# Chapter 10
# Ecoengineered Approaches for the Remediation of Polluted River Ecosystems

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**Abstract** Rivers are the vital support system providing sustainable development and agricultural production to our highly industrialized world. However, extreme anthropogenic inputs have disturbed the natural ecological balance, structures and functions of riverine matrices. The origins, fate and various health hazards of the riverine contaminants are outlined in this chapter. To mitigate the river pollution and restoring its healthy status, effective restoration strategies are required to be adopted, this chapter reviews the application of eco-engineered systems for remediation of the polluted rivers. Different laboratory scale and on-site treatment technologies for river bioremediation are reviewed in this chapter for instance, constructed wetlands, floating islands, bioracks, ecotanks, biofilters, microbial nano-bubble systems, periphyton based bioremediation systems, as well as hybrid integrated treatment systems. The application of combined bioremediation technologies and engineering approaches are discussed for removal of various river pollutants. Suggestions have been made on future research for developing pragmatic approaches in the remediation of polluted riverine ecosystems.

**Keywords** River pollution · Bioremediation · Restoration · Eco-engineered systems

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## 10.1 Introduction

Rivers, the outcome of the earth's evolutionary progression, are the major driving force for the human civilization as well as ecological and economic sustenance of mankind. Rivers offer many functional roles such as water resource, food production, mediate sediment transfer, electricity production, transportation and tourism (Central Pollution Control Board 2018a). Due to continued urbanization, industrialization and poor sanitation, the qualities and quantities of water bodies have been undergoing rigorous pressures and this is considered most grievous phenomenon around the globe for upcoming decades. Agricultural run-off, industrial discharges, domestic wastewaters and social interventions also considerably account for the river water contamination (Central Pollution Control Board 2018a). Discharges of various carcinogenic, mutagenic, teratogenic and persistent pollutants have deteriorated the aquatic ecosystems throughout the globe. River contaminants mainly comprise of loads of nutrients addition (i.e. N, P and others), organic contaminants, xenobiotics and toxic metals originating mainly from domestic and industrial wastewater sources.

Globally, extensive efforts have been initiated for the conservation of the fresh water resources, mitigation of the pollution using various sustainable strategies and water resources management. Around 2 million ton sewage, agricultural and industrial wastes are drained into water bodies per day (United Nations World Water Assessment Programme 2003), which corresponds to the mass of the entire human population. According to the United Nations report, annually about 1500 $km^3$ wastewaters are produced this is likely to be 6 times higher than the water present in the rivers around the globe (United Nations World Water Assessment Programme 2003). Inadequate sanitary practices have influenced 2.5 billion lives and deteriorated the qualities of the water bodies (United Nations Children's Fund 2009).

Three key riverine bodies of India (Indus, Ganga and Brahmaputra) have been alarmingly contaminated from the both point and non-point sources of pollution. Central Pollution Control Board has highlighted that many polluted river stretches and rivers from the 31 States and Union Territories of India are not meeting the water quality standards (Central Pollution Control Board 2018b). Reports from National River Water Quality Laboratory, Central Water Commission, New Delhi has declared many heavy metal polluted river sites throughout the India. Data collected by Central Water Commission from the water quality monitoring stations located throughout the Indian river basins have shown that 25 rivers contaminated with cadmium, samples from 21 rivers containing chromium, 10 rivers were showing presence of copper, 137 rivers have been polluted with iron, 69 rivers contaminated with lead, and nickel was found in 25 river samples (Ministry of Water Resource 2018).

Eco-remediation of rivers deals with the restoring the damages caused by anthropogenic inputs to the entire river dynamics and diversity of the ecosystem through various biological remedies, for instances plants and bacterial systems. Advantages of eco-remediation include cost effectiveness, environment friendly and green remedies for repairing the damaged river ecosystems compared to various physico-chemical remediation technologies many of which are environment disrupting and form secondary pollutants during treatments. Ecologists, strategy planners, officials, public health specialists and researchers have raised their concerns for the riverine pollution. The main initiatives to remediate the water bodies is detecting the source of pollution and groups of contaminants to avoid further decline in water qualities and take preventive measures.

