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REVIEW ARTICLE

Constructed wetland systems for greywater treatment and reuse: a review

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Abstract

In recent times, the requirement of freshwater has grown by leaps and bounds globally in agricultural, industrial, and domestic sectors due to anthropogenic and technological advancements, and this has resulted in over-exploitation of freshwater resources. The management of wastewater generated as a by-product of various human activities from these sectors is of global concern today. Greywater (GW) is a class of wastewater that is generated from the domestic sector. The quantity of GW generated is very high compared to other classes of wastewater. Due to lower contaminant levels and higher biodegradability, it is found to have very good potential for reuse. Amongst the several available GW treatment techniques, constructed wetlands (CW) is currently gaining attention. CW is an eco-friendly and cost-effective technique. It can be used on a smaller scale at the domestic level to a larger scale as far as GW treatment is concerned. It is thus a proven, viable option for GW recycling in this century. Treated GW can be reused for gardening, toilet flushing, etc., and it can reduce the demand on water. For reuse of water, there are different norms and regulations, for different regions. Once the treated GW meets those standards, it can be reused without constraints. Still, there are apprehensions about the negative impacts of GW reuse. This paper discusses the recent advances in techniques for GW treatment, particularly using constructed wetlands and the potential reuse of GW.

Keywords Constructed wetlands · Greywater treatment · Regulations for water reuse · Water reuse · Water treatment techniques

Introduction

Water is the elixir of life. An imbalance in water quantity and quality can affect organic production and life. This in turn breaks ecological balances, and can finally result in a threat to human life and existence (Gao, 2019). Water is underestimated all over the world and results in water scarcity and freshwater decline (Johnson et al., 2001). Some of the major challenges in the twenty-first century are water scarcity, groundwater depletion, water pollution, climate change, wastewater management, etc. (ElZein et al., 2016). Around 80% of the population in the world is facing the threat of water scarcity (Pulla et al., 2018) and this compromises future developments too. Water stress is a fact of life in parts of Asia and Africa (United Nations, 2012). According to the reports of the International Water Management Institute (IWMI), one in three Indians will live in conditions of absolute water scarcity by 2025 (Vymazal, 2010). Water demand is increasing day-by-day for domestic, agricultural, industrial, and other allied purposes. Only 20% of the total water consumed is used for potable purposes whereas the rest is wasted (Bhattacharyya & Prasad, 2020). Lack of proper water treatment systems and facilities adds to the impacts of water scarcity (Ghatani & Khawas, 2020). The misuse of potable water gives added impetus to water reuse, where treated water becomes valuable.

Water becomes wastewater when its physical, chemical, or biological properties are changed rendering it unsafe for drinking and domestic purposes. One-third of domestic water is used for bathing, showering, and hand-washing, and another one-third for toilet flushing (Dixon & Reaves, 1994). Urban waste water comprises of GW and black water (ElZein et al., 2016; Shaikh & Younus, 2015). GW (or sullage) is the low polluted wastewater from washing, laundry, bathtubs, showers, hand washing basins, and kitchens that

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has not come into contact with toilet waste, whereas black water includes toilet waste also along with GW (Avery et al., 2007; WHO, 2006; Prillwitz & Farwell, 1995; Kraume et al., 2010; Parameswara Murthy et al., 2016). About 55–75% of wastewater is GW (Shaikh & Younus, 2015). Greywater reuse at the domestic level can reduce the problems of water demand and scarcity to a major extent (Bakheet, 2020). Moreover, GW disposal without any treatment can result in environmental contamination (Rakesh et al., 2020). On-site GW treatment and reuse are advantageous and biological treatment techniques are more favorable compared to physical and chemical treatment techniques (Yoonus & Al-Ghamdi, 2020).

Greywater: characteristics and composition

Greywater is mainly of two types—light and dark greywater. Light GW is the wastewater from bathroom, showers, and tubs, washing machine sources, washbasin, etc. (Friedler & Hadari, 2006; Noah, 2002), and dark GW includes more contaminated waste from laundry facilities, dishwashers, and in instances, kitchen sinks (Birks & Hills, 2007; Noah, 2002). Arden and Ma (A2018), additionally defined mixed GW (wastewater including laundry and kitchen sink water). Some other types of GW are bathroom GW (includes soaps, shampoos, toothpaste, body care products, shaving waste, skin, hair, body fats, lint, traces of urine, and feces), and washbasin GW (includes bacteria, foam, food particles, high pH, hot water, odor, oil and grease, organic matter, salinity, soaps, suspended solids, and turbidity) (Noah, 2002).

The GW from the kitchen sink is rich in food residues, high amounts of oil and fat, dishwashing detergents, etc. (Morel & Diener, 2006; Yadav and Ghaiidak 2013). Likewise, laundry GW contains high concentrations of chemicals from soap powders (sodium, phosphorus, surfactants, and nitrogen), bleaches, oil, paints, solvents, and non-biodegradable fibres from clothing (Morel & Diener, 2006). Hand washing soap constitutes 90% dry mass loading in handwashing GW (Ziemba et al., 2018).

