Chapter 4
Biological Wastewater Treatment for Prevention of River Water Pollution and Reuse: Perspectives and Challenges

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Abstract Wastewater discharge with high biological oxygen demand (BOD) and high nutrient levels (e.g., nitrate, phosphate) affects water quality and is a major reason for degradation of water bodies, including rivers. In addition, metals and other toxic elements are also concentrated in aquatic bodies due to the continuous disposal of wastewater that is treated or partially treated. In many developing countries, wastewater treatment facilities are not fully operational due to energy crises and improper maintenance. However, under the provisions of the Environmental Protection Act, maximum permissible limits have been established for the disposal of different pollutants into surface water bodies. Therefore, the appropriate treatment of wastewater containing various pollutants is mandatory before its disposal into a body of water. Conventional methods of wastewater treatment use sewage treatment plants; however, they may be unable to treat wastewater properly and completely due to their higher cost and maintenance requirements. In this case, green plant-based technologies such as phytoremediation, the development of constructed wetlands, and algal pond systems may perform key roles in treating wastewater by removing nutrients and toxic metals before their discharge into rivers. By implementing plant-based, low-cost, and eco-friendly technologies for the treatment of wastewater at the source of origin up to a permissible level of discharge, we can prevent the pollution of surface water bodies and recycle the treated water in agriculture for irrigation, gardening, and other purposes.

Keywords Wastewater treatment · Water pollution · Reuse · Plant · Phytoremediation

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4.1 Introduction

Increasing overpopulation, urbanization, and modernization are creating problems for sewage discharge and thus the surface water contamination of lakes and rivers. Rivers are the major dumping site for highly polluted wastewaters emerging from different sources (Georgetti et al. 2011; Guittonny-Philippe et al. 2014). For example, the Ganga River became one of the most highly polluted rivers in the world in recent decades (Wong et al. 2007) because of sewage containing high BOD and toxic elements that was discharged without treatment from urban areas (Purushothaman and Chakrapani 2007; Rai et al. 2011). The most problematic source of water contamination is sewage that is discharged directly into the rivers without any kind of treatment (CPCB 2005). Therefore, the safe discharge of wastewater, including sewage, is essential to protect water resources and the environment in accordance with the Environmental Protection Act, which established maximum permissible limits for wastewater discharged into aquatic bodies, particularly rivers (EPA 1986). Therefore, the proper treatment of sewage and wastewater is mandatory prior to its final discharge into water bodies, including rivers. However, wastewater treatment facilities are not fully operational in many developing countries because of power shortages or inadequate maintenance.

The deteriorating water quality in rivers from anthropogenic and industrial activities has led to the need to establish efficient water management systems. Conventional methods of wastewater treatment are based on physicochemical methods and have limitations due to their high cost of implementation and operation (Carty et al. 2008). However, green plant-based technologies are innovative solutions for environmental protection due their low cost and ecofriendly nature. Plants and algae growing in the littoral zones of rivers are of particular importance in wastewater remediation because of their efficiency in removing accumulated metals and nutrients from wastewater. These efficient metal-accumulating plants and algae have water-purifying potential that can be used in phytoremediation technology, either individually or as a part of a constructed wetland. Plant-based technologies are solar driven, ecofriendly, and cost-effective because they require no energy and comparatively lower costs for their implementation and operation. After biological treatment, wastewater may be used for irrigation or gardening, or it may be recycled for other purposes. Therefore, treating wastewater by growing efficient aquatic plants and algae in a designed plant-based system could be used not only as an alternative to conventional methods, but also to prevent and control river water pollution.

4.2 Wastewater Sources and Characteristics

4.2.1 Sources of Wastewater

The direct discharge of untreated or partially treated sewage into rivers leads to pollution and affects water quality. According to Singh et al. (2004), on average more than 1.3 billion liters of sewage per day is discharged directly into rivers without any treatment. Out of 38,254 MLD (Million Litre per Day) sewage generated from 498 class I cities and 410 class II towns in India, only 11,787 MLD (35%) was treated in existing treatment facilities; therefore, 26,467 MLD (65%) of untreated sewage was discharged directly into the river system (CPCB 2007; CPCB 2009). Furthermore, other sources of contamination include effluent treatment plants and industrial operations in the watersheds of river, which deteriorate water quality by discharging wastewater with high BOD and nutrients into rivers (Rai et al. 2011; Markandya and Murty 2004). When wastewater containing heavy metals such as Hg, Cd, Zn, Ni, Pb, Cr, Co and Cu is discharged into rivers, it leads to bioaccumulation and biomagnification in the food chain, which affects aquatic biota because of their persistent nature (Gochfeld 2003).