## 10.2 Occurrence of Pollutants, Emerging Contaminants and Their Riverine Fates

Deterioration of aquatic bodies is mediated due to presence of organic and inorganic pollutants causing adverse alterations in physico-chemical properties of water that affects the flora and fauna of water bodies along with terrestrial organisms consuming such contaminated waters. There are different types of pollution sources based on their nature and origins that are categorised into natural and anthropogenic furthermore, point and defused sources. Ranges of natural phenomenon that deteriorate the water bodies are the changes in geographical landscape, geo-morphological features of the location, hydrological properties and biological interactions. Natural processes like surface integrated composites run-off through rain water, bed rock weathering and settlement of the atmospheric matters brings about alterations in normal status of the water bodies. Moreover, the chief anthropogenic and point sources such as household and industrial wastewaters, pesticides and fertilizers containing agronomic drains significantly impact the qualities and quantities of surface waters.

Industrialized and urbanized processes generate enormous amount of liquid and solid wastes which deteriorate water bodies through surface runoff and dumping (Khatri and Tyagi 2015). According to the investigations conducted by Pure Earth Black Smith Institute, untreated wastewater generated from the ore and mining sites that is being discharged directly into water bodies contains enormous amount of heavy metals and tailing contaminants. Tanneries are another mediator of surface water contamination that generate large amounts of effluent containing chromium, basic, acidic and coloured contaminants affecting the health of almost 1.5 million people (Pure Earth and Green Cross 2016). Textile industries are among the top most sectors utilizing large amount of water, eventually releasing toxic dyes into water bodies (Rathour et al. 2019a). About 17–20% of the water pollution is driven by textile industries, putting 1 million at risk (Pure Earth and Green Cross 2016). Petrochemical industries and refineries produce wastewater composed of toxic pollutants such as, crude oil, cyanides, ammonia, heavy metals, phenols and aliphatic hydrocarbons particularly toxic carcinogenic polyaromatic hydrocarbons which contribute to surface water contamination (Mitra et al. 2019; Rehman et al. 2019; Kleindienst and Joye 2019).

Recently, central pollution control board, India reported that 30,042 million litres per day of domestic sewage is discharged into rivers (Central Pollution Control Board 2018a). The chief sources of pharmaceuticals discharges into water matrices are wastewater treatment plants and direct release (Li et al. 2014). Many recent studies have drawn attention to the concentrations of pharmaceutical compounds in Indian rivers (Mutiyar and Mittal 2014; Shanmugam et al. 2014; Balakrishna et al. 2017; Archana et al. 2016). Sharma et al. (2019) reported the occurrence and distribution of 15 pharmaceuticals, personal care products and 5 artificial sweeteners in the river at numerous sites along the Ganga River. Recent research studies and developments in analytical chemistry have revealed that enormous amount of active pharmaceutical ingredients, endocrine active chemicals, polychlorinated biphenyls, polyaromatic hydrocarbons and other emerging pollutants are widely found in contaminated Indian water bodies (Philip et al. 2018). Apart from various sources of river pollution as described above, the spent water emanating from power plants has been reported to result in thermal pollution affecting river ecosystems (Verones et al. 2010; Hester and Doyle 2011).

Nonpoint sources are dispersed over catchment regions which drain through thin reels, canals, rain storm drains, and flow into water bodies. Run-off waters from defused agricultural and urban sources are the instances of nonpoint sources. Eutrophication of water bodies is the possible outcome of nonpoint sources as they contain substantial amount of organic compounds, nitrogen, and phosphorus besides agronomic chemicals. Due to its long range distribution, appropriate controlling of nonpoint sources is found to be challenging (Cestti et al. 2003). Availability of massive amounts of inorganic phosphorus and nitrogen through range of human activities leads to encouragement of phytoplankton growth and results into the recurrent incidence of harmful algal blooms (Wang et al. 2019). Bacteriological agents of human faeces origin can also drain into surface waters through sewage wastewater for instances, Hamner et al. (2007) have detected highly pathogenic *Escherichia coli* serotype O157:H7 in the Ganga river which poses a serious threat to public health.