The nature of GW is determined by various factors like the number of occupants, the age distribution of the occupants, their lifestyle, etc. It also depends on other water usage patterns, living standards, social and cultural habits, type (e.g., soaps, toothpaste, shampoos, detergents, etc.), quantity of household chemicals used, length of time for which GW is stored before being used, etc. (HSDH, 2009; Yadav & Ghaitidak, 2013). Based on the source of GW, its constituents also vary. The amount of GW (quantity) produced is different for different sources. For example, washbasin, bathroom, shower, laundry, washing machine, kitchen sink, and dishwater (Yadav & Ghaitidak, 2013). Common contaminants in GW are salts, food particles, oil, surfactants, microbes, etc. (Parameswara Murthy et al., 2016). Pathogens in GW are mainly from fecal contamination, peripheral pathogens (e.g., skin and mucous tissue), food handling, etc. (Maimon et al., 2010). The presence of fecal coliforms in GW should not be neglected (Winward et al., 2008). Suspended solids and pathogens are comparatively less in GW compared to black water. GW quality can be improved by storage through the settling of suspended material, aerobic microbial growth, and anaerobic release of soluble COD (Low organic strength is sometimes noticed due to the high dilution of GW. Influent BOD load changes with occupancy of flats/seasonal changes in water or product use behavior (Avery et al., 2007). A variety of xenobiotic substances also enter GW from bathroom and laundry products, but research is very limited in this area (Eriksson et al., 2003; Palmquist and Hanaeus, 2005).

Greywater has a high potential for recycling and reuse. It is a valuable resource and its reuse is an effective measure for saving water on a domestic level (Yadav & Ghaitidak, 2013). GW needs fewer treatment procedures compared to black water (Avery et al., 2007). GW management is very essential for reducing water stress in developing countries (Yadav & Ghaitidak, 2013). Usage of untreated raw GW for toilet flushing, gardening, etc., has a chance of resulting in risk causing environmental contamination and has many health risks (Yates & Gerba, 1998). On the other hand, treated GW has no significant negative impact on plants or soil (Gross et al., 2007).

Greywater: treatment techniques

Based on the types of contaminants removed, there are various levels of wastewater treatments viz., preliminary, primary, secondary, tertiary, and advanced treatments (Metcalf and Eddy, 2003; Yadav & Ghaitidak, 2013; Pangarkaret al., 2010). Preliminary treatment deals with the removal of coarse solids and large materials like rags, sticks, grit, and grease, whereas, the primary treatment removes remains of settleable and suspended solids. In secondary treatment, biodegradable organic matter is removed and in tertiary treatment removal of nutrients and disinfection takes place. Finally, advanced treatment helps in the removal of dissolved and suspended materials, remaining after applying earlier treatments. The preliminary treatment enhances the operation and maintenance of further treatment units (Pangarkar et al., 2010). In tertiary treatment, activated charcoal can be used to trap impurities and sodium hypochlorite as a disinfectant (Satyanarayana, 2013).

In the constructed wetland, the greywater is first diverted to a settling tank where all the suspended sediments settle to the bottom and only clear water from the undisturbed top layer of the settling tank is directed to the inlet pipe of the distribution zone (second unit—sand/gravel layer with plants on top). Usually, only very little waste material will be collected at the bottom of the settling tank. It is periodically collected and disposed off depending upon the type of material. If it is free of toxic heavy metals, and can be put in the farmland, in other cases it can be converted to materials like press mud, etc. The materials generated in the second zone (distribution zone) are usually biodegradable and decompose slowly under aerobic conditions. The sludge formed in greywater treatment systems is generally discharged to the municipal sewerage systems periodically (Donner et al., 2010).

GW treatment technologies can also be classified as physical, chemical, and biological treatments incorporating adsorption, coagulation, precipitation, filtration, aeration, biodegradation, and disinfection (Parameshwara Murthy et al., 2016; Revitt et al., 2011). Physical processes alone do not give an adequate reduction of organics, nutrients, and surfactants (Parameshwara Murthy et al., 2016). Coconut shell coal and charcoal can be used for filtration (Shaikh & Younus, 2015). Chemical processes are very efficient in removing suspended solids, organic materials, and surfactants in low-strength GW. The combination of aerobic biological processes with physical filtration is a feasible solution for GW recycling.

When coming to the area of application, wastewater treatment methods can be classified as traditional/centralized method (wastewater reuse systems applied on large scale) and decentralized (wastewater reuse systems applied on small scale). Decentralized treatment systems can be further divided into on-site treatment methods and cluster treatment methods (ElZein et al., 2016). Some other technologies for GW treatment are anaerobic filtration followed by UV disinfection, Drawer Compacted Sand Filter, Artificial wetland, Commercial Biofilter, Aerobic Digestion Unit, Submerged Sequential Batch Reactor (SM-SBR), Moving Bed Biofilm Membrane Reactor (MB-BMR), Submerged Spiral Wound Membrane Filtration, Rotating Biological Contactors (RBCs), Electro Coagulation etc. (Parameshwara Murthy et al., 2016). Amongst these, the anaerobic filtration followed by UV disinfection technique adopted at a Brazilian airport, in which the operational flow was maintained at 2.82 m^3/day, achieved a removal efficiency of turbidity and suspended solids of 88 and 77%, respectively.