4.2.2 Characteristics of Wastewater

Wastewater is defined as water used by different communities that contains a variety of impurities mixed with either suspended or dissolved solids. Generally, wastewater contains 99.9% water and 0.1% solids. The wastewater can be characterized as high or low pH, with high total suspended solids (TSS) and total dissolved solids (TDS), low dissolved oxygen (DO), high concentrations of nitrates and phosphates, high BOD, and high metal content. Wastewater includes sewage and effluent from different industries that have low DO, high BOD, phosphate, nitrate, and metals.

4.2.3 Effects of Wastewater

The water quality of rivers and lakes, which are the main source of drinking water, is continuously degrading because of discharge of wastewater. This can lead to a variety of waterborne diseases, including cholera, renal disease, heart diseases, diarrhea, and dysentery (Gray 2008). Furthermore, wastewater that is discharged on land can leach into underground water tables and contaminate groundwater, making it unsafe for use (Table 4.1). The discharge of sewage causes eutrophication of aquatic bodies, which damages the flora and fauna that grow in the water, as well as disturbs the food chain and food web of the ecosystem. Similarly, wastewater used in irrigation contains high nutrients, toxic elements, and organic contaminants that may affect the production of crops (Birol and Das 2010).

4.2.4 Wastewater Quality Parameters and Permissible Limits

The water quality parameters of wastewater and allowable levels of pollution and metal content are given in Table 4.2.

Table 4.1 Wastewater characteristics and their sources

Characteristics	Source
Color	Domestic sewage, industrial effluents, undecomposed organic materials
Odor	Wastewater, industrial waste
Solids	Municipal water supply, industrial wastewater, soil erosion, inflow infiltration
pH and temperature	Urban and industrial wastewater
Organic contents	Commercial and industrial wastewater
Oils and grease	Sewage and industrial wastewater
Pesticides	Agricultural runoff
Phenols	Industrial effluents
Proteins and fats	Sewage, commercial, and industrial wastes
Alkalinity	Domestic water supply, groundwater infiltration
Chlorides	Domestic wastes, domestic water supply
Heavy metals	Industrial effluent, agriculture runoff, groundwater infiltration
Nitrogen and phosphorus	Sewage, commercial and industrial wastes, natural runoff
Animals, plants, and microbes	Open watercourses, treatment plants, and domestic waste

Table 4.2 Water quality parameters of wastewater and their maximum permissible limits for discharge

Water quality parameter	Standards for wastewater discharge (EPA 1986)
pH	5.5–9.0
Temperature (°C)	Not to exceed 5 °C above the receiving water temperature
Conductivity (μs cm^{-1})	500
Total dissolved solids (TDS)	500
Dissolved oxygen (DO)	4–6
Biological oxygen demand (BOD)	30
Total suspended solids (TSS)	100
Nitrates (NO_3-N)	10
Ammoniacal nitrogen (NH_4-N)	50
Phosphates (PO_4-P)	5
Chromium (Cr)	2
Manganese (Mn)	2
Cobalt (Co)	3
Nickel (Ni)	3
Copper (Cu)	3
Zinc (Zn)	5
Arsenic (As)	0.2
Lead (Pb)	0.1

Values are in mg L^{-1} unless otherwise noted.

4.3 Biological Wastewater Treatment Technologies

The conventional approach of wastewater treatment includes sewage treatment plants based on physico-chemical processes (e.g., activated sludge, wastewater maturation ponds, trickling filters, high-rate stabilization ponds), anaerobic processes (e.g., anaerobic ponds, upflow anaerobic sludge blanket reactors), or a combination of both. However, because of the higher costs of operation, equipment corrosion, high requirements for electricity supply, and the non-reusability of treated water, these conventional methods are not more feasible and or more successful than biological methods. Biological wastewater treatment technologies are comparatively cheap and more ecofriendly. They often apply two methods: phytoremediation (i.e., the use of green plants to remove, degrade, and detoxify the pollutants) and bioremediation (i.e., the use of microorganisms to degrade, convert, transform, and detoxify the pollutants). In conventional sewage treatment plants, there is a possibility of operational failure due improper maintenance and accidents, thus risking a huge capital and harm to workers. However, plant- and microbe-based eco-technology have zero risk of hazards, create zero residues, and use zero energy.

4.3.1 Algae-Based Wastewater Oxidation Pond System

Algae-based wastewater oxidation pond system (AIWPS) technology is a very efficient way to use solar energy for algal growth. AIWPS releases photosynthetic oxygen from the supporting water and uses a special design to foster pond methane formation. This technology has been successfully used at many locations in California and elsewhere, and it has now been applied in Varanasi, India.

AIWPS has a series of four ponds: (i) an advance facultative pond, (ii) a high-rate pond, (iii) an algal settling pond, and (iv) a maturation pond. The wastewater is first screened out and then allowed to pass through the AIWPS. In this technology, produced methane gas is purified up to 85–88% and collected in the gas collectors for combustion. Greenhouse gas emissions are minimized as the carbon dioxide generated during fermentation and electricity generation is absorbed in the pond. The system is designed to grow crops of algae and release a maximum amount of free molecular oxygen as dissolved oxygen (DO) to the surrounding water under controlled conditions. The DO in soluble form goes to bacteria, which break down organic waste and purify water.

Algal systems can treat sewage, livestock waste, agro-industrial waste, and industrial waste (Shelef et al. 1980; Ibraheem 1998; Kaplan et al. 1988; Ma et al. 1990). The most commonly used arrangements for the treatment of wastewater are high-rate algal ponds (Oswald 1988) and the patented Algal Turf Scrubber (Craggs et al. 1996), which employs common green algae (*Chlorella, Scenedesmus, Cladophora*), cyanobacteria (*Spirulina, Oscillatoria, Anabaena*), or both. Various species of green algae, such as *Enteromorpha* and *Cladophora,* have been used to monitor heavy metal concentrations around the world (Al-Homaidan et al. 2011).

The ability of algae to accumulate and biotransform metals in their tissues is the key factor for their widespread use in the biomonitoring of different ecosystems (Mehta and Gaur 2005). The blue-green algae *Phormidium* has been reported to accumulate metals (Cd, Zn, Pb, Ni and Cu) from wastewater, while *Caulerpa racemosa* has been used for the removal of boron species from water (Bursali et al. 2009). Metal accumulation by microalgae and macroalgae can be used in phytoremediation methods, which are not costly and environmental friendly. Algae have different mechanisms for sequestering and synthesizing phytochelatins and metallothioneins, which bind with metals and translocate them into vacuoles (Suresh and Ravishankar 2004). The uptake of toxic elements by algae generally depends on the process of adsorption and metabolism-dependent active uptake (Lomax et al. 2011). Furthermore, the role of algae in arsenic transformation and the reduction of toxicity have been reported by many researchers (Wang et al. 2013; Bahar et al. 2013; Upadhyay et al. 2016).

4.3.2 Wastewater Treatment by Plants

The solar-driven and cost-effective technology for wastewater treatment, popularly known as phytotechnology or green technology, is based on the use of efficient metal-accumulating plants to remove pollutants, including metals and radionuclides, from soil and water. A variety of water-purifying plants may be used, depending on the local climate and geographical location. The chosen plants are usually indigenous to a specific location for ecological reasons and to optimize the functioning of the system.

Several aquatic plants have been found to be more efficient at utilizing solar energy than many terrestrial plants and hence show high growth rates. More than 450 angiospermic plants have been identified and reported as metal hyperaccumulators (Rascioa and Navari-Izzo 2011), which are able to accumulate potentially phytotoxic elements to concentrations up to 1000 times higher than average plants (Cherian and Oliveira 2005).

In phytoremediation processes, plants perform different mechanisms, such as phytoextraction, phytodegradation, rhizofiltration, phytostabilization, and phytovolatilization to remove toxic elements from wastewater. Several investigations have demonstrated that aquatic plants are quite effective at removing metals from wastewater without any visible injury (Lesage et al. 2007; Mishra and Tripathi 2009). Metal removal by the use of aquatic macrophytes is a cost-effective and eco-friendly technique for wastewater treatment (Tangahu et al. 2011; Rai et al. 2013). Submerged macrophytes have shown great potential to accumulate metals (Peng et al. 2008).

Furthermore, aquatic plants absorb metals and nutrients from the water and sediment to which they are exposed (Fritioff and Greger 2003; Upadhyay et al. 2014, 2017). High concentrations of arsenic and other heavy metals in naturally grown plants and algae have been reported in arsenic-affected areas of West Bengal, India, suggesting that macrophytes such as *Eichhornia crassipes, Lemna minor,* and

Spirodela polyrhiza may be used for removing metals from contaminated water in a plant-based treatment system (Singh et al. 2016).

4.3.3 Wastewater Treatment by Constructed Wetlands

Aquatic plants are used in constructed wetlands, which are designed wastewater treatment systems based on biological, chemical, and physical processes for treating wastewater (Rai 2004). Constructed wetlands mimic treatment processes that occur in natural wetlands to remove pollutants from the water (USEPA 1993). The treatment potential and efficiency of constructed wetlands can vary depending on plant combinations and their potential to accumulate and translocate metals in different parts of the plant (Sune et al. 2007). Constructed wetlands have been successfully used for the reduction of water contaminants by treating a wide variety of wastewaters, including industrial effluents, urban and agricultural runoff, sewage, leachates, pharmaceutical waste, and mine drainage (Scholz and Lee 2005; Hadad et al. 2006; Sheoran and Sheoran 2006; Zhang et al. 2012).

A constructed wetlands treatment system is composed of a bed substrate, efficient aquatic plants, and a microbial population. The substrate may be sand, gravel, or soil for anchoring wetland plants. There are two types of constructed wetland systems: horizontal flow systems and vertical flow systems. Most constructed wetland treatment systems are surface-flow or free-water surface systems. In surface-flow wetlands, the water flow on the surface of the wetland above the substrate has a variety of vegetation, such as emergent, floating, rooted, and submerged (Reed et al. 1995). In a subsurface flow system, also called a root-zone system, water flows below the substrate from one end to the other through a permeable bed due to gravitational force.

Various aquatic macrophyte species can be used in a constructed wetland system. However, naturally occurring emergent aquatic plants, such as common reed, adapt well to the local climate and soil conditions and provide adequate treatment. The plants supply oxygen and other nutrients that promote microbial growth in the substrate. The microbial population is largely responsible for treatment in the constructed wetland. In addition, the plants growing in constructed wetlands may provide a habitat for wildlife through remediation of pollution.

The planting and raising of reed beds are very popular in European countries for constructed wetlands, using plants such as cattails (*Typha* spp.), water hyacinth (*Eichhornia crassipes*), sedges, and *Pontederia* sp. Recent research in use of constructed wetlands for subarctic regions has shown that buckbeans (*Menyanthestrifoliata*) and pendant grass (*Arctophilafulva*) are also useful for metal uptake (Rai et al. 2010). Aquatic vegetation may play an important role in removal of phosphorus from water (Breen 1990; Guntensbergen 1989; Rogers et al. 1991). Phosphorus removal in a surface flow wetland treatment system has been reported using the aquatic plants *Scirpus* sp., *Phragmites* sp., and *Typha* sp. (Finlayson and Chick 1983). More often, the macrophyte *Phragmites australis* is used in sewage treatment systems to treat sewage. Constructed wetlands have been used for metal and metalloid removal from wastewater. Water-purifying plants, which supply oxygen and shade, are also added to the complete ecosystem to improve wastewater treatment. The aquatic plants *Phragmites australisa* and *Typha latifolia* have commonly been used for their metal tolerance, uptake, and filtration ability for wastewater treatment.

Over time, the bacterial suspension forms a biofilm around the roots of the treating plants (Peterson and Teal 1996). These micro-organisms assimilate the nutrients from the water and supply them to the aquatic plants for energy to grow and develop. Furthermore, macrophytes can transport atmospheric oxygen to into wastewater through their leaves, stems, and roots (Howes and Teal 1994). Some portion of transported oxygen is consumed for root respiration, with the remaining oxygen dissolved in the water column of the wetland, which leads to oxidation of organic carbon by facultative bacteria (Abbasi and Ramasami 1999). Moreover, anoxic conditions promote the growth of denitrifying micro-organisms. The plants not only assimilate nitrogen as a key nutrient in the life cycle for growth and development (Ellis et al. 1994) but also release oxygen and provide a suitable condition for purification reactions by enhancing a variety of chemical and microbial processes in constructed wetlands (Jenssen et al. 1993).

The key mechanisms of phosphorus removal from wastewater in constructed wetlands are physicochemical processes, such as the fixation of phosphate by iron and aluminum in the substrate (Arias et al. 2001). Aquatic plants accumulate metals in their tissue from water, which augments their use in designing a plant-based treatment system coupled with mechanical skills (Rai et al. 2012). A reduction of more than 90% of BOD and an increase in DO levels in sewage has been reported in constructed wetlands that treat water using the aquatic plants *Typha latifolia, Phragmites australis,* and *Colocasia esculenta* (Rai et al. 2013). Similarly, the metal removal potential of these aquatic plants was also reported after 36 h of sewage treatment (Rai et al. 2015). Masi et al. (2013) reported an average of 86% removal for the organic load, 60% for total nitrogen, 43% for total phosphorus, 89% for total suspended solids, and 76% for ammonium from sewage in constructed wetlands. The hardiness, ability to survive under adverse environmental conditions, and high productivity of vascular aquatic weeds can also be utilized to make them efficient bio-agents for treating wastewater (Abbasi and Ramasami 1999). These spent plants can be used as an energy feedstock. Recently, simulated constructed wetlands planted with *Typha latifolia* and *Polygonum hydropiper* were reported to efficiently treat sewage containing metals before its discharge into freshwater to prevent water pollution (Upadhyay et al. 2017).

4.4 Treatment Processes

A number of conventional approach for wastewater remediation have been put forth, but they have been unable to reach the desired safe disposal limit. In addition, different investment priorities, a large gap between treated and generated sewage, high costs, and maintenance requirements also contribute significantly to the disposal of untreated sewage. Plant-based technology, including constructed wetlands designed for the secondary treatment of wastewater, use physical, chemical, and biological processes with plants and microbes to reduce the toxic level of different pollutants to a safer level (Breitholtz et al. 2012).

Wetland microbes have the ability to remove excessive amounts of nutrient runoff from agricultural/human sources (Wu et al. 2011). It has been observed that the suspended solids and oxidized nutrients present in wastewater are readily used by wetland organisms for their growth and metabolism. As the water passes through the wetland system, contaminants are removed from the water through adsorption by the beds (phosphates and large organic compounds), microbially mediated removal (biochemical reactions), or uptake into plants (heavy metals and some organic compounds).

The phosphorus present in wastewater can be removed by different processes, including mineralization, absorption, uptake by the plants, dissolution of insoluble P to soluble by microbial secretion of the phosphatase enzyme, and precipitation through the formation of a complex with metals present in the wastewater. Similarly, nitrogen in the wastewater can be removed by the microbial actions of ammonification, nitrification, and denitrification (Stewart 1966). Nitrogen can be easily taken up by the plants (Kartal et al. 2010).

Metal accumulation processes involve the following steps: (1) binding to the substrate, particulates, and soluble organics; (2) precipitation as insoluble salts; and (3) uptake by plants and micro-organisms (Gill et al. 2014). Furthermore, enhancements in the metal uptake of plants can be regulated (increased or decreased) by the increased bioavailability of metals in solution, the addition of chelating molecules and the genetic modification of transporters because these proteins can directly control the uptake, distribution, and accumulation of various elements in plants (Ovecka and Takac 2014; Salt et al. 1995).

The key step in the hyperaccumulation of metals depends on genetic regulation and overexpression of different types of genes and transporters present in the plants (Raskin 1996). Metals are either absorbed in the roots or translocated to the aboveground parts of the plant through xylem, then deposited into vacuoles to remove excess metal ions (Assunção et al. 2003). Metal uptake is governed by a variety of molecules, such as the the transporter protein Zip family protein (zinc iron permease), natural resistance-associated macrophage, metallothionein, phytochelatins, Lsi 1 and 2, aquaporins, multidrug and toxin efflux, and heavy metal-transporting ATPases (Talke et al. 2006; Fulekar et al. 2009; Pilon et al. 2009). After treatment through the plant system, the wastewater could be recycled and reused for agriculture and industrial processes.

4.5 Conclusions

Green plant-based technologies such as phytoremediation, constructed wetlands, and algal pond systems play an important role in treating wastewater by removing nitrogen, phosphorus, and toxic metals before their discharge into rivers, thus preventing water pollution. Aquatic plants with high metal tolerances and accumulation potentials can be used to establish constructed wetlands for treating wastewater by removing metals and nutrients. Furthermore, planting soil binders and pollution abator plants along the banks of rivers may play an important role in CO_2 mitigation in the atmosphere, the settlement of suspended particulate matter from water, and the control of flooding in the river streams. Therefore, plant-based wastewater biological treatment may serve as an eco-friendly and cost-effective technology for prevention of river water pollution and conservation of their ecosystem compared with conventional methods. Biological wastewater treatment may be supplemented with conventional wastewater treatment for the proper and complete treatment of wastewater, filling the gap between sewage generation and existing treatment facilities to conserve the water quality and ecological entities of rivers.

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