Once contaminants penetrate into aquatic ecosystem they undergo the hydrological progression and resulting into numerous chemical modifications. Depending on the composition of water such alteration brings about more lethal forms of pollutants into water bodies. In order to keep an eye on water pollution, World Health Organization has established various drinking water standards (World Health Organization 2011). Thus, it is important to gauge the wide range of pollutants present in a given river ecosystem, for designing effective eco-remediation technologies.

## 10.3 Hazardous Effects of Water Contaminants on Aquatic and Terrestrial Biota

Water holds prime importance for all the biotic entities on earth. Therefore, any sort of contamination of water resources by hazardous wastes impacts all life forms. The quality and quantity of water resources are important to consider with regards to sustenance of the ecosystems, welfare and health of human populations. Improper sanitary practices as well as water scarcity have huge impact on the surface water and drinking water contamination leading to several diarrheal, hepatic, enteroviral and parasitic infectious diseases (World Health Organization 2011).

Various research groups have undertaken the health risk assessment of the Ganga River waters (Siddiqui et al. 2019; Mitra et al. 2019; Philip et al. 2018). Enormous amounts of carcinogenic and teratogenic pollutants have been discharged into Ganga River, India and were reported to cause disease, infections and abnormalities in surrounding communities (Dwivedi et al. 2018; Paul 2017). Major leather tanneries are situated in the state of Uttar Pradesh, India near Ganga River mostly engage with chrome-tanning processes producing million litres of wastewater per day. Health risk assessment survey conducted on the residents of communities near Kanpur leather tanning operations suggests higher rates of gastrointestinal, dermatological and haematological abnormalities owing to high concentration of metals in waterbodies (Chaudhary et al. 2017; Chaudhary and Walker 2019).

Maurya et al. (2019) and Siddiqui et al. (2019) have recently undertaken research studies concerning human health through the consumption of heavy metal contaminated fishes from Ganga River and have shown risk of kidney and skeletal damages, neurological disorders, endocrine disruption, cardiovascular dysfunction, and carcinogenic effects. Another research group, Mitra et al. (2019) investigated the risks of various organic pollutants mainly polyaromatic and chlorinated organic contaminants on human health through the estuaries arising from the Hooghly River, distributaries of the Ganges river. Findings of this research indicate high risks of carcinogenic polyaromatic hydrocarbons impacting the ecology of Hooghly River. As per the world health organization report, globally around, two billion individuals consume faeces contaminated water and nearly 829,000 humans are subjected to death owing to intake of the contaminated drinking water, improper sanitary practices (World Health Organization 2019).

Large numbers of pollutants persist in water matrices and ultimately lead to accumulation into both autotrophic and heterotrophic entities at different levels of food chain. The concentration of these pollutants increases from lower to higher trophic level and affects all the life forms. All sorts of anthropogenic activities that lead to water pollution are detrimental to freshwater biota (Lake et al. 2000; Revenga et al. 2005) due to their habitat loss, degradation, over exploitation, flow alterations and foreign species invasions (Dudgeon et al. 2006; Malmqvist and Rundle 2002) that contribute to quantitative and qualitative reductions of freshwater matrices. According to the research studies, globally more than 50% of the fresh water fish species and one-third of amphibians are at risk of extinction (Viéet et al. 2009).

Various research studies have shown that many fish species are at a risk of extinction owing to high levels of organochlorides and metals in their tissues (Kafilzadeh 2015; Rajeshkumar and Li 2018). Pesticides and herbicides through agricultural runoff accumulate in fish tissue which affects the metabolic and reproductive functions of fishes (Priyadarshani 2009). Rivers are among the major fresh water sources so, the presence of various contaminants toxic in rivers posing a threat to human health are of particular concern. Therefore, currently, major research focus is on developing eco-remediation strategies to mitigate river pollution problems.