Constructed wetlands (CW)

Constructed wetlands (CW) can be defined as a technology designed to employ ecological processes found in natural wetland ecosystems, utilizing wetland plants, soils, and associated microorganisms to remove contaminants from wastewater (USEPA, 2000; Yadav & Ghaitidak, 2013). Otherwise, constructed treatment wetlands are engineered systems, designed and constructed utilizing the natural functions of wetland vegetation, soils, and their microbial populations to treat contaminants in surface water, groundwater, or waste-streams (Mueller et al., 2003). In CWs, natural processes help to stabilize, sequester, accumulate, degrade, and metabolize/mineralize contaminants (Nelson, 2014). Other terms of CW are manmade, engineered, artificial, or treatment wetlands planted with soil filters, reed bed treatment system, vegetated submerged beds, vegetated gravel-bed, gravel bed hydroponics filters, phytorestoration, etc. (Nelson, 2014). Constructed wetlands are the natural alternative to technical methods of wastewater treatment (Stottmeister et al., 2003).

Types of constructed wetlands

Constructed wetlands differ in basic designs and flow characteristics. There are different types of CWs based on the flow of GW, soil surface, and feeding modes (Table 1). The major classification of CW is surface flow, horizontal flow, and vertical flow CW (Figs. 1, 2, 3).

Components of CW

Constructed Wetlands are one among the natural wastewater treatment systems which depend on natural responses (ElZein et al., 2016). The components and design of different CWs are shown in Figs. 1, 2, 3. It is usually constructed on the ground. The structure has an impermeable bottom and side layers (Nelson, 2014). It has an inlet pipe in the distribution zone for wastewater input, an outlet pipe in the collection zone for collecting the treated water, and a treatment zone filled with a medium of sand/gravel and is overlaid by aquatic plants.

Media used in CW

A variety of materials are used as media in CW. Gravel, sand, and soil are widely used media and they must be clean, washed, and without impurities (Zidan et al., 2013). Volcanic rock, limestone, river gravel, recycled concrete, recycled crushed glass, vermiculite, zeolite, lime, etc., are also used as media (Brix et al., 2001; Zhu et al., 2011). Gravel provides a growth medium for microorganisms, works like a sieve, and determines hydraulic residence time. Permeability of various media are coarse gravel (high permeability of 10–2 m/s); gravel (good permeability of 10–4 m/s); fine to medium sand(poor permeability of 10–5 m/s); loamy sand (permeable with difficulty—around 10–6 m/s); fine particulate clay (very poor permeability of 10–8 m/s). Finer particles present in sand, soil, etc., are likely to pass into the effluent, resulting in increased turbidity and suspended

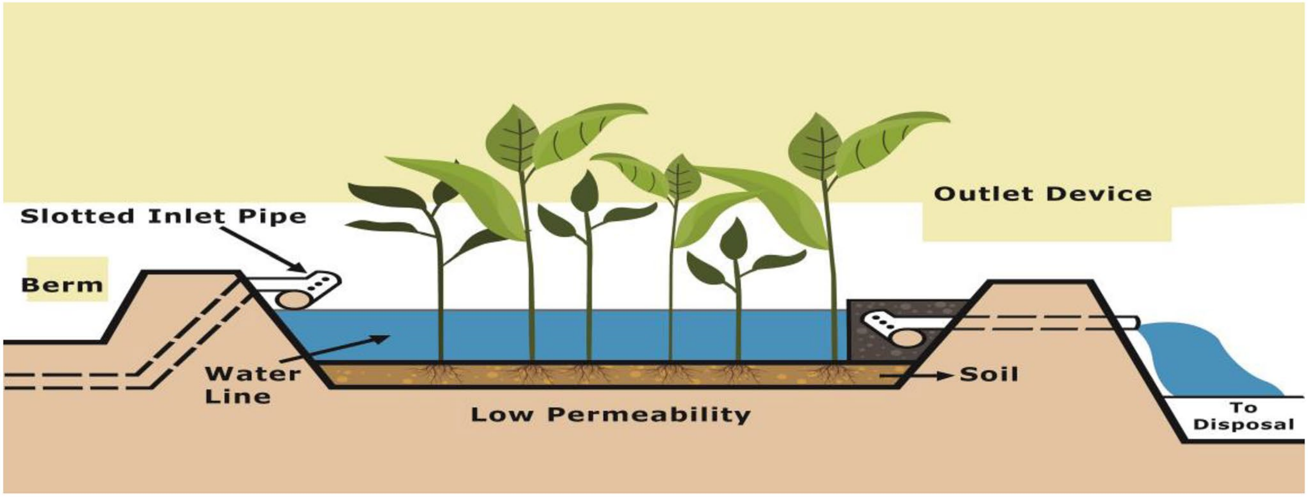

Fig. 1 Surface flow constructed wetland model (Nelson, 2014)

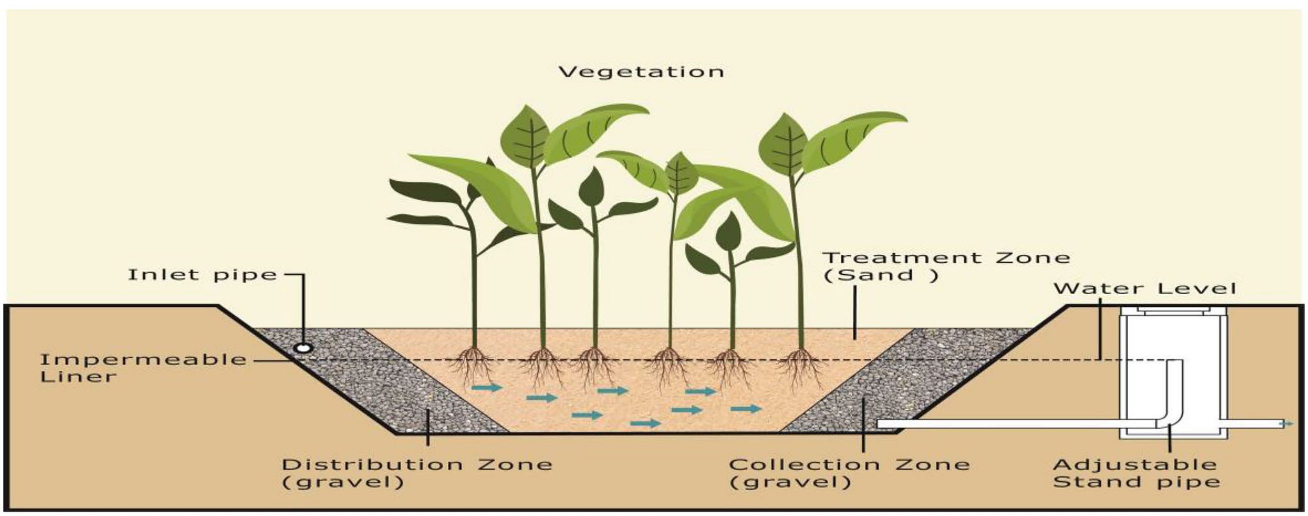

Fig. 2 Horizontal flow constructed wetland model (Nelson, 2014)

solids. Sand:soil:compost medium (65:25:10) with coarse gravel (20 mm) were also used (Avery et al., 2007).

Plants used in constructed wetlands

One of the major components of CWs is plants. Based on morphology and physiology, there are four groups of aquatic macrophytes used for constructed wetlands (a). Emergent macrophytes (e.g., *Acorus calamus, Phragmites australis, Typha latifolia)* (b). Floating leaved macrophytes (e.g., *Nymphaea odorata, Nuphorlutea*) (c). Submerged macrophytes (e.g., *Myriophyllum spicatum, Ceratophyllum demersum, Rhodophyceae red algae*) (d). Freely floating macrophytes (e.g., *Lemna minor, Spirodela polyrhiza, Eichhornia crassipes*) (Brix and Schierup, 1989; Vymazal et al., 1998; Haberl et al., 2003). Other plants used in CW are *Iris pseudocorus, Veronica beccabunga, Glyceria variegates, Juncus effuses, Iris versicolor, Caltha palustris, Lobelia cardinalis, Mentha aquatic* (Avery et al., 2007), *Cyperus haspan, Hydrocotyle leucocephala, Lemna spp., Hippuris vulgaris* (Gross et al., 2007), *Phragmites australis, Phragmites spp., Typha spp., Scripus californicus, Typha latifolia, Rumex hydrolapatum, Scripus validus, Axonopus compressus,* etc. (Arunbabu et al., 2015; Haberl et al., 2003; Lakatos, 2000; Simi et al., 2000; Revitt et al., 2004; Campagna et al., 2000; Permodo et al., 2000; Zachritz et al., 1996). Adequate drainage is needed around a constructed wetland, to prevent runoff rainwater and soil from entering the system. Usage of wetland macrophytes for wastewater treatment was experienced in Germany in the early 1950s (Vymazal, 2010).

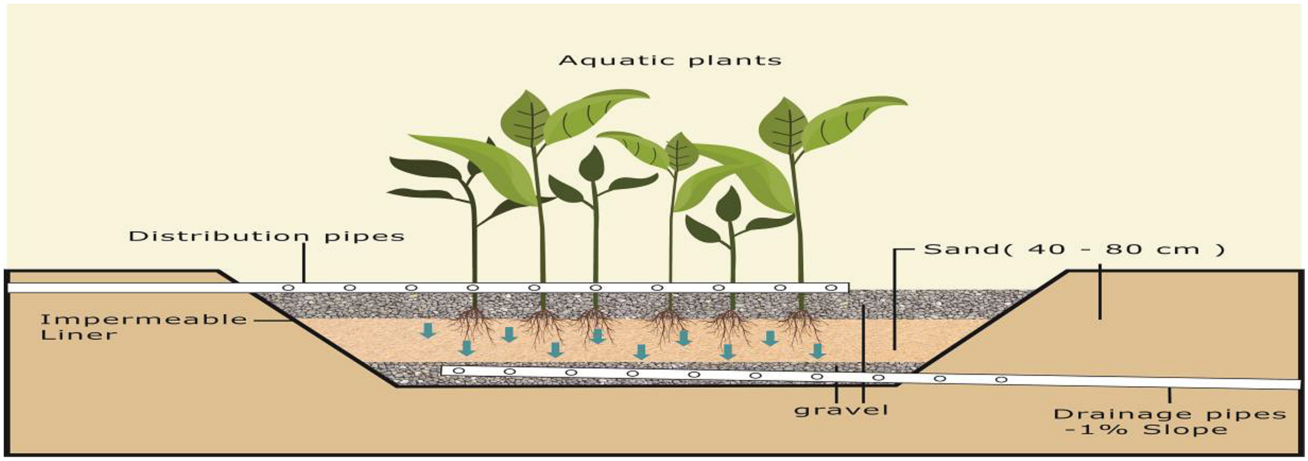

Fig. 3 Vertical flow constructed wetland model (Nelson, 2014)

Table 1 Different types of constructed wetlands

Based on flow of GW (Nelson, 2014; Borkar & Mahatme, 2013)	
1. Surface flow constructed wetlands (SFCW) (free water surface CWs)	Biological activity is mainly in superior layer of soil, in the stems of plants and in water Water proofing is not always used. Birthing grounds to mosquitoes Require greater protection from public access More land is required i.e. around 5–10 m^2
2. Subsurface flow constructed wetlands (SSFCW)	Subsurface Flow CW is filled with gravel/crushed rock whose level is 5–10 cm above water level No exposure of waste water to surface No odours, no mosquito breeding grounds, nor possibility of accidental contact with sewage Need water proofing Function as beautiful garden, green belts, etc. Less land is needed 1–5 m^2/person There are two classification of subsurface flow CW a. Vertical flow and horizontal flow SSFCW b. Soil-based and gravel-based SSFCW
Based on soil surface (Stottmeister et al. 2003)	
1. Horizontal surface flow systems	Waste water level is above soil surface
2. Horizontal subsurface flow system	Waste water level is below soil surface
3. Vertical flow system	Waste water level is below soil surface
Based on mode of feeding (Abdelhakeem et al. 2016)	
1. Continuous feeding modes	Waste water input is continuous
2. Batch feeding modes	Waste water input is intermittent

Bamboo species can adapt to various climatic conditions and are highly productive and fast-growing (Wolverton et al., 1983; DeVos, 2004). Reeds like *Phragmites australis* that are widely used in CW can be widely used as biomass fuel, high-strength fibre, pulp, and paper production, livestock forage, soil conditioner, etc. (Masi, 2009).

Mechanism of greywater treatment using constructed wetlands

Constructed wetlands employ physical, chemical, and biological processes for the treatment of greywater. Filtration, flocculation, settling, and sedimentation are the primary physical mechanisms employed in CWs (Arden & Ma, 2018). Chemical processes involved in pollutant removal are precipitation, oxidation, ligand exchange reactions, absorption, and decomposition (Nelson, 2014). Constructed wetlands utilized plants, microbes, sunlight, and gravity to transform wastewater into reusable forms like gardens, etc. (Nelson, 2014). Major biological mechanisms working in CWs are biological uptake, the transformation of nutrients by anaerobic and aerobic processes, metabolism, nitrification and denitrification, biochemical transportation, etc. Most of the reuse parameters can be efficiently removed by CWs in comparison to other technologies (Yadav & Ghaitidak, 2013). Constructed wetlands are mechanically simple, have relatively low operation and maintenance requirements (Nivala et al., 2012).

The purification efficiency of CWs depends on particle size, surface nature, bulk porosity, pore space of growth media, etc. (Amos & Younger, 2003). Constructed wetlands use rooted wetland plants and shallow, flooded, or saturated soil to provide wastewater treatment (Nelson, 2014). Physical and biological removal of contaminants from GW also depends on the planting regime (Avery et al., 2007; Vymazal, 2010). Constructed wetlands use no chemicals (Nelson, 2014). In CWs, the TSS removal takes place through settling, flocculation, and filtration (USEPA, 2000; Vymazal, 2007). Plant and media surfaces act as a primary mechanism for bacteria and virus removal (Arden & Ma, 2018; Jackson & Jackson, 2008).

Plants play the role of aerators. Different plants have diverse root architecture (Avery et al., 2007). Their roots support symbiotic bacteria and fungi and finally increase the microbial environment. Different rhizosphere microbial communities are supported by different plant species. Roots provide surface area for attached microbes, maintain hydraulic properties of the substrate, helps in the efficient degradation of organic material along with increased competition, production of antimicrobial compounds, and grazing pressure against pathogens in influent GW (Avery et al., 2007; Haberl et al., 2003). Activity and type of metabolism performed by microbes in the root zone of CWs depend on the supply of oxygen (Stottmeister et al., 2003). In CWs, active reaction zone is the root zone or rhizosphere and here physicochemical and biological processes induced by the interaction between plants, microorganisms, soil, and pollutants take place (Stottmeister et al., 2003). Vegetation prevents erosion and shading prevents algae growth (Haberl et al., 2003).

Plants need sufficient biomass and stem densities. The root system of plants helps in increasing the available surface for bacterial colonization and helps in transfer of oxygen to provide an aerobic/oxidized environment, thus providing a substrate for microorganisms. Hydraulic pathways in the substrate are provided and maintained by plants and also helps in the uptake of nutrients like nitrogen or phosphorus. Plants have a significant effect on pollutant removal (Abdelhakeem et al., 2016). Plant beds have more removal efficiencies of COD, BOD, TSS, NH_4, and Total-P compared to unplanted beds (Abdelhakeem et al., 2016). Plants provide a substrate for microbes (called periphyton) to grow and act on organic molecules, removing 7–10% of pollutants (Vymazal, 2007). Constructed wetland's vegetation is adapted to water-logged conditions (Mitsch & Gosselink, 2000). Artificial aeration in CW causes stress in macrophytes resulting in stunted growth and yellowing of leaves (Butterworth et al., 2016). In CWs, seasonal or spatial influences do not affect bacterial abundance. Ammonia-oxidizing bacteria are seen in the top layer; nitrite-oxidizing bacteria in the top and intermediate layers; and denitrifying bacteria in all layers (Pelissari et al., 2017).

Constructed wetlands remove 30–80% of the nitrogen in domestic wastewaters and it depends on plant type and flow regime (Ayaz et al., 2003). At anoxic conditions, CWs remove nitrate also through denitrification (Misiti et al., 2011). Microbes living in the pores of media particles consume the waste materials in wastewater, as they pass through the media (Zidan et al., 2015). Anaerobic treatment increases the efficiency of CWs by protecting them from clogging, removal of high suspended matters, increases wetland life, decreases organic matter loading, lowers influent organic loading, reduces the land requirement for CW (Ayaz, 2012; Vymazal, 2005; Caselles-osorio and Garcia, 2006). Gravel acts as a substrate to support plant growth (Knowles et al., 2011; Laaffat et al., 2015). Sand gives more pollutant removal efficiency than gravel (Priya and Urmila, 2013). CW with sand, gravel media, and the aquatic plant *Lepironia articulate* was successful in removing organic matter content from the bathroom, washing machine, and kitchen GW (Wurochekke et al., 2014). Plastic media was found to give better performance for BOD, COD, and TSS removal than gravel and rubber media (Zidan et al., 2015).

The efficiency of CW depends on local climate, wastewater characteristics, filling materials, etc. (Ayaz et al., 2012). Temperature is an important factor in nitrification (Ayaz et al., 2012). Decreased temperature, increased hydraulic loading rates result in decreased removal efficiency (Ayaz et al., 2012). Loss of vegetation also decreases the nitrification ability. In winter, removal of ammonia nitrogen is limited (Vymazal, 2011). Recirculation of effluent increases the effective removal of total nitrogen and in meeting discharge standards (Ayaz et al., 2012). Effluent quality is affected by path length of media (through which influent passes), hydraulic retention time, etc. Enteric microbe removal efficiency in CW depends on hydraulic loading rate (HLR), hydraulic residence time (HRT), presence of vegetation, etc. (Avery et al., 2007). Constructed wetlands perform better in warm, sunny conditions. Higher temperature and increased sunlight are good. Constructed wetlands are highly recommended for on-site system use.

Constructed wetlands remove contaminants such as BOD5, suspended solids, metals including cadmium, chromium, iron, lead, manganese, selenium, zinc, and toxic organisms from wastewater (USEPA, 2000; Yadav & Ghaitidak, 2013). Other major water quality parameters which are improved using CW are COD, turbidity, total coliforms, *E. coli*, Faecal Enterococci, pH, nitrate, ammonia, phosphate, etc. (Avery et al., 2007). Constructed wetlands are very effective in removing organics and suspended solids, but nitrogen and phosphorus removal are less (Vymazal, 2010). Organic compounds can also be removed using CW (Haberl et al., 2003). Greater than 90% removal of copper, lead, and zinc is reported from CW (Nelson, 2014). Constructed wetlands are also widely used in removing hydrocarbons, mineral oils, chlorinated volatiles, atrazine, TNT, RD4, organics, oil, and grease, etc. (Lakatos, 2000; Simi et al., 2000; Ji et al., 2002; Haberl et al., 2003; Best et al., 1999; Pucci et al., 2000).

Constructed wetlands are a proven option for remediation of acid mine drainage, hazardous waste site wastewaters, petroleum refinery wastes, compost and landfills leachates, food and distillery industries, animal wastes, highway runoff, agricultural wastes, and pre-treated industrial wastewaters such as those from pulp and paper mills and textile mills, for livestock wastewater management, for dairy wastewater treatment, etc. (Dipu et al., 2011; Healy et al., 2007; Knight et al., 2000; Mueller et al., 2003). For surfactants and personal care products GW, an HRT of 6.8 days is needed to meet the reuse standards (Ramprasad & Philip, 2016).

Constructed wetlands also act as a sustainable solution for wastewater treatment in small communities (Zidan et al., 2015; Hickey et al., 2018). CW is a good option for small-scale treatment of domestic GW as they are sustainable, affordable, low capital intensive and has low maintenance requirements (Avery et al., 2007; Ayaz, 2008; Ayaz et al., 2012; DuBowy & Reaves, 1994). But only a slow rate of its usage is reported in developing countries. The use of CWs on large scale was successfully reported from different countries like the US, New Zealand, Australia, Kenya, Canada, Argentina, Spain, China, Italy, Germany, UK, Brazil, etc. (DuBowy & Reaves, 1994).

A modified version of CW is Green Roof Water Recycling System (GROW). GROW is a good option for GW recycling, where GW is passed through five troughs where plants are rooted in optiroc clay (expanded clay) and gravel chippings (10–20 mm diameter) (Avery et al., 2007). The entire GROW system can be covered with a reinforced membrane to prevent rainwater from entering the system.

Construction and cost

The design of a constructed wetland is simple. The assumed size of CW is 3–5 square meter per 150 L of water for temperate to warm climate and this changes with climate. The good general ratio of construction of wetlands is 1:3 or 1:4 (1 m width for 3 or 4 m length). If not properly constructed, CW can cause clogging, surface run-off, short-circuiting, bad plant development, etc. Failure of installation devices, low temperature, etc., causes low activity (Haberl et al., 2003). At the beginning of CW, solids and liquids need to be separated to reduce the loading of suspended solids (Nelson, 2014) and a filter can be installed for the same. No shade or no rain gathering areas are good for Cws. Usually two to three plants per square meter is reasonable. Vegetation, soil, and hydrology are major components in CW (Haberl et al., 2003).

