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Wastewater Treatment and Reuse: a Review of its Applications and Health Implications

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Abstract Water scarcity is one of the major problems in the world and millions of people have no access to freshwater. Untreated wastewater is widely used for agriculture in many countries. This is one of the world-leading serious environmental and public health concerns. Instead of using untreated wastewater, treated wastewater has been found more applicable and ecofriendly option. Moreover, environmental toxicity due to solid waste exposures is also one of the leading health concerns. Therefore, intending to combat the problems associated with the use of untreated wastewater, we propose in this review a multidisciplinary approach to handle wastewater as a potential resource for use in agriculture. We propose a model showing the efficient methods for wastewater treatment and the utilization of solid wastes in fertilizers. The study also points out the associated health concern for farmers, who are working in wastewater-irrigated fields along with the harmful effects of untreated wastewater. The consumption of crop irrigated by wastewater has leading health implications also discussed in this review paper. This review further reveals that our current understanding of the wastewater treatment and use in agriculture with addressing advancements in treatment methods has great future possibilities.

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1 Introduction

Rapidly depleting and elevating the level of freshwater demand, though wastewater reclamation or reuse is one of the most important necessities of the current scenario. Total water consumption worldwide for agriculture accounts 92% (Clemmens et al., 2008; Hoekstra & Mekonnen, 2012; Tanji & Kielen, 2002). Out of which about 70% of freshwater is used for irrigation (WRI, 2020), which comes from the rivers and underground water sources (Pedrero et al., 2010). The statistics shows serious concern for the countries facing water crisis. Shen et al. (2014) reported that 40% of the global population is situated in heavy water–stressed basins, which represents the water crisis for irrigation. Therefore, wastewater reuse in agriculture is an ideal resource to replace freshwater use in agriculture (Contreras et al., 2017). Treated wastewater is generally applied for non-potable purposes, like agriculture, land, irrigation, groundwater recharge, golf course irrigation, vehicle washing, toilet flushes, firefighting, and building construction activities. It can also be used for cooling purposes in thermal power plants (Katsoyiannis et al., 2017; Mohsen, 2004; Smith, 1995; Yang et al., 2017). At global level, treated wastewater irrigation supports agricultural yield and the livelihoods of millions of smallholder farmers (Sato et al., 2013). Global reuse of treated wastewater for agricultural purposes shows wide variability ranging from 1.5 to 6.6% (Sato et al., 2013; Ungureanu et al., 2018). More than 10% of the global population consumes agriculture-based products, which are cultivated by wastewater irrigation (WHO, 2006). Treated wastewater reuse has experienced very rapid growth and the volumes have been increased ~10 to 29% per year in Europe, the USA, China, and up to 41% in Australia (Aziz & Farissi, 2014). China stands out as the leading country in Asia for the reuse of wastewater with an estimated 1.3 M ha area including Vietnam, India, and Pakistan (Zhang & Shen, 2017). Presently, it has been estimated that, only 37.6% of the urban wastewater in India is getting treated (Singh et al., 2019). By utilizing 90% of reclaimed water, Israel is the largest user of treated wastewater for agriculture land irrigation (Angelakis & Snyder, 2015). The detail information related to the utilization of freshwater and treated wastewater is compiled in Table 1.

Many low-income countries in Africa, Asia, and Latin America use untreated wastewater as a source of irrigation (Jiménez & Asano, 2008). On the other hand, middle-income countries, such as Tunisia, Jordan, and Saudi Arabia, use treated wastewater for irrigation (Al-Nakshabandi et al., 1997; Balkhair, 2016a; Balkhair, 2016b; Qadir et al., 2010; Sato et al., 2013).

Domestic water and treated wastewater contains various type of nutrients such as phosphorus, nitrogen, potassium, and sulfur, but the major amount of nitrogen and phosphorous available in wastewater can be easily accumulated by the plants, that's why it is widely used for the irrigation (Drechsel et al., 2010; Duncan, 2009; Poustie et al., 2020; Sengupta et al., 2015). The rich availability of nutrients in reclaimed wastewater reduces the use of fertilizers, increases crop productivity, improves soil fertility, and at the same time, it may also decrease the cost of crop production (Chen et al., 2013a; Jeong et al., 2016). The data of high nutritional values in treated wastewater is shown in Fig. 1.

Wastewater reuse for crop irrigation showed several health concerns (Ungureanu et al., 2020). Irrigation with the industrial wastewater either directly or mixing with domestic water showed higher risk (Chen et al., 2013). Risk factors are higher due to heavy metal and pathogens contamination because heavy metals are non-biodegradable and have a long biological half-life (Chaoua et al., 2019; WHO, 2006). It contains several toxic elements, i.e., Cu, Cr, Mn, Fe, Pb, Zn, and Ni (Mahfooz et al., 2020). These heavy metals accumulate in topsoil (at a depth of 20 cm) and sourcing through plant roots; they enter the human and animal body through leafy vegetables consumption and inhalation of contaminated soils (Mahmood et al., 2014). Therefore, health risk assessment of such wastewater irrigation is important especially in adults (Mehmood et al., 2019; Njuguna et al., 2019; Xiao et al., 2017). For this, an advanced wastewater treatment method should be applied before release of wastewater in the river, agriculture land, and soils. Therefore, this review also proposed an advance wastewater treatment model, which has been tasted partially at laboratory scale by Kesari and Behari (2008), Kesari et al. (2011a, b), and Kumar et al. (2010).

For a decade, reuse of wastewater has also become one of the global health concerns linking to public health and the environment (Dang et al., 2019; Narain et al., 2020). The World Health Organization (WHO)

Table 1 Freshwater and treated wastewater utilization status in different countries

Country	Water utilizing sectors		Status of water reuse (major sectors reusing water)		Reference
Europe	Agriculture	44%	Landscape irrigation	20%	EEA CSI, 2018; GWI/PUB Water Reuse Inventory, 2009
			Groundwater Recharge	2.2%	
			Recreational	6.8%	
	Industry and energy production	40%	Non-potable urban uses	8.3%	
			Indirect potable uses	2.3%	
			Agriculture irrigation	32%	
	Public water supply	16%	Industrial	19.3%	
			Environmental Enhancement	8%	
			Other	1.5%	
South Africa	Agriculture	60%	Landscape and sports field irrigation	9%	Adewumia et al., 2010; CoCT, 2007
	Domestic	27%			
	Industrial	3%	Industry	48%	
	Power	4%			
	Mining	3%	Agriculture	43%	
	Other	3%			
USA	Freshwater thermoelectric plants	41%	Agricultural irrigation	37%	Kenny et al., 2009; SWRCB, 2011
	Agricultural irrigation	37%	Geothermal energy	2%	
	Industries	6%	Golf course irrigation	7%	
	Domestic	14%	Landscape irrigation	17%	
	Livestock and aquaculture	3%	Groundwater recharge	12%	
			Seawater intrusion barrier	7%	
			Recreational impoundment	4%	
			Wetlands, wildlife habitat	4%	
			Industrial and commercial	8%	
			Other	2%	
India	Agriculture	87%	Agricultural irrigation	78%	Jindal & Kamat, 2011
	Industrial	7%	Industrial use	12%	
	Domestic	4%	Thermal power plant	4%	
	Energy	2%	Groundwater recharge and artificial lakes	6%	
Greece	Irrigation	83	Agricultural irrigation	58.38	Frontistis et al., 2011; Tsagarakis et al., 2001
	Animal husbandry	1.3	Irrigation of forested land and firefighting	17.7	
	Industry	2.2	Landscape irrigation	23.92	
	Public use (potable)	13			
	Other	1.2			

drafted guidelines in 1973 to protect the public health by facilitating the conditions for the use of wastewater and excreta in agriculture and aquaculture (WHO, 1973). Later in 2005, the initial guidelines were drafted in the absence of epidemiological studies with minimal risk approach (Carr, 2005). Although, Adegoke et al. (2018) reviewed the epidemiological shreds of evidence and health risks associated with reuse of wastewater for irrigation. Wastewater or graywater reuse has adverse health risks associated with microbial hazards (i.e., infectious pathogens) and chemicals or pharmaceuticals exposures (Adegoke et al., 2016; Adegoke et al., 2017; Busgang et al., 2018; Marcussen et al., 2007; Panthi et al., 2019). Researchers have reported that the exposure to wastewater may cause infectious (helminth infection) diseases, which are linked to anemia and impaired physical and cognitive development (Amoah et al., 2018; Bos et al., 2010; Pham-Duc et al., 2014; WHO, 2006).

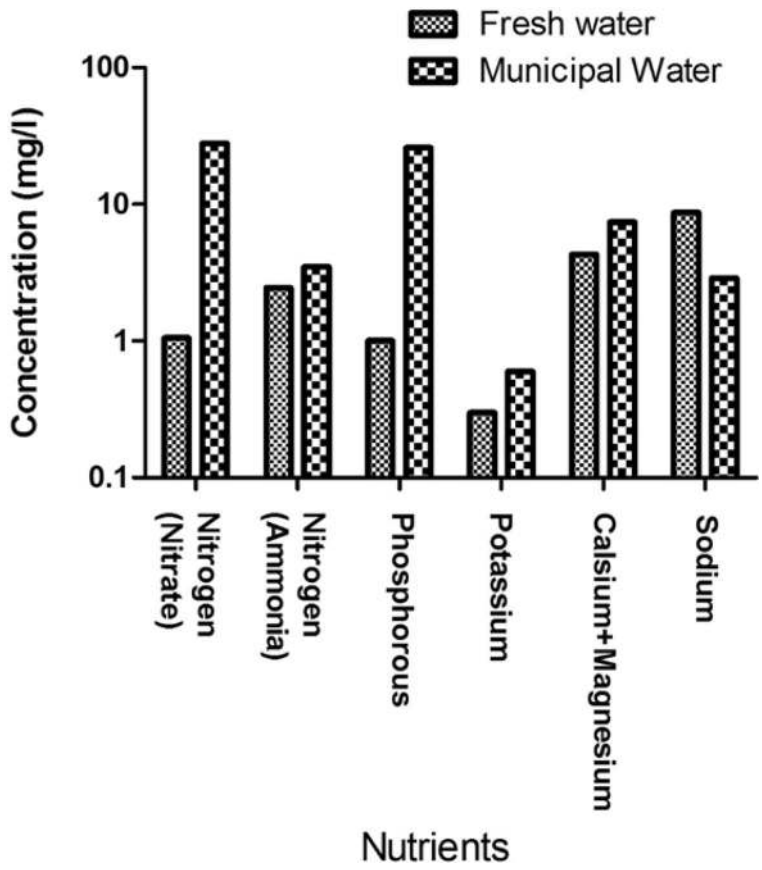

Fig. 1 Nutrient concentrations (mg/L) of freshwater/wastewater (Yadav et al., 2002)

Owing to an increasing population and a growing imbalance in the demand and supply of water, the use of wastewater has been expected to increase in the coming years (World Bank, 2010). The use of treated wastewater in developed nations follows strict rules and regulations. However, the direct use of untreated wastewater without any sound regulatory policies is evident in developing nations, which leads to serious environmental and public health concerns (Dickin et al., 2016). Because of these issues, we present in this review, a brief discussion on the risk associated with the untreated wastewater exposures and advanced methods for its treatment, reuse possibilities of the treated wastewater in agriculture.

2 Environmental Toxicity of Untreated Wastewater

Treated wastewater carries larger applicability such as irrigation, groundwater recharge, toilet flushing, and firefighting. Municipal wastewater treatment plants (WWTPs) are the major collection point for the different toxic elements, pathogenic microorganisms, and heavy metals. It collects wastewater from divergent sources like household sewage, industrial, clinical or hospital wastewater, and urban runoff (Soni et al., 2020). Alghobar et al. (2014) reported that grass and crops irrigated with sewage and treated wastewater are rich in heavy metals in comparison with groundwater (GW) irrigation. Although, heavy metals classified as toxic elements and listed as cadmium, lead, mercury, copper, and iron. An exceeding dose or exposures of these heavy metals could be hazardous for health (Duan et al., 2017) and ecological risks (Tytła, 2019). The major sources of these heavy metals come from drinking water. This might be due to the release of wastewater into river or through soil contamination reaches to ground water. Table 2 presenting the permissible limits of heavy metals presented in drinking water and its impact on human health after an exceeding the amount in drinking water, along with the route of exposure of heavy metals to human body.

Table 2 Total permissible limits of heavy metals in drinking water and diseases associated with the surplus amount

Heavy metals polluting the water quality	Permissible limits in drinking water according to WHO (mg/L)	Permissible limits in effluent water according to WHO (mg/L)	Diseases associated with the excess amount	Exposure routes	References
Arsenic	0.01	5.0	Skin, lung, bladder, kidney cancer, skin manifestations, gastrointestinal disorders, neurological effects, hormone disruption and infertility, psoriasis	Inhalation and ingestion	Kinuthia et al. (2020) Kumar et al. (2021); Punshon et al. (2017); Jyothi (2020)
Cadmium	0.005	0.003	Psychological disorders, gastrointestinal disorders, central nervous system complications, immune system deficiencies, DNA impairment, cancer, Itai-itai disease, osteoporosis, respiratory disease	Ingestion of contaminated food and water and, to a significant extent, through inhalation and cigarette smoking	Kinuthia et al. (2020); Briffa et al. (2020); Zhang and Reynolds (2019); Genchi et al. (2020); Jyothi (2020)
Chromium	0.1	0.05	Gastrointestinal ulceration, nausea and vomiting, fever, diarrhea, toxic nephritis, liver damage, gingivitis, bronchitis, pneumonia, lung cancer	Inhalation and ingestion	Kinuthia et al. (2020); Briffa et al. (2020); Jyothi (2020)
Iron	1.0	2.0	Genetic disorder, hemorrhagic necrosis	Ingestion	Yuen and Becker (2020); Jaishankar et al., 2014; EPA 2002.
Lead	0.01	0.05	Hypertension, miscarriages, premature and low births, renal impairment, brain injury, abdominal pain	Inhalation through the nose and ingestion through drinking water and soil	Wani et al. (2015); Goel et al. (2005); Kinuthia et al. (2020); Briffa et al. (2020); Jyothi (2020),
Mercury	0.006	0.001	Down's syndrome, affects the reproductive system, speech defects, memory loss, tremors and muscle incoordination, deafness, vision complication	Inhalation, ingestion and dermal contact	Kinuthia et al. (2020); Briffa et al. (2020); Jyothi and Farook (2020).
Copper	2.0	0.25	Insomnia, anxiety, agitation, restlessness, fatigue, jaundice, dizziness	Ingestion	Sharma et al. (2012); Briffa et al. (2020); WHO 2003 Taylor et al. (2020). (Agoro et al., 2020)
Nickel	0.07	0.02	Lung embolisms, asthma, respiratory failure, heart disorders, dizziness, increased possibilities of cancer	Inhalation and ingestion	Kinuthia et al. (2020); Briffa et al. (2020); Jyothi (2020)

Direct release in river or reuse of wastewater for irrigation purposes may create short-term implications like heavy metal and microbial contamination and pathogenic interaction in soil and crops. It has also long-term influence like soil salinity, which grows with regular use of untreated wastewater (Smith, 1995). Improper use of wastewater for irrigation makes it unsafe and environment threatening. Irrigation with several different types of wastewater, i.e., industrial effluents, municipal and agricultural wastewaters, and sewage liquid sludge transfers the heavy metals to the soil, which leads to accumulation in crops due to improper practices. This has been identified as a significant route of heavy metals into aquatic resources (Agoro et al., 2020). Hussain et al.

(2019) investigated the concentration of heavy metals (except for Cd) was higher in the soil irrigated with treated wastewater (large-scale sewage treatment plant) than the normal ground water, also reported by Khaskhoussy et al. (2015).

In other words, irrigation with wastewater mitigates the quality of crops and enhances health risks. Excess amount of copper causes anemia, liver and kidney damage, vomiting, headache, and nausea in children (Bent & Bohm, 1995; Madsen et al., 1990; Salem et al., 2000). A higher concentration of arsenic may lead to bone and kidney cancer (Jarup, 2003) and results in osteopenia or osteoporosis (Puzas et al., 2004). Cadmium gives rise to musculoskeletal diseases (Fukushima et al., 1970), whereas mercury directly affects the nervous system (Azevedo et al., 2014).

3 Spread of Antibiotic Resistance

Currently, antibiotics are highly used for human disease treatment; however, uses in poultries, animal husbandries, biochemical industries, and agriculture are common practices these days. Extensive use and/or misuse of antibiotics have given rise to multi-resistant bacteria, which carry multiple resistance genes (Icgen & Yilmaz, 2014; Lv et al., 2015; Tripathi & Tripathi, 2017; Xu et al., 2017). These multidrug-resistant bacteria discharged through the sewage network and get collected into the wastewater treatment plants. Therefore, it can be inferred that the WWTPs serve as the hotspot of antibiotic-resistant bacteria (ARB) and antibiotic resistance genes (ARGs). Though, these antibiotic-resistant bacteria can be disseminated to the different bacterial species through the mobile genetic elements and horizontal gene transfer (Gupta et al., 2018). Previous studies indicated that certain pathogens might survive in wastewater, even during and after the treatment processes, including methicillin-resistant *Staphylococcus aureus* (MRSA) and vancomycin-resistant *enterococci* (VRE) (Börjesson et al., 2009; Caplin et al., 2008). The use of treated wastewater in irrigation provides favorable conditions for the growth and persistence of total coliforms and fecal coliforms (Akponikpe et al., 2011; Sacks & Bernstein, 2011). Furthermore, few studies have also reported the presence of various bacterial pathogens, such as *Clostridium*, *Salmonella*, *Streptococci*, Viruses, Protozoa, and Helminths in crops irrigated with treated wastewater (Carey et al., 2004; Mañas et al., 2009; Samie et al., 2009). Goldstein (2013) investigated the survival of ARB in secondary treated wastewater and proved that it causes serious health risks to the individuals, who are exposed to reclaimed water. The U.S. Centers for Disease Control and Prevention (CDC) and the World Health Organization (WHO) have already declared the ARBs as the imminent hazard to human health. According to the list published by WHO, regarding the development of new antimicrobial agents, the ESKAPE (*Enterococcus faecium*, *S. aureus*, *Klebsiella pneumoniae*, *Acinetobacter baumannii*, *Pseudomonas aeruginosa*, and *Enterobacter* species) pathogens were designated to be "priority status" as their occurrence in the food chain is considered as the potential and major threat for the human health (Tacconelli et al., 2018).

These ESKAPE pathogens have acquired the multi drug resistance mechanisms against oxazolidinones, lipopeptides, macrolides, fluoroquinolones, tetracyclines, β-lactams, β-lactam–β-lactamase inhibitor combinations, and even those antibiotics that are considered as the last line of defense, including carbapenems and glycopeptides (Giddins et al., 2017; Herc et al., 2017; Iguchi et al., 2016; Naylor et al., 2018; Zaman et al., 2017), by the means of genetic mutation and mobile genetic elements. These cluster of ESKAPE pathogens are mainly responsible for lethal nosocomial infections (Founou et al., 2017; Santajit & Indrawattana, 2016).

Due to the wide application of antibiotics in animal husbandry and inefficient capability of wastewater treatment plants, the multidrug-resistant bacteria such as tetracyclines, sulfonamides, β-lactam, aminoglycoside, colistin, and vancomycin in major are disseminated in the receiving water bodies, which ultimately results in the accumulation of ARGs in the irrigated crops (He et al., 2020).

4 Toxic Contaminations in Wastewater Impacting Human Health

The release of untreated wastewater into the river may pose serious health implications (König et al., 2017; Odigie, 2014; Westcot, 1997). It has been already discussed about the household and municipal sewage which contains a major amount of organic materials and pathogenic microorganisms and these infectious microorganisms are capable of spreading various diseases like typhoid, dysentery, diarrhea, vomiting, and

malabsorption (Jia & Zhang, 2020; Numberger et al., 2019; Soni et al., 2020). Additionally, pharmaceutical industries also play a key role in the regulation and discharge of biologically toxic agents. The untreated wastewater also contains a group of contaminants, which are toxic to humans. These toxic contaminations have been classified into two major groups: (i) chemical contamination and (ii) microbial contamination.

4.1 Chemical Contamination

Mostly, various types of chemical compounds released from industries, tanneries, workshops, irrigated lands, and household wastewaters are responsible for several diseases. These contaminants can be organic materials, hydrocarbons, volatile compounds, pesticides, and heavy metals. Exposure to such contaminants may cause infectious diseases like chronic dermatoses and skin cancer, lung infection, and eye irritation. Most of them are non-biodegradable and intractable. Therefore, they can persist in the water bodies for a very long period and could be easily accumulated in our food chain system. Several pharmaceutical personal care products (PPCPs) and surfactants are available that may contain toxic compounds like nonylphenol, estrone, estradiol, and ethinylestradiol. These compounds are endocrine-disrupting chemicals (Bolong et al., 2009), and the existence of these compounds in the human body even in the trace amounts can be highly hazardous. Also, the occurrence of perfluorinated compounds (PFCs) in wastewater, which is toxic in nature, has been significantly reported worldwide (Templeton et al., 2009). Furthermore, PFCs cause severe health menaces like pre-eclampsia, birth defects, reduced human fertility (Webster, 2010), immunotoxicity (Dewitt et al., 2012), neurotoxicity (Lee & Viberg, 2013), and carcinogenesis (Bonefeld-Jorgensen et al., 2011).

4.2 Microbial Contamination

Researchers have reported serious health risks associated with the microbial contaminants in untreated wastewater. The diverse group of microorganisms causes severe health implications like campylobacteriosis, diarrhea, encephalitis, typhoid, giardiasis, hepatitis A, poliomyelitis, salmonellosis, and gastroenteritis (ISDH, 2009; Okoh et al., 2010). Few bacterial species like *P. aeruginosa*, *Salmonella typhimurium*, *Vibrio cholerae*, *G. intestinales*, *Legionella* spp., *E. coli*, *Shigella sonnei* have been reported for the spreading of waterborne diseases, and acute illness in human being (Craun et al., 2006; Craun et al., 2010). These aforementioned microorganisms may release in the environment from municipal sewage water network, animal husbandries, or hospitals and enter the food chain via public water supply systems.

5 Wastewater Impact on Agriculture

The agriculture sector is well known for the largest user of water, accounting for nearly 70% of global water usage (Winpenny et al., 2010). The fact that an estimated 20 million hectares worldwide are irrigated with wastewater suggests a major source for irrigation (Ecosse, 2001). However, maximum wastewater that is used for irrigation is untreated (Jiménez & Asano, 2008; Scott et al., 2004). Mostly in developing countries, partially treated or untreated wastewater is used for irrigation purpose (Scott et al., 2009). Untreated wastewater often contains a large range of chemical contaminants from waste sites, chemical wastes from industrial discharges, heavy metals, fertilizers, textile, leather, paper, sewage waste, food processing waste, and pesticides. World Health Organization (WHO) has warned significant health implications due to the direct use of wastewater for irrigation purposes (WHO, 2006). These contaminants pose health risks to communities (farmers, agricultural workers, their families, and the consumers of wastewater-irrigated crops) living in the proximity of wastewater sources and areas irrigated with untreated wastewater (Qadir et al., 2010). Wastewater also contains a wide variety of organic compounds. Some of them are toxic or cancer-causing and have harmful effects on an embryo (Jarup, 2003; Shakir et al., 2016). The pathway of untreated wastewater used in irrigation and associated health effects are shown in Fig. 2.

Alternatively, in developing countries, due to the limited availability of treatment facilities, untreated wastewater is discharged into the existing waterbodies (Qadir et al., 2010). The direct use of wastewater in agriculture or irrigation obstructs the growth of natural plants and grasses, which in turn causes the loss of biodiversity. Shuval et al. (1985) reported one of the earliest evidences connecting to agricultural wastewater reuse with the occurrence of diseases. Application of untreated wastewater in irrigation increases soil salinity, land sealing followed by sodium accumulation, which

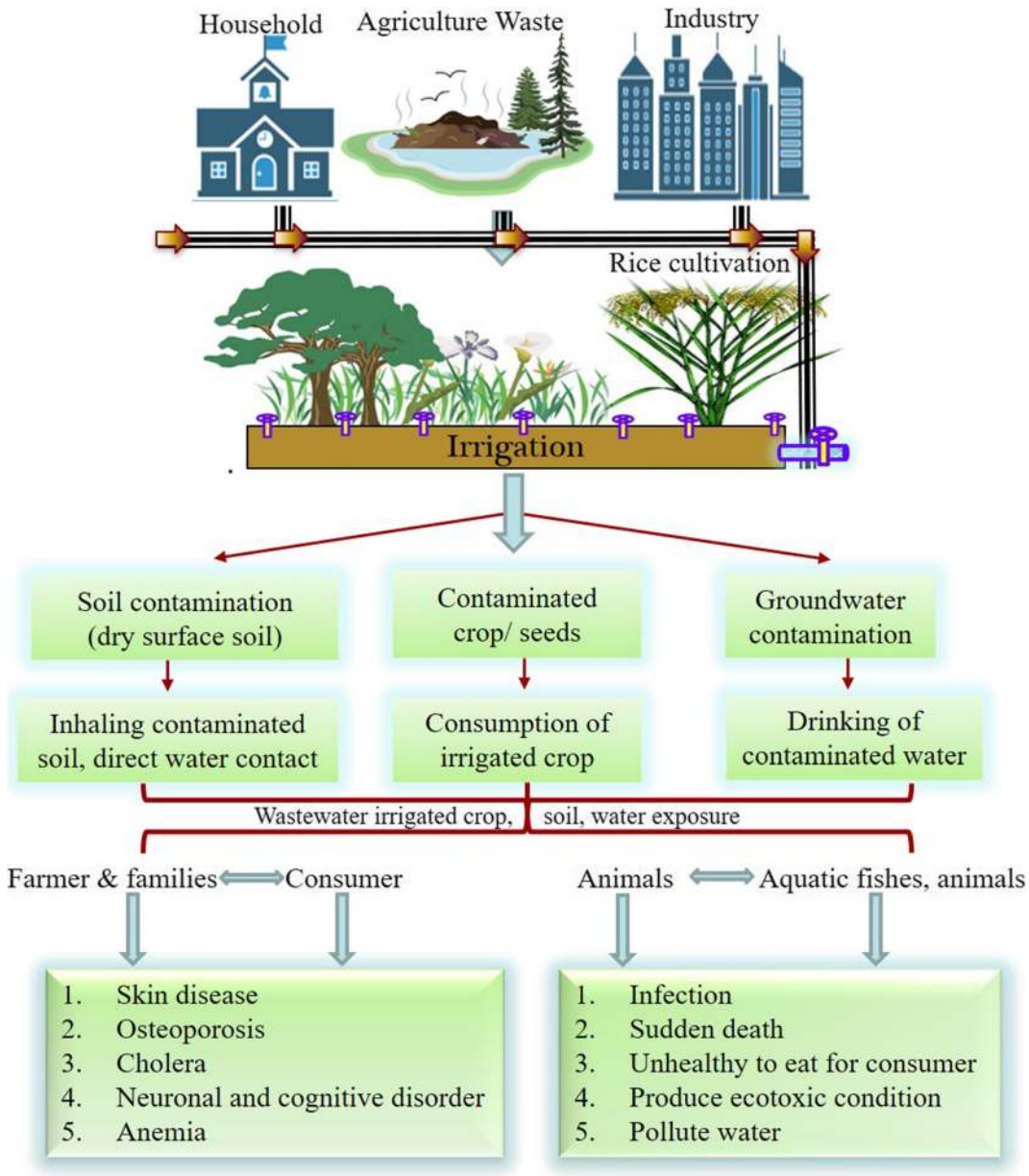

Fig. 2 Exposure pathway representing serious health concerns from wastewater-irrigated crops

results in soil erosion. Increased soil salinity and sodium accumulation deteriorates the soil and decreases the soil permeability, which inhibits the nutrients intake of crops from the soil. These causes have been considered the long-term impact of wastewater reuse in agriculture (Halliwell et al., 2001). Moreover, wastewater contaminated soils are a major source of intestinal parasites (helminths—nematodes and tapeworms) that are transmitted through the fecal–oral route (Toze, 1997). Already known, the helminth infections are linked to blood deficiency and behavioral or cognitive development (Bos et al., 2010). One of the major sources of helminth infections around the world is the use of raw or partially treated sewage effluent and sludge for the irrigation of food crops (WHO, 1989). Wastewater-irrigated crops contain heavy metal contamination, which originates from mining, foundries, and metal-based industries (Fazeli et al., 1998). Exposure to heavy

metals including arsenic, cadmium, lead, and mercury in wastewater-irrigated crops is a cause for various health problems. For example, the consumption of high amounts of cadmium causes osteoporosis in humans (Dickin et al., 2016). The uptake of heavy metals by the rice crop irrigated with untreated effluent from a paper mill has been reported to cause serious health concerns (Fazeli et al., 1998). Irrigating rice paddies with highly contaminated water containing heavy metals leads to the outbreak of Itai-itai disease in Japan (Jarup, 2003).

Owing to these widespread health risks, the WHO published the third edition of its guidelines for the safe use of wastewater in irrigating crops (WHO, 2006) and made recommendations for threshold contaminant levels in wastewater. The quality of wastewater for agricultural reuse have been classified based on the availability of nutrients, trace elements, microorganisms, and chemicals contamination levels. The level of contamination differs widely depending on the type of source, household sewage, pharmaceutical, chemical, paper, or textile industries effluents. The standard measures of water quality for irrigation are internationally reported (CCREM, 1987; FAO, 1985; FEPA, 1991; US EPA, 2004, 2012; WHO, 2006), where the recommended levels of trace elements, metals, COD, BOD, nitrogen, and phosphorus are set at certain limits. Researchers reviewed the status of wastewater reuse for agriculture, based on its standards and guidelines for water quality (Angelakis et al., 1999; Brissaud, 2008; Kalavrouziotis et al., 2015). Based on these recommendations and guidelines, it is evident that greater awareness is required for the treatment of wastewater safely.

6 Wastewater Treatment Techniques

6.1 Primary Treatment

This initial step is designed to remove gross, suspended and floating solids from raw wastewater. It includes screening to trap solid objects and sedimentation by gravity to remove suspended solids. This physical solid/liquid separation is a mechanical process, although chemicals can be used sometimes to accelerate the sedimentation process. This phase of the treatment reduces the BOD of the incoming wastewater by 20–30% and the total suspended solids by nearly 50–60%.

6.2 Secondary (Biological) Treatment

This stage helps eliminate the dissolved organic matter that escapes primary treatment. Microbes consume the organic matter as food, and converting it to carbondioxide, water, and energy for their own growth. Additional settling to remove more of the suspended solids then follows the biological process. Nearly 85% of the suspended solids and biological oxygen demand (BOD) can be removed with secondary treatment. This process also removes carbonaceous pollutants that settle down in the secondary settling tank, thus separating the biological sludge from the clear water. This sludge can be fed as a co-substrate with other wastes in a biogas plant to obtain biogas, a mixture of CH_4 and CO_2. It generates heat and electricity for further energy distribution. The leftover, clear water is then processed for nitrification or denitrification for the removal of carbon and nitrogen. Furthermore, the water is passed through a sedimentation basin for treatment with chlorine. At this stage, the water may still contain several types of microbial, chemical, and metal contaminations. Therefore, to make the water reusable, e.g., for irrigation, it further needs to pass through filtration and then into a disinfection tank. Here, sodium hypochlorite is used to disinfect the wastewater. After this process, the treated water is considered safe to use for irrigation purposes. Solid wastes generated during primary and secondary treatment processes are processed further in the gravity-thickening tank under a continuous supply of air. The solid waste is then passed into a centrifuge dewatering tank and finally to a lime stabilization tank. Treated solid waste is obtained at this stage and it can be processed further for several uses such as landfilling, fertilizers and as a building.

Other than the activated sludge process of wastewater treatment, there are several other methods developed and being used in full-scale reactors such as ponds (aerobic, anaerobic, facultative, and maturation), trickling filters, anaerobic treatments like up-flow *anaerobic* sludge blanket (UASB) reactors, artificial wetlands, microbial fuel cells, and methanogenic reactors.

UASB reactors are being applied for wastewater treatment from a very long period. Behling et al. (1996) examined the performance of the UASB reactor without any external heat supply. In their study, the COD loading rate was maintained at 1.21 kg COD/m^3/day, after 200 days of trial. They achieved an average of 85% of COD removal. Von-Sperling and Chernicharo

(2005) presented a combined model consisted of an Upflow Anaerobic Sludge Blanket-Activated Sludge reactor (UASB–AS system), using the low strength domestic wastewater with a BOD_5 amounting to 340 mg/l. Outcomes of their experiment have shown a 60% reduction in sludge construction and a 40% reduction in aeration energy consumption. In another experiment, Rizvi et al. (2015) seeded UASB reactor with cow manure dung to treat domestic wastewater; they observed 81%, 75%, and 76% reduction in COD, TSS, and total sulfate removal, respectively, in their results.

6.3 Tertiary or Advanced Treatment Processes

The tertiary treatment process is employed when specific constituents, substances, or contaminants cannot be completely removed after the secondary treatment process. The tertiary treatment processes, therefore, ensure that nearly 99% of all impurities are removed from wastewater. To make the treated water safe for drinking purposes, water is treated individually or in combination with advanced methods like the US (ultrasonication), UV (ultraviolet light treatment), and O_3 (exposure to ozone). This process helps to remove bacteria and heavy metal contaminations remaining in the treated water. For the purpose, the secondarily treated water is first made to undergo ultrasonication and it is subsequently exposed to UV light and passed through an ozone chamber for the complete removal of contaminations. The possible mechanisms by which cells are rendered inviable during the US include free-radical attack and physical disruption of cell membranes (Phull et al., 1997; Scherba et al., 1991). The combined treatment of US + UV + O_3 produces free radicals, which are attached to cell membranes of the biological contaminants. Once the cell membrane is sheared, chemical oxidants can enter the cell and attack internal structures. Thus, the US alone or in combination facilitates the deagglomeration of microorganisms and increases the efficiency of other chemical disinfectants (Hua & Thompson, 2000; Kesari et al., 2011a, b; Petrier et al., 1992; Phull et al., 1997; Scherba et al., 1991). A combined treatment method was also considered by Pesoutova et al. (2011) and reported a very effective method for textile wastewater treatment. The effectiveness of ultrasound application as a pre-treatment step in combination with ultraviolet rays (Blume & Neis, 2004; Naddeo et al., 2009), or also compared it with various other combinations of both ultrasound and UV radiation with TiO_2 photocatalysis (Paleologou et al., 2007), and ozone (Jyoti & Pandit, 2004) to optimize wastewater disinfection process.

An important aspect of our wastewater treatment model (Fig. 3) is that at each step of the treatment process, we recommend the measurement of the quality of treated water. After ensuring that the proper purification standards are met, the treated water can be made available for irrigation, drinking or other domestic uses.

6.4 Nanotechnology as Tertiary Treatment of Wastewater Converting Drinking Water Alike

Considering the emerging trends of nanotechnology, nanofillers can be used as a viable method for the tertiary treatment of wastewater. Due to the very small pore size, 1–5-nm nanofillers may eliminate the organic–inorganic pollutants, heavy metals, as well as pathogenic microorganisms and pharmaceutically active compounds (PhACs) (Mohammad et al., 2015; Vergili, 2013). Over the recent years, nanofillers have been largely accepted in the textile industry for the treatment of pulp bleaching pharmaceutical industry, dairy industry, microbial elimination, and removal of heavy metals from wastewater (Abdel-Fatah, 2018). Srivastava et al. (2004) synthesized very efficient and reusable water filters from carbon nanotubes, which exhibited effective elimination of bacterial pathogens (*E. coli* and *S. aureus*), and *Poliovirus sabin-1* from wastewater.

Nanofiltration requires lower operating pressure and lesser energy consumption in comparison of RO and higher rejection of organic compounds compared to UF. Therefore, it can be applied as the tertiary treatment of wastewater (Abdel-Fatah, 2018). Apart from nanofilters, there are various kinds of nanoparticles like metal nanoparticles, metal oxide nanoparticles, carbon nanotubes, graphene nanosheets, and polymer-based nanosorbents, which may play a different role in wastewater treatment based on their properties. Kocabas et al. (2012) analyzed the potential of different metal oxide nanoparticles and observed that nanopowders of TiO_2, FeO_3, ZnO_2, and NiO can exhibit the exceeding amount of removal of arsenate from wastewater. Cadmium contamination in wastewater, which poses a serious health risk, can be overcome by using ZnO nanoparticles (Kumar & Chawla, 2014). Latterly, Vélez et al. (2016) investigated that the 70% removal of mercury from wastewater through iron oxide nanoparticles

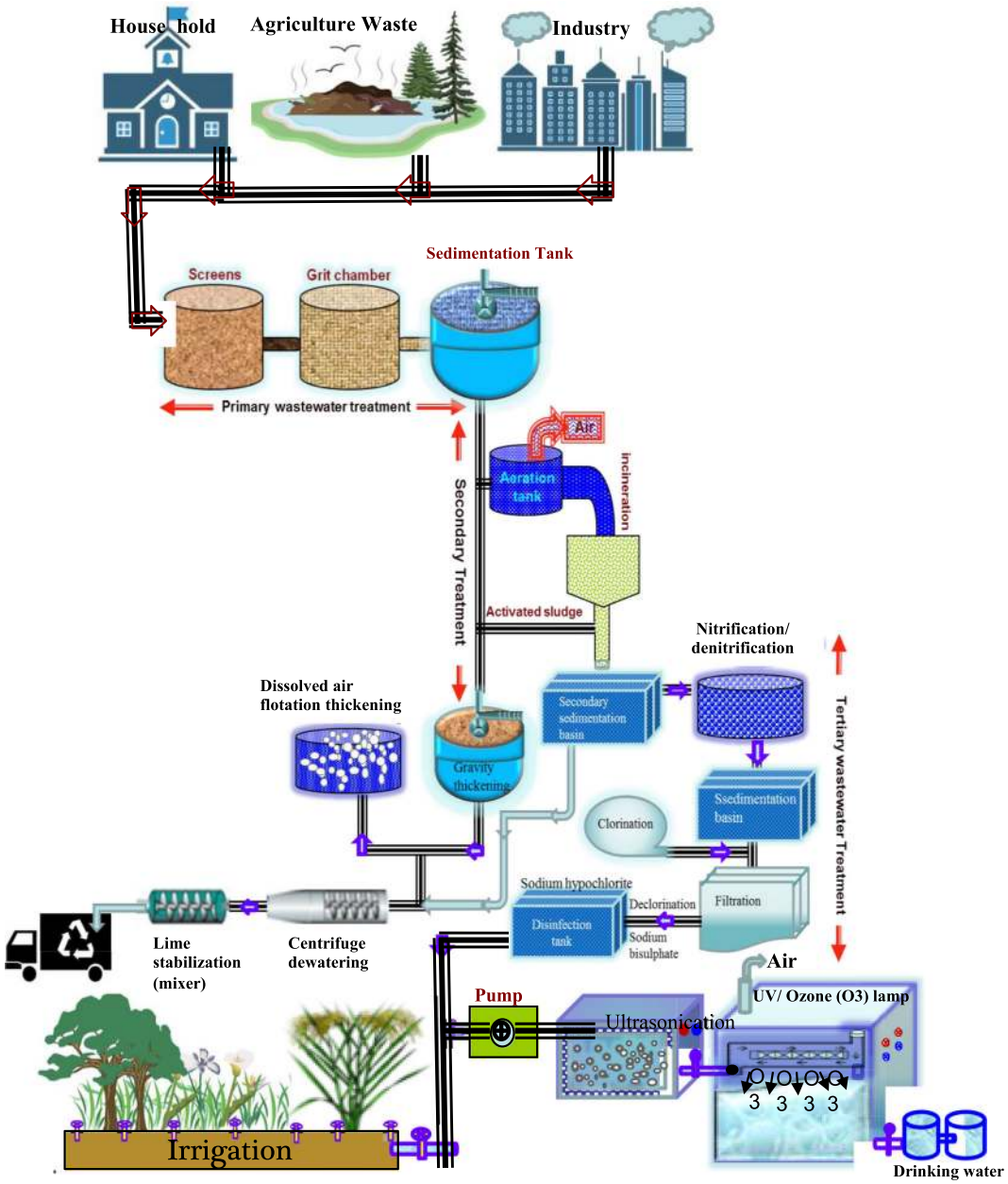

Fig. 3 A wastewater treatment schematic highlighting the various methods that result in a progressively improved quality of the wastewater from the source to the intended use of the treated wastewater for irrigation purposes

successfully performed. Sheet et al. (2014) used graphite oxide nanoparticles for the removal of nickel from wastewater. An exceeding amount of copper causes liver cirrhosis, anemia, liver, and kidney damage, which can be removed by carbon nanotubes, pyromellitic acid dianhydride (PMDA) and phenyl aminomethyl trimethoxysilane (PAMTMS) (Liu et al., 2010).

Nanomaterials are efficiently being used for microbial purification from wastewater. Carbon nanotubes (CNTs) are broadly applied for the treatment of wastewater contaminated with *E. coli*, *Salmonella*, and a wide range of microorganisms (Akasaka & Watari, 2009). In addition, silver nanoparticles reveal very effective results against the microorganisms present in wastewater.

Hence, it is extensively being used for microbial elimination from wastewater (Inoue et al., 2002). Moreover, CNTs exhibit high binding affinity to bacterial cells and possess magnetic properties (Pan & Xing, 2008). Melanta (2008) confirmed and recommended the applicability of CNTs for the removal of *E. coli* contamination from wastewater. Mostafaii et al. (2017) suggested that the ZnO nanoparticles could be the potential antibacterial agent for the removal of total coliform bacteria from municipal wastewater. Apart from the previously mentioned, applicability of the nanotechnology, the related drawbacks and challenges cannot be neglected. Most of the nanoengineered techniques are currently either in research scale or pilot scale performing well (Gehrke et al., 2015). Nevertheless, as discussed above, nanotechnology and nanomaterials exhibit exceptional properties for the removal of contaminants and purification of water. Therefore, it can be adapted as the prominent solution for the wastewater treatment (Zekić et al., 2018) and further use for drinking purposes.

6.5 Wastewater Treatment by Using Plant Species

Some of the naturally growing plants can be a potential source for wastewater treatment as they remove pollutants and contaminants by utilizing them as a nutrient source (Zimmels et al., 2004). Application of plant species in wastewater treatment may be cost-effective, energy-saving, and provides ease of operation. At the same time, it can be used as in situ, where the wastewater is being produced (Vogelmann et al., 2016). Nizam et al. (2020) analyzed the phytoremediation efficiency of five plant species (*Centella asiatica*, *Ipomoea aquatica*, *Salvinia molesta*, *Eichhornia crassipes*, and *Pistia stratiotes*) and achieved the drastic decrease in the amount of three pollutants viz. total suspended solids (TSS), ammoniacal nitrogen (NH_3-N), and phosphate levels. All the five species found to be efficient removal of the level of 63.9-98% of NH_3-N, TSS, and phosphate. Coleman et al. (2001) examined the physiological effects of domestic wastewater treatment by three common Appalachian plant species: common rush or soft rush (*Juncus effuses* L.), gray club-rush (*Scirpus Validus* L.), and broadleaf cattail or bulrush (*Typha latifolia* L.). They observed in their experiments about 70% of reduction in total suspended solids (TSS) and biochemical oxygen demand (BOD), 50% to 60% of reduction in nitrogen, ammonia, and phosphate levels, and a significant reduction in feacal coliform populations. Whereas, Zamora et al. (2019) found the removal efficiency of chemical oxygen demand (COD), total solids suspended (TSS), nitrogen as ammonium (N-NH_4) and nitrate (N-NO_3), and phosphate (P-PO_4) up to

Table 3 Various plant species applied for the wastewater remediation and their effects

S.N.	Plant species	Common name	Effects	References
1.	*Juncus effusus* L.	Common rush or soft rush	Reduction of BOD, COD, TSS, nitrogen, phosphate, and fecal coliforms	Coleman et al. (2001)
2.	*Scirpus validus* L.	Grey club-rush		
3.	*Typha latifolia* L.	Broadleaf cattail or bulrush		
4.	*Azolla californiana*	Fairy moss	Reduction of turbidity BOD, COD, and TSS	Jacquez and Walner (1985)
5.	*Oenanthe javanica*	Chinese celery, Indian pennywort, Japanese parsley,	Influences dissolved oxygen, pH, and temperature wastewater purification and nutrient uptake	Zhou and Wang (2010); Zhu et al. (2011)
6.	*Hydrocotyle vulgaris*	marsh pennywort	Removal of total nitrogen and NH_4^- nitrogen	Duan et al. (2016).
7.	*Ipomoea aquatica*	Swamp morning or water spinach		
8.	*Eichornia crassipes*	Water hyacinth	Reduction of ammonia, nitrate BOD, COD, TSS, turbidity, and heavy metals	Brumer (2000); Jacquez and Walner (1985)

20–60% higher using the three ornamental species of plants viz. *Canna indica*, *Cyperus papyrus*, and *Hedychium coronarium*. The list of various plant species applied for the wastewater treatment is shown in Table 3.

6.6 Wastewater Treatment by Using Microorganisms

There is a diverse group of bacteria like *Pseudomonas fluorescens*, *Pseudomonas putida*, and different *Bacillus* strains, which are capable to use in biological wastewater systems. These bacteria work in the cluster forms as a floc, biofilm, or granule during the wastewater treatment. Furthermore, after the recognition of bacterial exopolysaccharides (EPS) as an efficient adsorption material, it may be applied in a revolutionary manner for the heavy metal elimination (Gupta & Diwan, 2017). There are few examples of EPS, which are commercially available, i.e., alginate (*P. aeruginosa*, *Azotobacter vinelandii*), gellan *(Sphingomonas paucimobilis*), hyaluronan (. *aeruginosa*, *Pasteurella multocida*, *Streptococci attenuated strains*), xanthan *(Xanthomonas campestris*), and galactopol (*Pseudomonas oleovorans*) (Freitas et al., 2009; Freitas, Alves, & Reis, 2011a; Freitas, Alves, Torres, et al., 2011b). Similarly, Hesnawi et al. (2014) experimented biodegradation of municipal wastewater using local and commercial bacteria (Sludge Hammer), where they achieved a significant decrease in synthetic wastewater, i.e., 70%, 54%, 52%, 42% for the Sludge Hammer, *B. subtilis*, *B. laterosponus*, and *P. aeruginosa*, respectively. Therefore, based on the above studies, it can be concluded that bioaugmentation of wastewater treatment reactor with selective and mixed strains can ameliorate the treatment. During recent years, microalgae have attracted the attention of researchers as an alternative system, due to their applicability in wastewater treatment. Algae are the unicellular or multicellular photosynthetic microorganism that grows on water surfaces, salt water, or moist soil. They utilize the exceeding amount of nutrients like nitrogen, phosphorus, and carbon for their growth and metabolism process through their anaerobic system. This property of algae also inhibits eutrophication; that is to avoid over-deposit of nutrients in water bodies. During the nutrient digestion process, algae produce oxygen that is constructive for the heterotrophic aerobic bacteria, which may further be utilized to degrade the organic and inorganic pollutants. Kim et al. (2014) observed a total decrease in the levels of COD (86%), total nitrogen (93%), and total phosphorus (83%) after using algae in the municipal wastewater consortium. Nmaya et al. (2017) reported the heavy metal removal efficiency of microalga *Scenedesmus* sp. from contaminated river water in the Melaka River, Malaysia. They observed the effective removal of Zn (97-99%) on the 3rd and 7th day of the experiment. The categorized list of microorganisms used for wastewater treatment is presented in Table 4.

7 The Computational Approach in Wastewater Treatment

7.1 Bioinformatics and Genome Sequencing

A computational approach is accessible in wastewater treatment. Several tools and techniques are in use such as, sequencing platforms (Hall, 2007; Marsh, 2007), metagenome sequencing strategies (Schloss & Handelsman, 2005; Schmeisser et al., 2007; Tringe et al., 2005), bioinformatics tools and techniques (Chen & Pachter, 2005; Foerstner et al., 2006; Raes et al., 2007), and the genome analysis of complex microbial communities (Fig. 4). Most of the biological database contains microorganisms and taxonomical information. Thus, these can provide extensive details and supports for further utilization in wastewater treatment–related research and development (Siezen & Galardini, 2008). Balcom et al. (2016) explored that the microbial population residing in the plant roots immersed in the wastewater of an ecological WWTP and showed the evidence of the capacity for micro-pollutant biodegradation using whole metagenome sequencing (WMS). Similarly, Kumar et al. (2016) revealed that bioremediation of highly polluted wastewater from textile dyes by two novel strains were found to highly decolorize Joyfix Red. They were identified as *Lysinibacillus sphaericus* (KF032717) and *Aeromonas hydrophila* (KF032718) through 16S rDNA analysis. More recently, Leddy et al. (2018) reported that research scientists are making strides to advance the safety and application of potable water reuse with metagenomics for water quality analysis. The application of the bio-computational approach has also been implemented in the advancements of wastewater treatment and disease detection.

Table 4 Microorganisms applied for wastewater treatment

S.N.	Species	Effects	References
		Algae	
1.	*Scenedesmus* sp.	Removal of heavy metal (Zn) from wastewater	Nmaya et al. (2017)
2.	*Scenedesmus abundans*	Removal of Cd and Cu, detoxification of cyanide from wastewater.	Oilgae (2014)
3.	*Botryococcus braunii*	Removal of nitrogen, phosphorus, and other inorganic compounds from industrial wastewater	Oilgae (2014)
4.	*Dunaliella salina*	Eliminates Cu, Cd, Co, and Zn from polluted water, applied in the treatment of hypersaline wastewater	Oilgae (2014)
5.	*Sargassum muticum*	Removes Methylene Blue dye from wastewater.	Oilgae (2014)
6.	*Chlorella* sp.	Removal of lead (II), N, P, and detoxification of cyanide from wastewater	Oilgae (2014)
		Fungi	
1.	*Bjerkandera adusta* MUT 2295,	Effective in wastewater decolourisation and detoxification	Anastasi et al. (2010); Spina et al. (2012)
2.	*Phanerochaete chrysosporium* (white-rot fungi)	Degrade several aromatic compounds	Spina et al. (2012)
3.	*Trametes versicolor*	Wastewater decolourisation, humic acid removal from industrial wastewater	Zahmatkesh et al. (2018)
4.	*Rhizopus arrhizus*	Biosorption of heavy metals	Sağ (2001)
5.	*Fusarium flocciferum*	Absorption of Ni(II) and Cd(II) from wastewater	Delgado et al. (1998)
6.	*Penicillium chrysogenum*	Absorption of Cd(II) from wastewater	Volesky (1994)
		Bacteria	
1.	*Sphingomonas* sp. strain BN6	Degrades naphthalene-2-sulphonate (a building block of azo dyes) present in contaminated water	Russ et al. (2000)
2.	*Paenibacillus azoreducens*	Color removal from wastewater with 98% efficiency	Meehan et al. (2001)
3.	*Pseudomonas luteola*	Decoloration of wastewater	Chang et al. (2001)
4.	*Bacillus subitlis*	Reduction of TOC	Hesnawi et al. (2014)
5.	*Bacillus laterosponus*		
6.	*Pseudomonas aeruginosa*		
7.	*Methylobacterium organophilum*	Removal of Cu and Pb from wastewater	Kim et al. (1996)
8.	*Herminiimonas arsenicoxydans*	Arsenic absorption in wastewater	Marchal et al. (2010)

7.2 Computational Fluid Dynamics in Wastewater Treatment

In recent years, computational fluid dynamics (CFD), a broadly used method, has been applied to biological wastewater treatment. It has exposed the inner flow state that is the hydraulic condition of a biological reactor (Peng et al., 2014). CFD is the application of powerful predictive modeling and simulation tools. It may calculate the multiple interactions between all the water quality and process design parameters. CFD modeling tools have already been widely used in other industries, but their application in the water industry is quite recent. CFD modeling has great applications in water and wastewater treatment, where it mechanically works by using hydrodynamic and mass transfer performance of single or two-phase flow reactors (Do-Quang et al., 1998). The level of CFD's capability varies between different process units. It has a high frequency of application in the areas of final sedimentation, activated sludge basin modeling, disinfection, and greater needs in primary sedimentation and anaerobic digestion (Samstag et al., 2016). Now, researchers are enhancing the CFD modeling with a developed 3D model of the anoxic zone to evaluate further hydrodynamic performance (Elshaw et al., 2016). The overall conceptual framework and the applications of the computational approach in wastewater treatment are presented in Fig. 4.

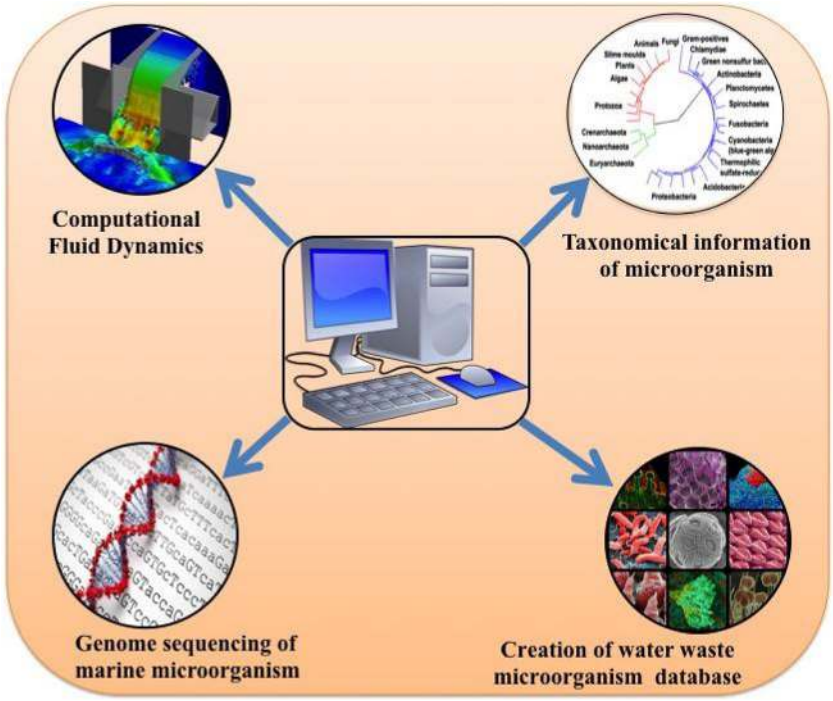

Fig. 4 A schematic showing the overall conceptual framework on which depicting the computational approach in wastewater treatment

7.3 Computational Artificial Intelligence Approach in Wastewater Treatment

Several studies were obtained by researchers to implement computer-based artificial techniques, which provide fast and rapid automated monitoring of water quality tests such as BOD and COD. Recently, Nourani et al. (2018) explores the possibility of wastewater treatment plant by using three different kinds of artificial intelligence methods, i.e., feedforward neural network (FFNN), adaptive neuro-fuzzy inference system (ANFIS), and support vector machine (SVM). Several measurements were done in terms of effluent to tests BOD, COD, and total nitrogen in the Nicosia wastewater treatment plant (NWWTP) and reported high-performance efficiency of artificial intelligence (Nourani et al., 2018).

7.4 Remote sensing and Geographical Information System

Since the implementation of satellite technology, the initiation of new methods and tools became popular nowadays. The futuristic approach of remote sensing and GIS technology plays a crucial role in the identification and locating of the water polluted area through satellite imaginary and spatial data. GIS analysis may provide a quick and reasonable solution to develop atmospheric correction methods. Moreover, it provides a user-friendly environment, which may support complex spatial operations to get the best quality information on water quality parameters through remote sensing (Ramadas & Samantaray, 2018).

8 Applications of Treated Wastewater

8.1 Scope in Crop Irrigation

Several studies have assessed the impact of the reuse of recycled/treated wastewater in major sectors. These are agriculture, landscapes, public parks, golf course irrigation, cooling water for power plants and oil refineries, processing water for mills, plants, toilet flushing, dust control, construction activities, concrete mixing, and artificial lakes (Table 5). Although the treated wastewater after secondary treatment is adequate for reuse since the level of heavy metals in the effluent is similar to that in nature (Ayers & Westcot, 1985), experimental evidences have been found and evaluated the effects of irrigation with treated wastewater on soil fertility and chemical characteristics, where it has been

Table 5 Applications, methods and health concerns of treated or untreated wastewater for irrigation

Approach	Experimental details	Results and remarks	References
Groundwater, secondary (SW) and tertiary wastewater (TW)	Tomato and broccoli was irrigated with agro-industrial treated wastewater	No significant effects neither on marketable yield nor on the qualitative traits of tomato and broccoli crops. Treated wastewater has been found more effective for irrigation and to cope with the agricultural water shortage	Libutti et al. (2018)
Irrigation with groundwater (GW) and treated agro-industrial wastewater (TW)	Physico-chemical characteristics of the irrigation waters. Monitoring of fruit quality parameters, *E. coli*, fecal *Enterococci*, and *Salmonella* spp.	No significant effects on yields quantitative traits in an irrigated water, although marketable fruit yield was higher in GW than with TW GW	Gatta, Libutti, Gagliardi, Disciglio, et al. (2015a); Gatta, Libutti, Gagliardi, Beneduce, et al. (2015b)
Surface water, groundwater and wastewater	Water samples were analyzed for *E. coli* using the most probable number method	The incidence of diarrhea in the groundwater area was 7.92 episodes/1000 person-weeks, while the wastewater and surface water group had incidences of 13.1 and 13.4 episodes/1000 person-weeks. The average treatment effect of wastewater quality obtained was 2.73	Falkenberg and Saxena (2018)
Simulated sugar effluent (lab-made)	Treated with batch electrochemical reactor where current density was varied from 1 to 5 A/dm^2	The percentage removal of COD was 80.74% at 5 A/dm^2 (current density) and 5 g/L of electrolyte concentration	Asaithambi and Matheswaran (2016)
Raw sewage from WWTP	Irrigated water, soil and vegetable samples for Zn, Cu, Pb and Cd concentrations and transfer factor from soils to plants (TF) were analyzed. Health risk index was also calculated	The irrigated soil was contaminated and trend of heavy metals concentrations was Zn > Pb > Cu > Cd. Health risk index was >1 for Cd and Pb. Study indicates potential health risk the human and animal populations	Chaoua et al. (2019)
Wastewater treatment plant/treated wastewater	Pollution load indexes (PLI), enrichment factor (EF) and contamination factor (CF) of metals were calculated	Ni, Pb, Cd and Cr concentrations in the edible portions were above the safe limit in 90%, 28%, 83%, and 63% of the samples, respectively. The health risk index (HRI) was >1 indicating a potential health risk and suggests that wastewater irrigation is not safe for human health	Balkhair and Ashraf (2016)
Raw sugarcane wastewater	Wastewater treated with UMAS (10 kHz, 7 days incubation) and membrane anaerobic system	More than 90% (>90%) of removal efficiency (BOD, COD, and TSS), and reduced flux decline was achieved by using UAMS	Mahendran et al. (2014)
Raw sugarcane wastewater	Wastewater treated with ultrasonic membrane anaerobic system (UMAS), 25 kHz after 28 days experiment	After 28 days, the COD removal efficiency obtained was 97 %, and the methane gas composition nearly reached 79 %. The TSS and VSS removal efficiency also reached 99 % of removal	Nour and Zainal (2014)
Municipal wastewater (MWW)	Ultrasonication at 20 kHz, for 15, 30, and 45 min	High bacterial densities were employed, percentages of inactivation >99% were reached at 45 min	Amabilis-Sosa et al. (2018)

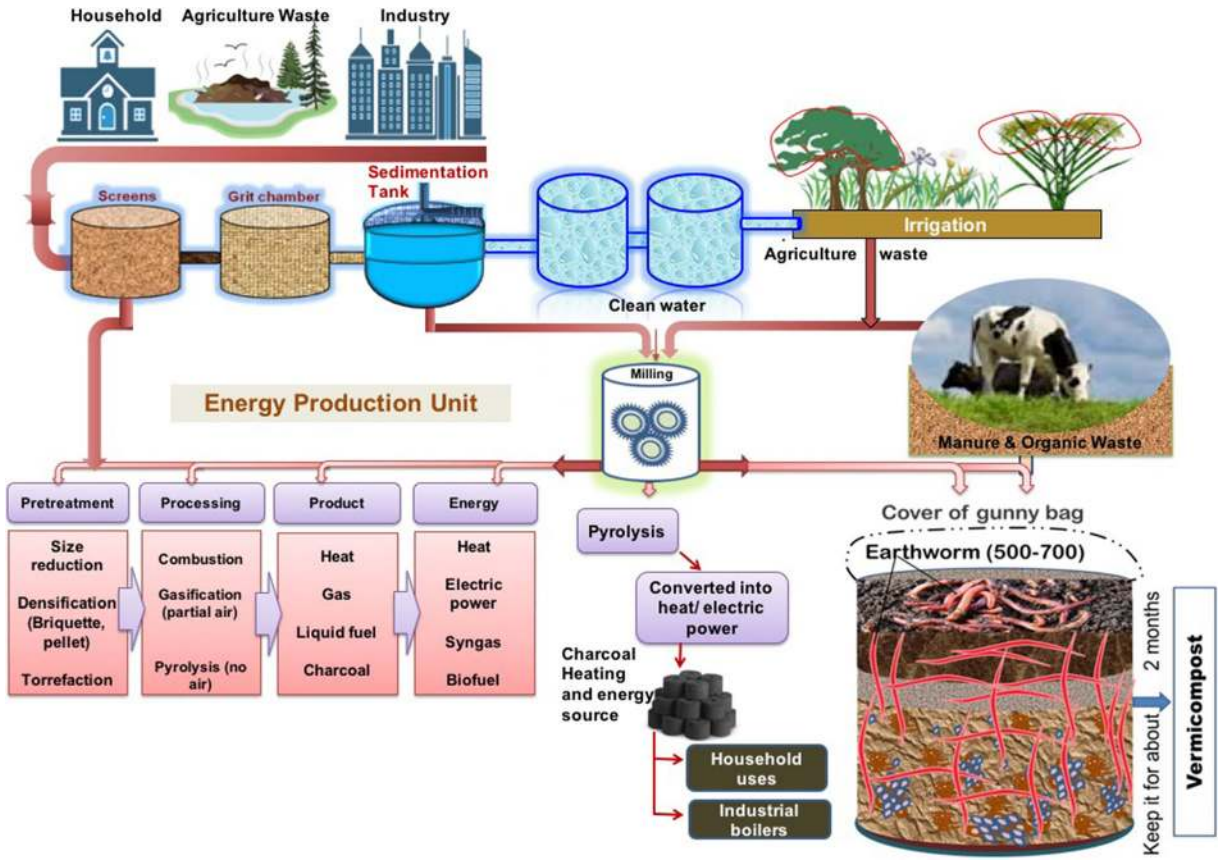

Fig. 5 Energy production through wastewater (reproduced from Bhatnagar et al., 2016; Kesari & Jamal, 2017)

concluded that secondary treated wastewater can improve soil fertility parameters (Mohammad & Mazahreh, 2003). The proposed model (Fig. 3) is tested partially previously at a laboratory scale by treating the wastewater (from sewage, sugar, and paper industry) in an ultrasonic bath (Kesari et al., 2011a, b; Kesari & Behari, 2008; Kumar et al., 2010). Advancing it with ultraviolet and ozone treatment has modified this in the proposed model. A recent study shows that the treated water passed quality measures suited for crop irrigation (Bhatnagar et al., 2016). In Fig. 3, a model is proposed including all three (UV, US, nanoparticle, and ozone) techniques, which have been tested individually as well as in combination (US and nanoparticle) (Kesari et al., 2011a, b) to obtain the highest water quality standards acceptable for irrigation and even drinking purposes.

A wastewater-irrigated field is a major source of essential and non-essential metals contaminants such as lead, copper, zinc, boron, cobalt, chromium, arsenic, molybdenum, and manganese. While crops need some of these, the others are non-essential metals, toxic to plants, animals, and humans. Kanwar and Sandha (2000) reported that heavy metal concentrations in plants grown in wastewater-irrigated soils were significantly higher than in plants grown in the reference soil in their study. Yaqub et al. (2012) suggest that the use of US is very effective in removing heavy or toxic metals and organic pollutants from industrial wastewater. However, it has been also observed that the metals were removed efficiently, when UV light was combined with ozone (Samarghandi et al., 2007). Ozone exposure is a potent method for the removal of metal or toxic compounds from wastewater as also reported earlier (Park et al., 2008). Application of US, UV, and O_3 in combination lead to the formation of reactive oxygen species (ROS) that oxidize certain organics, metal ions and kill pathogens. In the process of advanced oxidizing process (AOP) primarily oxidants, electricity, light, catalysts etc. are implied to produce extremely reactive free radicals

(such as OH) for the breakdown of organic matters (Oturan & Aaron, 2014). Among the other AOPs, ozone oxidization process is more promising and effective for the decomposition of complex organic contaminants (Xu et al., 2020). Ozone oxidizes the heavy metal to their higher oxidation state to form metallic oxides or hydroxides in which they generally form limited soluble oxides and gets precipitated, which are easy to be filtered by filtration process. Ozone oxidization found to be efficient for the removal of heavy metals like cadmium, chromium, cobalt, copper, lead, manganese, nickel, and zinc from the water source (Upadhyay & Srivastava, 2005). Ultrasonic-treated sludge leads to the disintegration of biological cells and kills bacteria in treated wastewater (Kesari, Kumar, et al., 2011a; Kesari, Verma, & Behari, 2011b). This has been found that combined treatment with ultrasound and nanoparticles is more effective (Kesari, Kumar, et al., 2011a). Ultrasonication has the physical effects of cavitation inactivate and lyse bacteria (Broekman et al., 2010). The induced effect of US, US, or ozone may destroy the pathogens and especially during ultrasound irradiation including free-radical attack, hydroxyl radical attack, and physical disruption of cell membranes (Kesari, Kumar, et al., 2011a; Phull et al., 1997; Scherba et al., 1991).

8.2 Energy and Economy Management

Municipal wastewater treatment plants play a major role in wastewater sanitation and public health protection. However, domestic wastewater has been considered as a resource or valuable products instead of waste, because it has been playing a significant role in the recovery of energy and resource for the plant-fertilizing nutrients like phosphorus and nitrogen. Use of domestic wastewater is widely accepted for the crop irrigation in agriculture and industrial consumption to avoid the water crisis. It has also been found as a source of energy through the anaerobic conversion of the organic content of wastewater into methane gas. However, most of the wastewater treatment plants are using traditional technology, as anaerobic sludge digestion to treat wastewater, which results in more consumption of energy. Therefore, through these conventional technologies, only a fraction of the energy of wastewater has been captured. In order to solve these issues, the next generation of municipal wastewater treatment plants is approaching total retrieval of the energy potential of water and nutrients, mostly nitrogen and phosphorus. These plants also play an important role in the removal and recovery of emerging pollutants and valuable products of different nature like heavy and radioactive metals, fertilizers hormones, and pharma compounds. Moreover, there are still few possibilities of improvement in wastewater treatment plants to retrieve and reuse of these compounds. There are several methods under development to convert the organic matter into bioenergy such as biohydrogen, biodiesel, bioethanol, and microbial fuel cell. These methods are capable to produce electricity from wastewater but still need an appropriate development. Energy development through wastewater is a great driver to regulate the wastewater energy because it produces 10 times more energy than chemical, thermal, and hydraulic forms. Vermicomposting can be utilized for stabilization of sludge from the wastewater treatment plant. Kesari and Jamal (2017) have reported the significant, economical, and ecofriendly role of the vermicomposting method for the conversion of solid waste materials into organic fertilizers as presented in Fig. 5. Solid waste may come from several sources of municipal and industrial sludge, for example, textile industry, paper mill, sugarcane, pulp industry, dairy, and intensively housed livestock. These solid wastes or sewage sludges have been treated successfully by composting and/or vermicomposting (Contreras-Ramos et al., 2005; Elvira et al., 1998; Fraser-Quick, 2002; Ndegwa & Thompson, 2001; Sinha et al., 2010) Although collection of solid wastes materials from sewage or wastewater and further drying is one of the important concerns, processing of dried municipal sewage sludge (Contreras-Ramos et al., 2005) and management (Ayilara et al., 2020) for vermicomposting could be possible way of generating organic fertilizers for future research. Vermicomposting of household solid wastes, agriculture wastes, or pulp and sugarcane industry wastes shows greater potential as fertilizer for higher crop yielding (Bhatnagar et al., 2016; Kesari & Jamal, 2017). The higher amount of solid waste comes from agricultural land and instead of utilizing it, this biomass is processed by burning, which causes severe diseases (Kesari & Jamal, 2017). Figure 3 shows the proper utilization of solid waste after removal from wastewater; however, Fig. 5 showing greater possibility in fertilizer conversion which has also been discussed in detail elsewhere (Bhatnagar et al., 2016; Nagavallemma et al., 2006)

9 Conclusions and future perspectives

In this paper, we have reviewed environmental and public health issues associated with the use of untreated wastewater in agriculture. We have focused on the current state of affairs concerning the wastewater treatment model and computational approach. Given the dire need for holistic approaches for cultivation, we proposed the ideas to tackle the issues related to wastewater treatment and the reuse potential of the treated water. Water resources are under threat because of the growing population. Increasing generation of wastewater (municipal, industrial, and agricultural) in developing countries especially in India and other Asian countries has the potential to serve as an alternative of freshwater resources for reuse in rice agriculture, provide appropriate treatment, and distribution measures are adopted. Wastewater treatment is one of the big challenges for many countries because increasing levels of undesired or unknown pollutants are very harmful to health as well as environment. Therefore, this review explores the ideas based on current and future research. Wastewater treatment includes very traditional methods by following primary, secondary, and tertiary treatment procedures, but the implementation of advanced techniques is always giving us a big possibility of good water quality. In this paper, we have proposed combined methods for the wastewater treatment, where the concept of the proposed model works on the various types of wastewater effluents. The proposed model not only useful for wastewater treatment but also for the utilization of solid wastes as fertilizer. An appropriate method for the treatment of wastewater and further utilization for drinking water is the main futuristic outcome. It is also highly recommendable to follow the standard methods and available guidelines provided WHO. In this paper, the proposed role of the computational model, i.e., artificial intelligence, fluid dynamics, and GIS, in wastewater treatment could be useful in future studies. In this review, health concerns associated with wastewater irrigation for farmers and irrigated crops consumers have been discussed.

The crisis of freshwater is one of the growing concerns in the twenty-first century. Globaly, about 330 km^3 of municipal wastewater is generated annually (Hernández-Sancho et al., 2015). This data provides a better understanding of why the reuse of treated wastewater is important to solve the issues of the water crisis. The use of treated wastewater (industrial or municipal wastewater or Seawater) for irrigation has a better future for the fulfillment of water demand. Currently, in developing countries, farmers are using wastewater directly for irrigation, which may cause several health issues for both farmers and consumers (crops or vegetables). Therefore, it is very imperative to implement standard and advanced methods for wastewater treatment. A local assessment of the environmental and health impacts of wastewater irrigation is required because most of the developed and developing countries are not using the proper guidelines. Therefore, it is highly required to establish concrete policies and practices to encourage safe water reuse to take advantage of all its potential benefits in agriculture and for farmers.

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Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

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