## 10.4 Historic Concepts of River Bioremediation

Concept of the river restoration initiated from Europe and America, where most of the river restoration projects were conducted on-site. Results of the previous projects have concluded that the success of restoration relies on consideration of indigenous state, involvement of multi-disciplinary research, directions from administration and the combination of ecological and engineered restoration systems (Porta et al. 1993). Ordinarily used practises for the treatment of polluted rivers all over the globe are physico-chemical and bioecological approaches. Physical and chemical practices have their own hindrances and are expensive. Hence, biological approaches are presently the utmost acceptable eco-remediation processes for regulation of deteriorated rivers.

Previous research studies have revealed that the ecological restoration and river pollution abatement is restricted to a small-scale river restoration (Xiao et al. 2016; Liu et al. 2016; Bu and Xu 2013). The river ecology is susceptible to influences from surroundings near river banks, together with anthropogenic inputs and natural weathering (Yang et al. 2005). Thus, large-scale ecological restoration practices should be conducted on a water shed scale, that combine treatment of riverine and terrestrial ecosystems (Bohn and Kershner 2002; Holl et al. 2003; Wohl et al. 2005). Eco-remediation schemes have to recover the river ecosystem entirely instead of aiming only at water quality improvement.

## 10.5 Physico-chemical River Remediation Methods

For restoring polluted rivers a range of physico-chemical restoration approaches are practiced to deal with pollutions. Physical approaches comprise of sewage diversion, excavation, mechanical separation of algae and water re-routing. Sewage interception and digging deal with the removal of contaminants from the sediments (Zhong et al. 2010). Covering of sediment involve the covering the sediment with plastic films slow down the release nutrients from sediment thereby, improve the transparency of water (Bona et al. 2000). High amount of algal blooms containing river water can be restored by mechanical facilities to remove algae (Pan et al.

2006). The costs of these methods are remarkably higher. Therefore, physical restorations are implemented at small scales and have a limited application for the filed scale restoration projects.

Chemical methods for the river restoration comprise of chemical flocculation, addition of algaecidal compounds, treating water with Calcium hydroxide and on-site chemical treatment. Various chemical algaecides for instances $CuSO_4$, $KMnO_4$, $ClO_2$, $O_3$, $H_2O_2$ and liquefied chlorine can be used to treat the algal polluted rivers (Umphres et al. 2012). To deal with river water acidification lime is added to water bodies (Whitehead and Brown 1989). On-site chemical treatment deals with removal of contaminants like heavy metals through chemical processes such as oxidoreduction, adsorptive, coagulation and precipitation based approaches (Kanan and Nocera 2008). But these methods may introduce secondary pollution of chemicals into the river ecosystems.

## 10.6 Eco-engineered River Water Remediation Technologies

Eco-remediation of polluted river can be defined as the process of repairing deteriorated water bodies through the biotechnological approaches such as plants and microbial processes. It deals with restoring the overall ecosystem of the rivers and dynamics of flora and fauna. Bioecological approaches like microbial enhanced strategies, biofilters, constructed wetlands, periphyton remediation, floating island and beds, eco-tanks, micro-nano bubble technology and bio-rack, these systems do not form secondary pollution (Liu et al. 2016; Brix 1997; Webb and Erskine 2003; Cao et al. 2012; Chang et al. 2019; Sun et al. 2018; Xiao et al. 2016; Wang et al. 2012). Therefore, bioecological approaches are prudent choice for improvement and regulation of contaminated rivers. Based on the system design and their implementation, eco-remediation technologies are further mainly divided into two categories; plant and microorganisms based river remediation systems.

### *10.6.1 Plant Based River Remediation Systems*

Pollutants removal is the main objective of all restoration practices. Hydrophytes are well researched for their ability to remove metalloids, nutritive loads, organic and inorganic pollutants from aquatic matrices. Aquatic macrophytes can mitigate eutrophication through uptake of N, P and heavy metals; furthermore, heterotrophs residing in the root systems have ability to eliminate contaminants by assimilative and catabolic processes (Webb and Erskine 2003). Depending on the growth pattern of vegetation, there are three main types of hydrophytes: emergent, floating-leaved, and submerged hydrophytes.

For the implementation of these approaches, the level of nutrients must be narrowed down firstly; or else, the restored hydrophytes will unable to reach steady phase (Pan et al. 2016). Plant dependent remediation strategies have gained attention since long period of time. Ranges of plants have proved to be a prudent choice for mitigating the environmental contaminant. Many different plant based systems have been used for river eco-remediation as described below, such as constructed wetlands, floating beds, floating island, floating, bio-racks and eco-tanks.

#### 10.6.1.1 Constructed Wetlands

Constructed wetlands are considered as an ecofriendly approach for sustainable wastewater treatment (Rathour et al. 2019b). Constructed wetlands are considered as "black boxes" that treat the wastewater effectively within considerable time regime (Langergraber et al. 2009). Constructed wetlands have long been implemented for the treatment of various wastewaters for instances, agricultural, household, and industrial wastewater. On the basis of hydrodynamic patterns certain wetland designs are available such as surface flow and subsurface flow constructed wetlands (Wu et al. 2015). Both the constructed wetlands are additionally grouped into horizontal and vertical flow due to their mode of water flow. As the names suggest in horizontal flow wetlands water flows from sides whereas, in vertical flow wetlands, water moves from top to bottom through the hollow cylindrical systems.

There are various factors to be considered while designing the constructed wetlands remediation systems such as substrate selection, hydraulic loading rate, hydraulic retention time, plant species selection, wetland hydrodynamics and surface area of wetland. There are different types of substratums which can be selected as a packing material of constructed wetlands such as pebbles, soil, grit, organic substratum, slag, fly ash, charcoal, and sludge. These packing materials provide growth platform to plants, encourage chemical and biological conversion of pollutants along with control water flow (Kadlec and Wallace 2009).

In the field of river bioremediation certain lab scale models of constructed wetlands have been well investigated by many researchers, wetlands constructed with various materials are described in (Table 10.1). Cao et al. (2016) developed a lab scale cubical floating wetland system for efficient removal of nitrogen pollution containing riverine water. In this study, rice straws and light ceramsite were used as substrates for biofilm development in constructed wetlands planted with *Canna indica*. Rice straws as a substratum achieved 78.2%, 62.1%, 81.2% removal efficiencies for total nitrogen, nitrate and ammonium respectively. Likewise, light ceramsite as substratums were found to be less efficient achieving 65.5%, 42.2%, 71.6% removal efficiencies for total nitrogen, nitrate and ammonium, respectively upon 7 days of treatment. Furthermore, certain on-site constructed wetland systems (Table 10.2) have also proved to be efficient for the treatment of river contaminants.

Zheng et al. (2014) demonstrated on-site constructed wetlands with surface and subsurface-flow cells near the Xi'an River, China. System configuration was made with pebbles and grit as supporting platform planted with *P. australis* and *T. orientalis*. The on-site pump was fitted into systems for water inflow. Average surface