Constructed wetlands have very low operation and maintenance costs (Vymazal, 2010). Constructed wetland for a residential unit consists of a primary clarification tank, inlet, impermeable liner, planting medium, wetland vegetation, and outlet (ElZein et al., 2016). Basic investment costs for CWs include land, site investigation, system design, earthwork, liners, filtration, rooting media, vegetation, hydraulic control structures, miscellaneous costs like fencing, etc. Cost also depends on topography, distance to receiving water, existing devices, availability of area, settling tank, buffering tank, plastic liners, soil materials, and pipe systems (Haberl et al., 2003).

Advantages and disadvantages/limitations of constructed wetlands

Constructed wetlands possess a lot of advantages as well as a few disadvantages. These are listed below.

Advantages of constructed wetlands

Major advantages of constructed wetlands are as follows: reduction of overall water demand; reduction of organic and hydraulic loading on municipal wastewater system; reduction in water bills (Parameshwara Murthy et al., 2016; Nelson, 2014; Haberl et al., 2003); replenishment of groundwater which contributes to a healthy water cycle; protection of aquatic ecosystems due to decreased diversions of freshwater (ElZein et al., 2016; Mueller et al 2003; Vymazal, 2010); long life—minimum of 15 years renewable cycles; low cost-compared to conventional wastewater treatment plants; adaptability and flexibility of treatment; simplicity; aesthetics; highly productive system and water-saving (Ayaz et al., 2012; Parameshwara Murthy et al., 2016); no additional pollution nor chemical products; protection of vital ecosystems, e.g., rivers, lakes, groundwater, oceans, soils, etc., as water is purified before release into environment (ElZein et al., 2016; Masi, 2009; Vymazal, 2010); potential economic tool—vermicomposting from primary treatment, flowers and animal fodder, weaving material, etc., (Mueller et al., 2003; Nelson, 2014; Haberl et al., 2003); lower total lifetime costs; tolerate fluctuations in flow and pollutant concentrations; built to fit harmoniously into landscape; habitats for plants and wildlife; can be integrated into existing gardens (ElZein et al., 2016; Parameshwara Murthy et al., 2016; Vymazal, 2010); economical and long lasting than conventional sewage treatment systems; effective; environmental friendly (Ayaz et al., 2012); bring economic benefits to developing countries; effective at reducing loads of BOD/COD, nitrogen, phosphorus and suspended solids up to 98%; built and operated simply; utilize natural process (Ayaz et al., 2012; Mueller et al 2003); low operation and maintenance expense; tolerate fluctuations in flow; treat waste water with different constituents and concentration (Parameshwara Murthy et al., 2016; Nelson, 2014; Haberl et al., 2003; Masi, 2009); high process stability and buffering capacity; water reuse and recycling; environmentally sensitive approach; flood protection and storm water management (Ayaz & Akca, 2000; Mueller et al 2003); carbon sequestration; eliminate need for sludge removal; easy to control as they have engineered systems; nutrients recovery and biomass production (Ayaz & Akca, 2000; ElZein et al., 2016; Parameshwara Murthy et al., 2016; Vymazal, 2010).

Disadvantages of constructed wetlands

Greywater cannot be stored for more than 24 h (nutrients breakdown causing bad odor) (Nelson, 2014). There are water quality concerns and health standard issues (Parameshwara Murthy et al., 2016). Presence of soaps and detergents makes treated water unfit for irrigation (Mueller et al., 2003). Presence of fats, oils, grease, hair, lint, cleansers, (Nelson, 2014) fabric softeners, and other chemicals that can cause harm to plants. A large space of 1–4 m^2 per person is required in warm weather and double that in cold climates (Mueller et al., 2003). Require experience to ensure proper design and implementation (Nelson, 2014). Other disadvantages are lack of awareness; surge in flow or pollutants may temporarily reduce treatment effectiveness (Parameshwara Murthy et al., 2016); require a base flow of water (Nelson, 2014); chemical and biological process-rate are dependent on environmental factors like temperature, oxygen, and pH (Parameshwara Murthy et al., 2016); metabolic activities decreased by low temperature, thus reducing the effectiveness of pollutant uptake processes (Ayaz et al., 2012); low oxygen concentration limits processes involving aerobic respiration and enhances the anaerobic process and it degrades water quality. Constructed Wetlands are less effective if pH is too low or high (Nelson, 2014).

Greywater reuse

The GW treatment and reuse is the need of the hour (Maimon et al., 2010). Rapid population growth, unplanned urbanization, surface water pollution, and continuous groundwater extraction increase the demand for water in agricultural, industrial, and domestic sectors (Shaikh & Younus., 2015). Climate change is also directly linked with water scarcity (Dahal et al., 2020; Güiza-Villa et al., 2020). A potential source of water-saving is GW recycling (Shaikh & Younus, 2015). Wastewater reuse increases the total available water supply (Yadav & Ghaitidak, 2013). Water reuse and recycling can help in decreasing the increasing demand for water (Avery et al., 2007). GW carries fewer organics, nutrients, and pathogens than black water and can be treated easily for reuse purposes (Arden & Ma, 2018; Eriksson et al., 2002; Li et al., 2009; Yadav & Ghaitidak, 2013). To reuse GW, biological treatment is required to reduce high levels of microbes and organic matter and to eliminate pathogens, and control biofilm growth in the pipe networks, disinfection is required (Yadav & Ghaitidak, 2013). GW recycling system consists of the collection, storage, treatment, and reuse (Shaikh & Younus, 2015). Treated GW can be used for private garden irrigation, toilet flushing, gardening, etc., and thus reduces the freshwater requirement (Avery et al., 2007; Gross et al., 2007; Yadav & Ghaitidak, 2013). High-quality water for landscape irrigation can be produced by 8–12 h of GW recycling. For surface irrigation, the process needs to follow a disinfection method (Gross et al., 2007). GW reuse for irrigation is a common practice worldwide (Maimon et al., 2014). GW reuse reduces domestic water demand (Ghisi & Ferreira, 2007). In low-income countries, GW reuse can be done in agriculture and augmentation of water bodies (Yadav & Ghaitidak, 2013).

Recycle and reuse of wastewater helps in water demand management. Recycle and reuse groundwater, rainwater harvesting, etc., are options to save fresh drinking water. Recycled GW can be reused for non-potable purposes like agricultural and landscape irrigation, public parks irrigation, open yards, fire protection practices, toilet flushing, etc., where high-quality water is not necessary (Negahban-Azar et al., 2012; Shaikh & Younus., 2015; Karpiscak et al., 1990; Lu & Leung, 2003). GW is easily available and can be purified and reused for various purposes, thus reducing water demand (Singh et al., 2016). Reuse of GW saves freshwater resources, reduces the price of water, minimizes the energy needed for transporting water, reduces the presence of pathogenic organisms and inorganic micropollutants (ElZein et al., 2016; Miller, 2006). GW has a higher biodegradation rate than black/mixed (grey and black water) water in a constructed wetland.

Table 2 Suggested water reuse standards (selected) for different purposes, from different countries

Reuse	pH	BOD (mg/L)	Turbidity (NTU)	TSS (mg/L)	Fecal coliform (per 100 mL)	TOC (mg/L)	COD (mg/L)	TOC (mg/L)	Oil and grease (mg/L)	TDS (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	References
Unrestricted, urban reuse	6.0–9.0	≤ 10	≤ 2		ND								USEPA (2012)
Restricted, urban reuse	6.0–9.0	≤ 30		≤ 30	≤ 200								
Food crops, Agricultural reuse	6.0–9.0	≤ 10	≤ 2		ND								
Non-Food crops, Agricultural reuse	6.0–9.0	≤ 30		≤ 30	≤ 200								
Environmental reuse		≤ 30		≤ 30	≤ 200								
Groundwater recharge-Nonpotable reuse	6.5–8.5		≤ 2		ND	≤ 2							
Unrestricted reuse	6.0–8.4	10	5	10	2.2		50	40	Absent	2500	5	10	Saudi (Al-Jasser, 2011)
Restricted reuse	6.0–8.4	40	5	40	1000				Absent	2500	5	10	
On land for irrigation	5.5–9.0	100		200									India (CPCB 2008)
Into inland surface water	5.5–9.0	30		100									
Into public sewers	5.5–9.0	350		600									

ND non-detectable

1–2 days HRT is sufficient for getting reusable water from GW in a constructed wetland (Masi, 2009).

Norms and regulations for water reuse

The major barriers in GW treatment and reuse are limited human and financial resources, reliability of wastewater treatment, system energy demand, the economic feasibility of the system, public perception and willingness, social and institutional acceptance, water right issues and political process, insufficient and inconsistent codes and guidelines, etc. The challenges of reuse of GW are pathogen, salt buildup in certain soils, a rapid increase of microorganisms, lack of maintenance leading to mosquito menace, reduction in downstream discharge in streams leading to serious consequences for downstream users (Yadav & Ghaitidak, 2013). Greywater reuse sometimes has public health risk, environmental risks (Maimon et al., 2014). Pathogenic organisms are the main culprits for causing public health hazards when considering GW reuse (Chen et al., 2013). For reusing GW, the reclaimed water needs to comply with five criteria viz. hygiene, safety, aesthetics, environmental tolerance, and economical feasibility (Nolde, 2000).

Water reuse standards are different for different regions (Arden & Ma, 2018). Selected reuse standards of different countries are given in Table 2. Laboratory determination needed to evaluate common irrigation water quality problems are pH, salinity, EC, TDS, cations, and anions like calcium, magnesium, sodium, carbonate, bicarbonate, chloride and sulfate, and other miscellaneous parameters like boron, and sodium adsorption ratio (SAR) (Pedrero et al., 2010).

Conclusion

Water is an important issue globally. On one hand, water demand is increasing and on the other hand, increasing wastewater is posing a threat. Climate change has also adversely affected the water sector. Greywater treatment and reuse is the best option to cope with the increasing water demand. There are a lot of treatment techniques for the reuse of greywater. Among them, constructed wetlands (CWs) are environmentally and economically friendly for domestic and large-scale applications. As CWs are low-tech, robust and cost-effective, they can be employed for greywater treatment in all the regions in future. No environmental pollution is added from CWs and it helps in environmental sustainability. Apart from a few limitations, it has numerous advantages. Treated greywater can be reused for gardening, toilet flushing, irrigation, etc., following water quality reuse standards. This will help very much in overcoming the water demand and pressure exerted on groundwater systems. Greywater treated using CWs mostly comply with the standard regulations for water reuse. Thus it can be thought of as a proven option for greywater treatment, thereby alleviating water scarcity. It also opens a vast area of research involving different plants, different climatic and terrain conditions, structure modification, etc., to improve the efficiency in greywater treatment.

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Declarations

Conflict of interest The funding was provided by UGC-DSKPDF and the award number is No.F.4-2/2006(BSR)/OT/18-19/0019.

Ethical standards All ethical standards are met and no animal/human research is done in this paper.

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