Treated municipal wastewater to fulfil crop water footprints and irrigation demand – a review

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ABSTRACT

Direct application of raw municipal wastewater for irrigation purposes may create many undesirable harmful consequences. Therefore, treated effluent through different technologies is generally preferred for reuse especially in water-scarce regions. In the present study, the performances of some treatment technologies like constructed wetland (CW), waste stabilisation pond (WSP), membrane bioreactor (MBR), vermi-biofiltration (VBF) and land treatment methods for removal of chemical and biological impurities from municipal wastewater were reviewed. The study revealed that the treated water quality varied depending on the hydraulic retention time under different treatment methods. The reservoir should be considered an integral part of the wastewater treatment system and not merely an operative ponding volume for irrigation. The comparatively advanced MBR technique showed better performance for removal of BOD, COD, fecal coliforms, *Escherichia coli* and other biological impurities than the traditional approach. Some techniques like land treatment methods and VBF were found to be equally attractive in developed as well as developing nations. The future projections of global green and blue water scarcities indicate treated water to be a valuable alternative water resource to fulfil required crop water footprints as well as irrigation demands.

Key words | BOD, COD, coliforms, membrane bioreactor, municipal wastewater, water footprints

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HIGHLIGHTS

- The treated water quality varied depending on the hydraulic retention time under different treatment methods.
- The reservoir should be considered an integral part of the wastewater treatment system.
- Land treatment methods and VBF were found to be equally attractive in developed as well as developing nations.
- The treated water is a valuable alternative water resource to fulfil crop water footprints and irrigation demands.

INTRODUCTION

Water is an indispensable component in agricultural crop production. Out of the total freshwater resources withdrawn (3,906.70 km^3/yr), about 70% is used for agricultural purposes (Biswas *et al.* 2020). In India, the agricultural sector accounts for more than 80% of water usage. Hoekstra & Hung (2002) introduced the concept of water footprint to assess the total freshwater requirement during crop production. The agricultural sector accounts for about 99% of the global consumptive water footprint (CWF), which includes both precipitation and irrigation (Mekonnen & Hoekstra 2014). According to the 2011 census report, the world population is

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about 7 billion and is projected to be about 9.50 billion by the year 2050 (Biswas *et al.* 2020). Such population growth, rapid urbanisation, industrialisation and advanced lifestyles will lead to an unprecedented increase in freshwater demand as well as water footprints for agricultural crops in the future. Specifically, paddy rice is the largest consumer of water (Xinchun *et al.* 2018). The global average CWF of rice is 1,486 $m^3 t^{-1}$. The CWF for food fodder crop production is expected to be increased to 9,600 billion m^3 per year in 2050 from 6,400 billion m^3 per year in 2000 (Mekonnen & Hoekstra 2014). Therefore, other alternative water resources will be indispensable to satisfy the unparalleled freshwater requirement (AbdEL-rahman *et al.* 2015). In such a critical situation, municipal wastewater can play a vital role as an alternative source of water particularly for agricultural irrigation.

Municipal wastewater can be categorised as one of the major types of marginal-quality water. In India, the municipal wastewater generation from cities and towns (representing 72% of the urban population) was estimated at 38,524 million litres day^{-1} (Banerjee 2016). Only 30% of generated municipal wastewater is treated through different treatment facilities. In Pakistan, only 26% of vegetable production is irrigated with wastewater (Ensink *et al.* 2004). In Ghana, informal irrigation including diluted wastewater from rivers and streams occurs on about 11,500 ha of area, which is larger than the formal irrigated areas (Pedrero *et al.* 2010). In Mexico about 260,000 ha are irrigated with untreated wastewater mostly (Mexico CAN 2004). In most cases, farmers irrigate the crop field with diluted, untreated or partially treated wastewater. The absence of proper treatment facilities leads to health risk for farmers as well as consumers from heavy metals, viruses, parasitic worms and bacteria. Therefore, the proper treatment facilities for reclamation of generated municipal wastewater and its application for agricultural irrigation purposes are the biggest challenge in the coming decades (Banerjee 2016).