**Table 10.1** Lab scale treatment technologies for river bioremediation

| Sr. no. | Types of systems | Components of the systems | References |
|---|---|---|---|
| 1. | Tidal-operated biofilters | Biofilter carrier: Clay ceramsite, lava rock, fibrous carriers and biological ball | Chang et al. (2019) |
| 2. | Bio-rack wetlands | Plant species: *Thalia dealbata*, *Acorus calamus*, *Zizania latifolia* and *Iris sibirica* | Wang et al. (2012) |
| 3. | Floating constructed wetlands | Biofilm carrier: Rice straw and light ceramsite | Cao et al. (2016) |
| | | Plant species: *Canna indica* | |
| 4. | Integrated ecological floating-bed | Biofilm carrier: Artificial semi-soft assembly medium<br>Plant species: *Ipomoea aquatic, Corbicula fluminea* | Li et al. (2010) |
| 5. | Hybrid floating treatment bed | Periphyton biofilm community: Cyanobacteria, Proteobacteria, Bacteroidetes, Planctomycetes, Firmicutes, Actinobacteria, Chlorobi and Acidobacteria | Liu et al. (2016) |
| | | Plant species: *Ipomoea aquatic* | |
| 6. | Biofilm technology | Biofilm carrier: Carbon fibre grasses and artificial aeration | Pan et al. (2016) |
| 7. | Double-layer biofilter | Bio-filter carrier: Ceramic granules fly ash and coal | Jing et al. (2012) |
| 8. | Biofilms technology | Biofilm carrier: Filamentous bamboo and suspended activated sludge | Cao et al. (2012) |
| 9. | Biofilms technology | Biofilm carrier: Elastic filler and AquaMats® ecobase | Xu et al. (2012) |
| 10. | Eco-tank system | Biofilm carrier: Carbon fibre ecological grass | Xiao et al. (2016) |
| | | Plant species: *Myriophyllum aquaticum*, *Hydrocotyle leucocephala*, *Alternanthera Philoxeroides* (Mart.), Griseb and *Ludwigia peploides* (Kunth) | |
| 11. | Constructed floating islands | Plant species: *Canna generalis, Scirpus validus, Alternanthera philoxeroides, Cyperus alternifolius* and *Thalia geniculate* | Zhang et al. (2014) |
| 12. | Biofilter technology | Biofilter carrier: Activated carbon filter | Gao et al. (2010) |
| 13. | Floating bed | Plant species: *Canna indica, Accords calamus, Cyperus alternifolius* and *Vetiveria zizanioides* | Bu and Xu (2013) |
| 14. | Floating treatment wetlands | Microorganisms: Rhizospheric and endophytic bacterial strains, *Bacillus cereus*, *Aeromonas salmonicida* and *Pseudomonas gessardii* | Shahid et al. (2018) |
| | | Plant species: *Typha domingenis* and *Leptochloa fusca* | |

loading of 0.053 $m^3/(m^2.\ day)$ was maintained. Zheng et al. (2014) constructed in-situ series of five constructed wetlands for achieving highest treatment efficiency, which were composed of five free-surface flow wetlands and four horizontal subsurface flow wetlands planted with *P. australis* and *T. orientalis* covering the surface area of around 8000 $m^2$. Results have shown good efficiencies in terms of performance.

**Table 10.2** *In situ* treatment technologies for the river bioremediation

| Sr. no. | Types of the systems | System components | Treatment site | References |
|---|---|---|---|---|
| 1. | Surface-flow constructed wetland | Plant species: *Phragmites australis* and *Typha orientalis* | Zaohe River, China | Dzakpasu et al. (2015) |
| 2. | Constructed wetland | Plant species: *Canna indica*, *Iris pseudacorus* and *Acorus calamus* | Nanfeihe River, China | Guo et al. (2014) |
| 3. | Hybrid constructed wetlands | Plant species: *Phragmites australis* and *Typha orientalis* | Zaohe River to Weihe River, China | Zheng et al. (2014) |
| 4. | Integrated eco-engineered system | Physical treatment: Dredging, Multi-pond constructed wetland<br>Plant species: *Eichhornia crassipes*, *Hydrocharis dubia*, *Vallisneria natans*, *Hydrilla verticillata, Canna indica* L., *Arundodonax* var. *versicolor, Iris pseudacorus* L., *Cyperus alternifolius* L., *Phragmites australis, Nelumbo nucifera* Gaertn and *Lythrum salicaria* L. | The Shuangqiao River, China | Fang et al. (2016) |
| 5. | Combined eco-engineered system | Physical treatment: Artificial aeration Ecological floating beds:<br>Plant species: Candocks and *Ipomoea aquatic* Forsk<br>Microorganisms: Photosynthetic bacterial reagents and *Bacillus subtilis* powder, biological aerated filtration:<br>Biofilm carrier: Slag and coal cinder<br>Artificial biofilms: Biofilm carrier (Beier film) | The Dihe River, China | Sheng et al. (2013) |
| 6. | *In-situ* treatment pods | Plant species: *Eichhorni acrassipes* | Northern Hemisphere river | Jones et al. (2018) |
| 7. | Submerged resin floating bed and micro-nano bubble technology | Physical treatment: Artificial aeration<br>Biofilms | Urban rivers, China | Sun et al. (2018) |
| 8. | Micro-nano bubble technology | Physical treatment: Artificial aeration<br>Biofilms | Urban river, China | Wu et al. (2019) |
| 9. | Microbial technology | Microbial agent: HP-RPe-3 | Chengnan River, China | Gao et al. (2018) |
| 10. | Surface-flow constructed wetland | Plant species: *Typha latifolia, Phragmites australis, Colocasia esculenta, Polygonum hydropiper, Alternanthera sessilis* and *Pistia stratoites* | Ganga River, India | Rai et al. (2013) |

Dzakpasu et al. (2015) configured two floating wetland cells in series, each with a length of 45 m, a width of 20 m and a height of 0.6 m. Pump was fitted into tank systems for water inflow with hydraulic retention time of 4 h. The system was planted with *Phragmites australis* and *Typha oriental.* In another study, on-site treatment system was developed by Guo et al. (2014) where they have fabricated integrated constructed wetland systems comprised of an up-down and horizontal subsurface flowing systems. The systems were planted with *Canna indica*, *Iris pseudacorus* and *Acorus calamus*. Systems were filled with slags and zeolites in the upper level of the down-flow bed and the up-flow bed respectively. *In situ* constructed wetlands configurations shown in various research studies were focused on the engineering aspects and the systems construction according to the level of pollution present and the structure of systems depending on the hydrology of the water bodies.

#### 10.6.1.2 Ecological Floating Wetlands, Beds and Islands

Ecological floating beds, wetlands and islands are the plant based systems which are constructed with few differences in system configuration. A floating treatment wetland consists of floating mats and linked ecosystem communities, such as macrophytes, macro invertebrates, zooplankton, and biofilms (Hubbard et al. 2004; Kato et al. 2009). For the treatment enhancement of polluted river water various biofilm carriers were added to floating wetlands (Zhang et al. 2016). Whereas, the ecological floating bed systems are constructed from free floating plants that lack a substratum as a packing material in the system. Root systems of the floating plants offer surface for the microbial assemblage where they entrap the suspended solids and mediate the breakdown of organic pollutants (Sun et al. 2017).

Furthermore, floating island consists of a broad floating organic mat as a supporter of plants. The top layer of the mat is the root zone made up of tangled plant roots. Lower layer made up of peat and decaying plant material (Lu et al. 2015). Range of lab scale models of all of these systems have been demonstrated by several researchers as described in (Table 10.1), Shahid et al. (2018) have investigated the floating wetland systems to reduce pollution load from Ravi river water. The wetland was constructed of polyethylene foam and floating mat was prepared and planted with *Typha domingensis* and *Leptochloa fusca.* In addition to that rhizospheric and endophytic bacterial strains were isolated and augmented for treatment enhancement.

Bu and Xu (2013) have reported construction of the parallel four floating bed integrated with identical dimensions (2.7 m long, 2.3 m wide and 1.0 m deep with a water depth of 0.8 m) planted with *C. indica*, *A. calamus*, *C. alternifolius*, and *V. zizanioides*. Polluted river was fed into these systems using polyvinyl chloride pipes with valves to control the flow. This system showed the 15.3–38.4, 29.9–88.1 25.4–48.4 and 16.1–42.1% chemical oxygen demand, Chlorophyll a, combined nitrogen and phosphorus reduction efficiencies respectively. While, Zhang and coworkers developed a lab scale floating island fabricated from polyethylene foam planted with *Canna generalis, Scirpus validus, Alternanthera philoxeroides, Cyperus alternifolius* and *Thalia geniculate* which showed better efficiency in removal of biochemical oxygen demand, total nitrogen, total phosphorus from polluted river waters (Zhang et al. 2014).

#### 10.6.1.3 Eco-tanks

Eco-tank systems are constructed using aquatic plants for the remediation of contaminated riverine water as described in (Table 10.1). Xiao et al. (2013) fabricated sequential eco-tank system for the treatment of the contaminated riverine waters. Five quadrangular tanks constructed from polyvinyl chloride that were consecutively connected and contained floating aquatic plants *P. stratiotes, H. leucocephala*, *M. aquaticum* and *P. crispus.* The entire configuration was installed in greenhouse assembly to mimic the polluted riverine environment. The pollutants removal effectiveness of this approach, for chemical oxygen demand, ammonium and overall phosphorus were found to be 71.95%, 97.96% and 97.84%, respectively.

Previous research studies also showed the applicability of lab scale models for the remediation of N,N-dimethylformamide contaminated riverine matrices. Construction of the system was carried out by four hydrophytes namely, *M. aquaticum*, *H. leucocephala*, *A. philoxeroides* (Mart.) Griseb and *L. peploides* (Kunth) Kaven subsp. The eco-tank was found efficient in complete removal of the N,N-dimethylformamide and total organic carbon reduction effectiveness of these models under hydraulic retention time of 10, 7, and 5 d were 72.2, 64.7 and 63.0%, separately while the ammonium concentrations were 2.58, 3.41 and 5.85 mg $L^{-1}$ under hydraulic retention time of 10, 7 and 5 d individually (Xiao et al. 2016).

#### 10.6.1.4 Bio-racks

Bio-rack systems are an emerging approach for treatment of deteriorated river waters. System fabrication contained more than 150 plants per $m^2$ which showed better efficiency in terms of pollutants removal compared to conventional constructed wetlands (Wang et al. 2012). The biorack system also showed enhanced root zones, which provided more surface area for microbial colonization. However, the bio-rack systems were implemented for the treatment of domestic wastewaters only. Additionally, few research studies have also shown the applicability of the biorack systems to combat lower river pollution.

As described in the (Table 10.1), Wang et al. (2012) constructed bio-rack systems for the treatment of river water contaminated with low pollution loads in terms of total nitrogen, phosphorus, biochemical and chemical oxygen demands. This system was constructed with polyvinyl chloride pipes and planted with four different plant species *Iris sibirica*, *Thalia dealbata*, *Thalia dealbata*, *Acorus calamus* and *Zizania latifolia*. This biorack system achieved removal 62.05 to 74.81% of total phosphorus removal and 34.9 to 43.81% nitrogen removal form the river water. It was suggested in this study that bio-rack systems are applicable to river waters with lower pollution load.

## *10.6.2 Microorganisms Based River Remediation Systems*

Microorganisms based eco-engineered systems utilize the potential of bacteria to degrade a range of contaminants efficiently in a cost effective manner. Furthermore, the microbial treatment technologies do not produce secondary metabolites so; practically it is feasible option for the field scale studies. This section covers most of the microbial biofilms and periphyton based eco-engineered technologies used for river bioremediation.

### 10.6.2.1 Biofilm Based Eco-engineered Treatment Systems

The biofilm based approaches comprised of bio-membrane adhered to riverine matrices and micro-transporter for the movement of the contaminants present into water through sorption, degradation and purification under the influence of aeration or dissolved oxygen. Biofilm technology utilizes intensive microbial collaborative structure emended in extracellular polymeric substances that keeps biofilm hydrated. A wide range of microorganisms have functional roles to play in the biofilm communities. Few research studies have shown that biofilms have ability to transform the nitrogen efficiently, which has found application in the river bioremediation (Ribot et al. 2012). Furthermore, biofilms have superiority in providing the contaminant degradation at field as well as lab scale in river remediation technologies (Gao et al. 2018; Cao et al. 2012; