assessment is conservative and can safely be used toward the establishment of regulations (Busgang *et al.* 2015). A Quantitative Microbial Risk Assessment was conducted to estimate the public health risks for two grey water reuse scenarios: toilet flushing and food-crop irrigation. Household grey water quality from three sources (bathroom, laundry and kitchen) was analyzed. Mathematical exposure rates of different scenarios were established based on human behavior using Monte-Carlo simulation (Shi *et al.* 2018).

CONCLUSIONS

Grey water reuse is an important alternative for reducing potable water consumption in the different building occupancies.

- The review shows significant variations in quality and quantity of grey water in terms of time and sources, and that variability is largely the selection of the treatment system.
- The review also reveals that in recycled grey waters, heavy metals and organic micro-contaminants generally pose no threat to human health when properly treated.
- The results showed that the environmental advantage of the strategy is the use of water-efficient systems. This saves significant water and reduces wastewater.
- The environmental impact is low due to the reduced consumption of energy over the life cycle.

RECOMMENDATIONS AND FUTURE WORKS

Grey water reuse is an important alternative for reducing potable water consumption in the different building occupancies. We think that grey water reuse is a way to increase the productivity of sustainable backyard ecosystems that produce food, clean water, and shelter wildlife. Such systems recover valuable ‘waste’ products – grey water, household compost, and humanure – and reconnect their human inhabitants to ecological cycles. In the future, works should be to develop systems for treatment the grey water in the different buildings.

CONFLICT OF INTEREST

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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