For the treatment of municipal wastewater, different technologies are practiced in different parts of the world. These different technologies are waste stabilisation pond (WSP) (Gruchlik *et al.* 2018), vermi-biofiltration (VBF) (Bhavini *et al.* 2020), membrane bioreactor (MBR) (Biswas 2020a, 2020b), constructed wetlands (CWs) (Biswas 2020a, 2020b), land treatment method (Ritter 2020) etc. The performances and intricacies of these technologies in removing different contaminants vary from one to another. In some cases, combined technologies (like CW + WSP, CW + VBF etc.) provided satisfactory results from chemical and biological points of view. Although different technologies for wastewater treatment are available, many have countries faced the problem of public resistance to the implementation of these modern innovative water projects (Dolnicar *et al.* 2011). The worldwide amount of treated wastewater reuse is very small (<1%) compared with the total withdrawal of water. Some previous studies (Dolnicar *et al.* 2011; Brahim-Neji *et al.* 2014) pointed out that the age, education and knowledge of the local farmers about the reuse of treated wastewater were the main reasons behind this public resistance. Therefore, a greater level of awareness about the advantages of wastewater reuse in agriculture should be frequently highlighted by researchers through social experiments. Therefore, the present study aims to review the performances of the four well-known technologies of CW, WSP, VBF, MBR and the land treatment method to remove different hazardous chemical and biological impurities from municipal wastewater. This review article will also discuss the suitability of treated municipal wastewater for agricultural irrigation purposes to fulfil crop water footprints with reduced freshwater irrigation requirements.

MATERIALS AND METHODS

Concept of water footprints of crop production

The total water footprint (TWF) of crop production refers to the volume of freshwater that is consumed during the crop growing period (Xinchun *et al.* 2017). It consists of three parts: blue, green and grey WFs. Green WF (GWF) is expressed as the volume of rainwater consumed to crop yield, and blue WF (BWF) is defined as the volume of irrigation water consumed to crop yield. Green and blue WFs in crop production are combined as consumptive WF (CWF). This CWF refers to the total evapotranspiration (ET) during the crop growth period (Biswas & Mailapalli 2019). The grey WF (GrWF) refers to the freshwater volume that is required to assimilate the pollutant loads caused by fertiliser leaching given natural background concentrations as well as existing ambient water quality standards. The GrWF is also known as degradable WF.

Table 1 | Water quality standards according to USEPA and FAO guidelines

Serial no.	Chemical and biological parameters	Unit	Guidelines USEPA	Guidelines FAO
1.	pH	*[a]	6.50–8.40	6.50–8.50
2.	Total dissolved solid (TDS)	mg/l	<450	2,000
3.	Biochemical oxygen demand (BOD)	mg/l	10	**[b]
4.	Chemical oxygen demand (COD)	mg/l	**[b]	**[b]
5.	Ammonium (NH_4)	mg/l	**[b]	0–5
6.	Nitrite (NO_2)	mg/l	**[b]	**[b]
7.	Nitrate (NO_3)	mg/l	<5	0–10
8.	Total nitrogen (TN)	mg/l	**[b]	30
9.	Phosphate (PO_4)	mg/l	**[b]	0–2
10.	Total phosphorus (TP)	mg/l	**[b]	**[b]
11.	Potassium (K)	mg/l	**[b]	0–2
12.	Calcium (Ca)	mg/l	**[b]	400
13.	Magnesium (Mg)	mg/l	**[b]	60
14.	Sodium (Na)	mg/l	<69	900
15.	Manganese (Mn)	mg/l	0.20	0.20
16.	Iron (Fe)	mg/l	5.00	5.00
17.	Cadmium (Cd)	mg/l	0.01	0.01
18.	Chromium (Cr)	mg/l	0.10	0.10
19.	Zinc (Zn)	mg/l	2.00	**[b]
20.	Lead (Pb)	mg/l	5.00	2.00
21.	Nickel (Ni)	mg/l	0.20	5.00
22.	Boron (B)	mg/l	0.75	0–2
23.	Chloride (Cl)	mg/l	<70	1,100
24.	Sulphate (SO_4)	mg/l	**[b]	1,000
25	Carbonate (CO_3)	mg/l	**[b]	0–100
26.	Bicarbonate (HCO_3)	mg/l	<150	600
27.	Sodium adsorption ratio (SAR)	*[a]	<3	15
28.	Electrical conductivity (EC)	dS/m	<0.70	3.00
29.	Copper (Cu)	mg/l	0.20	0.10
30.	Aluminium (Al)	mg/l	5.00	**[b]
31.	Cobalt (Co)	mg/l	0.05	0.05
32.	Fluoride (F)	mg/l	1.00	**[b]
33.	Arsenic (As)	mg/l	0.10	**[b]
34.	Beryllium (Be)	mg/l	0.10	**[b]
35.	Molybdenum (Mo)	mg/l	0.01	**[b]
36.	Vanadium (V)	mg/l	0.10	**[b]
37.	Selenium (Se)	mg/l	0.02	**[b]
38.	Lithium (Li)	mg/l	2.50	**[b]
39.	Fecal coliform (FC)	Count per 100 ml	23	<200

*[a]indicates no units; **[b]indicates data unavailability.

Permissible limits of different chemical and biological parameters for agricultural irrigation

The allowable limits of different chemical and biological properties of wastewater for irrigation purposes are documented in this section. The standard levels of different chemical and biological impurities provided by the United States Environmental Protection Agency (USEPA 2012) and Food and Agriculture Organisation (FAO-AQUASTAT 2015) are presented in Table 1.

Concept of different wastewater treatment methods

Constructed wetland (CW)

Wetlands are 'innate filters of water' (Biswas *et al.* 2020). The capability of wetland to renovate and accumulate organic matter and nutrients makes this technology 'the natural kidneys of the land' (Hammer 1989). CWs were primarily used for secondary treatment of municipal wastewaters and these systems were capable of eliminating organics and suspended solids significantly (Biswas *et al.* 2020). Treatment of wastewater by this method is generally accomplished through biological processes (like microbial metabolic activity and plant uptake) and physicochemical processes (like precipitation, adsorption and sedimentation at the root–sediment, water–sediment and plant–water interfaces). The CWs can be categorised according to different criteria such as flow path in subsurface wetlands (such as vertical and horizontal), hydrology (like open surface and subsurface flow) and macrophytic growth (such as free floating, emergent, submerged) etc. (Vymazal 2014). The most common CWs are the horizontal subsurface flow type. Horizontal flow constructed wetlands (HF CWs) have the capability to treat wastewater having low organic concentrations (Bakhshoodeh *et al.* 2017). But, the vertical type is also being admired recently (Badejo *et al.* 2018). Sometimes hybrid CWs (combination of different types of CWs) have also been utilised instead of a particular type for successful treatment of wastewater (Ali *et al.* 2018a, 2018b).

Waste stabilisation pond (WSP)

Waste stabilisation pond (WSP) is one of the natural treatment methods for municipal wastewater (Kamyotra & Bhardwaj 2011). This is generally a shallow artificial basin (Buchanan *et al.* 2018). It consists of a single or a series of several anaerobic (2–5 m depth in general), facultative, or maturation ponds (1–1.50 m depth in general). The treatment through anaerobic ponds is considered as the first step of the filtration process. At this first stage (anaerobic ponds), generally sludge generation takes place (Eland *et al.* 2019). At the second stage (facultative ponds), algae grows on the water surface and provides oxygen for both aerobic and anaerobic digestion of the organic pollutants. The last stage (maturation ponds) plays a vital role in stabilising solids and inactivating pathogens completely. The temperature and intensity of sunlight play the key role in the operation of the WSP method. Therefore, it is suitable for wastewater treatment, especially in tropical and subtropical countries (Gopalang & Letshwenyo 2018).

Membrane bioreactor (MBR)

Membrane bioreactor (MBR) is an innovative approach for wastewater treatment. It is a biochemical engineering process. It involves the action of both a suspended growth bioreactor and a membrane separator (Ozgun *et al.* 2013; Biswas 2020a, 2020b). The MBR combines the traditional activated sludge (AS) process (Roy & Biswas 2020) and membrane filtration technique (Younggeun *et al.* 2020) for removal of hazardous impurities from wastewater. The traditional AS process consists of different treatment stages. These are: (i) the making of a mixed liquor by mixing the activated sludge with the wastewater to be treated, (ii) aeration and agitation of this mixed liquor for a certain duration, (iii) separation of the activated sludge from the mixed liquor in the final clarification process, (iv) return of the proper amount of activated sludge for mixing with the wastewater and (v) disposal of the excess activated sludge. The performance of the AS process depends on some important factors such as temperature, return rates, amount of available oxygen, amount of available organic matter, pH, waste rates, time of aeration and wastewater toxicity (Roy & Biswas 2020). During the MBR process, liquid–solid separation is accomplished by ultra-filtration or micro-filtration membranes. Sometimes, a pre-treatment step is required to remove unwanted solids from the raw wastewater. Membrane fouling is a major limitation in MBR operation. Generally, fouling indicates the deposition and accumulation of solids and biomass on membranes (Biswas 2020a, 2020b). It is formed due to two major incidents: (i) pore blocking caused by colloidal materials and (ii) formation of cake by suspended solids (Zahid & El-Shafai 2011; Aslam *et al.* 2019). The MBR is generally categorised into two groups: (i) integrated and (ii) re-circulated. Generally, outer skin membranes are involved in the first group. Under this category, the operational force is obtained by the formation of a negative force on the permeate face. In the second group, mixed liquor recirculation takes place. In this case, the pressure formed by high cross-flow velocity develops the driving force for operation (Goswami *et al.* 2018).

Vermi-biofiltration (VBF)

The usage of earthworms in wastewater or sewage treatment is called vermi-biofiltration (Tomar & Suthar 2011; Phothisansakul & Runguphan 2017). The VBF is an innovation that gives a reasonable answer for the treatment of wastewater with synchronous sewage reduction and treatment (Krishnasamy *et al.* 2013). This treatment method is the combination of traditional filtration mechanisms and vermicomposting systems. Raw wastewater is treated by this method through the earthworms. The earthworm's body acts as a biofilter in this wastewater treatment. The earthworms disintegrate organic particles into small particles and increase the hydraulic conductivity and aeration of those organic substances. The earthworms increase the total specific surface area of media particles by grinding them and increase the contaminant adsorption capability of the filter. Biodegradation, microbial simulation and enzymatic degradation of waste solids are brought about by earthworms in this filter (Chowdhary *et al.* 2020).

Land treatment methods

Land treatment is one of the most cost-effective ways of wastewater treatment. The process refers to the application of wastewater to the land at a controlled rate in a designed and engineered setting. The purpose of the activity is to obtain beneficial use of these materials, to improve environmental quality, and to achieve treatment and disposal goals in a cost-effective manner. Land treatment systems include slow rate (SR), overland flow (OF), and soil aquifer treatment (SAT) or rapid infiltration (RI). These systems require minimal effort for operation and maintenance (Ritter 2020).

RESULTS AND DISCUSSIONS

Performance of different treatment methods

Removal through CWs

Morari & Giardini (2009) used two pilot-scale vertical flow constructed wetlands with *Typha latifolia* and *Phragmites australis*. Both wetlands performed well for removal of BOD and COD, whereas lower efficiencies for Na and Mg indicated that an efficient pre-cleaning system was necessary for better performance of the wetlands. García *et al.* (2013) worked with hybrid technology (with *Cyperus* sp. (papyrus)) and documented satisfactory performance in removal of total coliforms (3 log units), *Escherichia coli (E. coli*; 4 log units) and helminth eggs (99%) from raw wastewater. The COD and BOD removal efficiency was also more than 85%. Morari *et al.* (2015) reported better removal efficacy for Cu (91%), Zn (85%), Al (96%) and Pb (88%) as compared with B (40%), Fe (44%) and Co (31%) by CW with *Typha latifolia* L. and *Phragmites australis* L. The study suggested an additional pre-cleaning system with CW for making treated water suitable for agricultural irrigation. According to Andreo-Martínez *et al.* (2017), horizontal subsurface flow (HSSF) CW was able to remove BOD, COD, nematode eggs and *E. coli* by 98%, 93%, 100% and 100%, respectively from wastewaters. However, the SAR and EC values of treated water were still above the allowable limits for agricultural reuse. He *et al.* (2018) experimented with hybrid CW at pilot scale over a nine-month period and reported mean removal efficiency of COD, TP and TN of 59%, 83% and 58%, respectively. The study suggested that HSF CW was more suitable for denitrifying bacteria growth. Ali *et al.* (2018a, 2018b) used hybrid CW (vertical subsurface flow CW + phyto-treatment pond) with *Hydrocotyle umbellata* L., *Canna indica* L., *Typha latifolia* L. and *Phragmites australis* Cav. Trin. ex Steud. The process removed EC, BOD, COD, TDS, chloride, alkalinity, sulphate, phosphate, Mn, Ni, Na, Cr, Fe, Cd, Pb, Co, Cu, Ca, K, Zn, Mg and total hardness by about 57%, 69%, 64%, 57%, 40%, 40%, 47%, 55%, 65%, 81%, 29%, 78%, 70%, 100%, 81%, 100%, 68%, 22%, 60%, 60%, 17% and 20% respectively. The study recommended the treated water for safe irrigation under water-limited areas. Russo *et al.* (2019) reported that the HSSF CW alone might not be effective in pathogen removal from raw wastewater. Even the change in plant species (*Typha latifolia*, *Phragmites australis* etc.) did not influence the performance of CW significantly. However, the HSSF CW coupled with UV treatment performed better for removal of different biological (*E. coli*, total coliforms, Enterococcus, somatic coliphages) impurities. Rahi & Faisal (2019) studied the performance of HSSF CW with coarse gravel (40–60 mm) to treat wastewater. In this study, a local plant (*Phragmites australis*) was utilised in CW. The highest BOD and phosphate removal efficiency through this method was achieved as 84% and 55%, respectively at a two-day detention period. The pilot-scale experiment of Collivignarelli *et al.* (2020) with HF CW (*Phragmites australis*, *Carex oshimensis* and *Cyperus papyrus*) reported 88% BOD and 89% COD removal efficiency with HRT of 1–3 days. But, the study suggested the requirement of a disinfection process along with HF CW for improving bacterial elimination. In addition, the investigation also emphasised higher (>3 days) HRTs for better BOD removal efficacy.

Removal through WSP

Mozaheb *et al.* (2010) evaluated the performance of stabilisation ponds consisting of three phases: anaerobic pond (AP), primary facultative pond (PFP) and secondary facultative pond (SFP). The performance of AP and PFP was significant from the BOD-removal point of view, while as for COD concern the performance of AP and SFP was significant. The treated effluent was found to contain 2,400 MPN/100 ml. But, the levels of BOD and COD in the effluent were found to exceed the recommended Iranian standard limit for irrigation. Therefore, up-gradation of the method was recommended in this study for better performance. Kihila *et al.* (2014) reported that the combined method of WSP-CW was able to remove COD, TDS, FC and chloride by 32%, 8%, 86% and 4% respectively from raw wastewater. The treated water contained sufficient quantity of nutrients. But, the low removal efficiency for some chemical parameters made the treated water applicable to restricted irrigation for maize or other cereals. The study emphasised proper management of the CW so that the outlet of the CW was not blocked as blocking might decrease the performance efficacy of the CW. According to AbdEL-rahman *et al.* (2015), season-wise variations in concentrations of different chemical parameters were observed along the pond series. During the study, the maximum temperature was 35 °C (in summer) and the minimum was 18 °C (in winter). The BOD removal efficiency was maximum in summer and minimum in winter. The season-wise variation of DO concentration was due to the rate of algal photosynthesis and cellular metabolism of microorganisms in the ponds. The EC concentration variation took place because of water and air temperature and rate of evapo-transpiration. High pH values indicated high heavy-metal removal efficiency in this study. The study suggested that the operational simplicity and cost effectiveness would make this technology an ideal choice for wastewater decontamination especially in developing countries. Along with these advantages, this technology also has some drawbacks: the large land area required, high capital cost depending on land price, expert design requirement and not always being effective in cold climates. The maintenance of this system can be accomplished by froth elimination, floating vegetation removal from the pond surfaces and by maintaining clean inlets and outlets. The investigation of Bansah & Suglo (2016) revealed the satisfactory performance of WSP for removal of FC (99.94%), BOD (97.30%) and different heavy metals from raw wastewater. The treated water met the chemical and biological quality guidelines successfully. Johnson *et al.* (2018) reported that total ammonia removal by microbial oxidation and anabolic uptake varied from 45% to 60% at HRT of 0.5–2 days at pilot-scale level. Zacharia *et al.* (2019) reported the highest removal of FC by 3.80 log units (100 m L^{-1}) under this method. Adhikari & Fedler (2020) also documented 86% BOD removal efficacy with HRT of 22 days under this treatment mechanism.

Removal through MBR

Zhang *et al.* (2010) experimented with anaerobic dynamic MBR with high flux (65 l/m^2-h) for 100 days to remove particulate COD from raw wastewater. The dynamic membrane of the AnMBR could not retain soluble COD effectively. Effluent pH was 7.20–7.60. Ultimately, further downstream treatment was recommended for soluble COD removal. Martinez-Sosa *et al.* (2011) used anaerobic submerged MBR (AnSMBR) for their study. The anaerobic process depends mainly on operational temperature. Such an anaerobic treatment technique performs successfully under tropical climatic conditions. The chief advantages of such an anaerobic process include production of biogas (energy source), 20 times less production of sludge compared with the aerobic process and the presence of inorganic nutrients like nitrogen and phosphorus in the treated effluents. In this study, operation continued for 100 days. The AnSMBR consisted of two containers as anaerobic reactor and membrane container. The total volume of the reactor was 350 litres. A flat-sheet polythene sulfone ultra-filtration membrane (mean pore size 38 nm) was used and the total membrane surface area was 3.50 m^2. Operation was accomplished in four steps: feeding, filtration, relaxation and backwashing. Mesophilic conditions (35 °C) prevailed in the first 69 days. After that, a transition period lasted for ten days. After 79 days, the operation was done in psychrophilic conditions (20 °C). The overall performance of this reactor indicated 94% BOD and 5 log units FC removal efficiency. The study suggested that the final effluent was suitable for irrigation purposes. Zahid & El-Shafai (2011) used a cloth media filter in MBR technology for treatment of municipal wastewater. The performance of this method in terms of COD removal was satisfactory. Four log of faecal reduction was observed in this study. Therefore, this method can be considered as an ideal alternative over the traditional activated sludge process because of high biomass concentration resulting in better elimination of nutrients as well as improved preservation capacity of slow-growing microorganisms like nitrifiers. Finally, the treated effluent was found suitable for restricted irrigation purposes. Gouveia *et al.* (2015) used ultra-filtration with anaerobic submerged MBR at $18 \pm 2\,^{\circ}C$ temperatures and 12.8–14.2 h HRT for treating municipal wastewater. This advanced technique revealed 90% COD removal efficiency. Harb & Hong (2017) recommended anaerobic MBR with some improvement for removal (2–5.5 log) of pathogens effectively from municipal wastewater. The single anaerobic MBR treated effluent had potential risks in agricultural irrigation application. Dolar *et al.* (2019) reported 96% COD and 88% dissolved organic carbon removal efficacy by MBR coupled with reverse osmosis and nano-filtration. The treated effluent was recommended for irrigation purposes. Peña *et al.* (2019) used anaerobic submerged MBR with 8–10 h HRT and obtained 89% COD removal efficiency. The treated water quality met the Spanish guideline for agricultural irrigation.

Removal through VBF

Xing (2008) used a vermi-biofilter with two filter media of quartz sand and ceramisite grain. The performance of the ceramisite grain was 15.07%, 7.39% and 49.70% better in terms of COD, BOD and NH_4-N removal than the quartz sand medium. On the other hand, no obvious removal of TN and TP was observed during this experiment. More organics were used by the earthworms for their movement in the ceramisite grain media. The results of the study indicated that the ceramisite grain medium was less damaged than the quartz sand under identical experimental situations. The study concluded that this VBF technique was more appropriate than the conventional activated sludge method for small towns in Southern China. The total cost involved in this method was found to be 36% lower than that of AS. Tomar & Suthar (2011) obtained better performance of VBF compared with vertical subsurface-flow constructed wetlands. The VBF was able to remove TDS and COD by more than 90%. Kumar *et al.* (2015) used different types of natural ingredients like river bed material, glass balls, wood coal and mud balls as filter media in a vermi-filter for wastewater treatment. Among those four types of filter media, river bed materials performed the best in terms of BOD (81.20%) and COD (72.30%) removal. This media also performed excellently in removal of FC, total coliform, fecal streptococci and *E. coli*. This study suggested that the produced vermi-compost was suitable for sewage farming as it was rich in phosphate and nitrate. The vermi-filtration mechanism for wastewater treatment is economically feasible (Arora *et al.* 2014). Jiang *et al.* (2016) reported the possibility of 98% BOD and 81% COD removal efficiency from raw wastewater by this method. The chemical quality of the treated effluent was also found to be comparable to that of other methods like MBR, WSPs and batch reactor. The study emphasised proper earthworm species, different types of filter materials (like agricultural waste, artificial products and industrial by-products) and integration with some traditional methods for better performance of this technique. Lourenço & Nunes (2017) recommended multistage VBFs (98.50% BOD, 74%–91% COD removal efficacy) as compared with a single stage for gaining better quality effluents. Singh *et al.* (2017) documented 78%–98% BOD and 64%–95% COD removal efficiency by this method with HRT of 2–9 h. Addy *et al.* (2019) showed that this VBF technique had the capability to remove different types of bacteria (like *E. coli*) and fungi (like *Aspergillus*) by 68%–98% from raw influent.

Land treatment methods

Taebi & Droste (2008) used evaluated OF systems at pilot-scale level. Each pilot was operated for eight months. Treatment of primary effluent, activated sludge secondary effluent, and lagoon effluent of wastewater were investigated at application rates of 0.15, 0.25, and 0.35 $m^3\,m^{-1}\,h^{-1}$. During five months of stable operation after a three-month adaptation period, mean removals of BOD_5 and COD were 74.5% and 54.8% for primary effluent; 52.9% for activated sludge effluent; 65.7% and 58.7% for lagoon effluent, respectively. The constructed rapid infiltration system (CRIS) is a reasonable option for treating wastewater, owing to its simplicity, low cost and low energy consumption (Zhang *et al.* 2016). However, the RI system has a difficulty with blockage due to usage of natural soil as a filtration medium, and a low hydraulic loading rate (HLR), etc. (Su *et al.* 2020). The SAT, an environmentally friendly and robust multi-contaminant removal system, is effective in removing pathogens, nitrogen, bulk organic matter and the majority of organic micro-pollutants. The contaminant removal efficiency of the SAT system depends on source water quality, local hydro-geological conditions and process conditions. The SAT system performance can be improved by proper site selection and appropriate design of its components including pre- and post-treatment. SAT serves as an environmental and psychological barrier for water use applications (Sharma & Kennedy 2017).

Suitability of treated sewage for agricultural irrigation

Biswas *et al.* (2015) tested the quality of low-cost technique treated municipal wastewater for irrigation purposes. Low-cost filtering materials like sand, wood dust, rice husks, brick chips, charcoal and gravel were used in the study. The EC and TDS levels in the effluent were acceptable for use in irrigation. However, the pH level was not allowable according to the FAO. Heavy metal removal percentages varied from 46% to 95% depending on the type of filtering media as well as heavy metal. The maximum amount of Cu and Zn was absorbed by wood charcoal, As and Pb by sawdust, Cu and Mn by sand and Fe by gravel. However, As and Pb exceeded their safe limits for irrigation. The treated effluent was concluded to be suitable for agricultural irrigation with some restrictions. Moghadam *et al.* (2015) investigated potential salinity, soluble sodium percentage (SSP) and sodium adsorption ratio (SAR) through application of treated wastewater for irrigation. In this study the SAR and SSP for effluent were 2.62 and 39.7%, respectively. According to the FAO, these were excellent for irrigation. Potential salinity of 4.81 meq/l showed the medium suitability of the treated water for irrigation. Along with these, the 1,250 μS/cm EC value of the effluent illustrated that the treated water was permissible for irrigation. According to Jasim *et al.* (2016), properly treated sewage water was able to promote soil enrichment due to the possible presence of essential macro- and micro-nutrients like nitrogen, phosphorus, potassium, iron, manganese, zinc, copper etc. The treated sewage could play a key role in agricultural fields by improving soil condition as well as plant biological health with reduced use of additional chemical fertilisers. The reduction in chemical fertiliser addition minimised the environmental pollution related to chemical run-off. Gatta *et al.* (2018) experimented with secondary and tertiary treated municipal wastewater to assess soil and artichoke crop heavy metal content with human risks. The study illustrated that the heavy metal contents of the crops harvested after irrigation were less than the international threshold values and small bioaccumulation factors suggested that these heavy metals did not accumulate in the edible part of the crop. The hazard indices that were based on the consumption of the artichoke heads remained less than 1.0 for both adults and children, thus indicating that the health risks involving the different heavy metals were not considerable. Da Silva Júnior *et al.* (2019) documented that irrigation with treated sewage effluents added 10 kg ha^{-1} total nitrogen and potassium along with 0.50 kg ha^{-1} total phosphate to the soil, providing better productivity of pepper than that from irrigation with river water. Tripathi *et al.* (2019) obtained reduced total coliforms (12%–20%) and *E. coli* (15%–25%) populations when evaluated against untreated wastewater in vegetable cultivation. Singh *et al.* (2020) investigated the incidence of *E. coli* (35 ± 2.66 and 25 ± 2.26 colony forming units (CFU) g^{-1}) in cauliflower, bitter gourd and soil profile irrigated with treated municipal wastewater in a semi-arid peri-urban area of India. Along with the proper treatment, optimum storage time of treated sewage water within a reservoir is also essential to remove BOD, detergents, and heavy metals as well as coliforms quite effectively. A system of more than two reservoirs either in series or in parallel (depending on regions) can reduce 90% of the BOD and detergents, and five orders of magnitude of faecal coliforms. Therefore, the reservoir should be considered an integral part of the wastewater treatment system and not merely an operative ponding volume for irrigation.

Global average water footprints of a few different agricultural crops

The global average water footprints of different agricultural crops (Mekonnen & Hoekstra 2014) are presented in Table 2.

Hoekstra *et al.* (2012) improved upon previous works by assessment of BWFs (consumptive use of surface and groundwater flows) rather than water withdrawals, accounting for the flows required to maintain essential ecological

Table 2 | Global average water footprints of a few different agricultural crops

Agricultural crops	CWF (m^3 t^{-1})	GrWF (m^3 t^{-1})	TWF (m^3 t^{-1})
Paddy	1,486	187	1,673
Wheat	1,620	208	1,828
Potatoes	224	63	287
Maize	1,028	194	1,222
Cotton	3,589	440	4,029
Sorghum	2,960	87	3,047
Millet	4,363	115	4,478
Sugarcane	197	13	210
Barley	1,292	131	1,423
Soybean	2,107	37	2,144

functions and by taking into consideration monthly rather than yearly values. The study explored 405 river basins for the period 1996–2005 and concluded that in 201 basins with 2.67 billion inhabitants there was severe water scarcity during at least one month of the year. The ecological and economic consequences of rising degrees of water shortage – as proved by the Rio Grande (Rio Bravo), Murray-Darling and Indus River Basins – could be complete aridity in dry seasons, decimation of aquatic biodiversity, and considerable economic disorder. Some recent studies such as Schyns *et al.* (2019), Hogeboom *et al.* (2020) and Xie *et al.* (2020) also documented that several regions including India, Central America, the Middle East and Southern Europe are subject to severe green and blue water scarcities. Under such circumstances, an alternative water source like properly treated municipal wastewater can play a significant role in fulfilling total crop WFs (Table 2) in the future. Some water-saving irrigation technologies like drip irrigation (Yimam *et al.* 2020) and alternate wetting and drying (Biswas & Mailapalli 2019) are already available to reduce crop WFs. In addition to those water-saving irrigation practices, application of treated municipal wastewater will reduce the pressure on freshwater resources to meet WFs of different agricultural crops.

CONCLUSIONS

The present review study was accomplished with some wastewater treatment methods' performances for removal of chemical and biological contaminants from municipal wastewater. Along with these, the suitability and essentiality of treated water for agricultural irrigation and water footprints were discussed in this study. Positive responses of some pilot-scale studies showed a ray of hope for mitigating the problem of freshwater scarcities in the agricultural sector in the future. Some techniques like land treatment methods and VBF were found to be equally attractive in developed as well as developing nations. This review indicated that the reservoir for treated water should be considered an integral part of the wastewater treatment system and not merely an operative ponding volume for irrigation. The green and blue water shortages in some large river basins are quite obvious for the future. Hence, the application of treated water for agricultural irrigation purposes can play an important role in fulfilling required crop water footprints in the future by mitigating global green and blue water scarcities.

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DATA AVAILABILITY STATEMENT

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

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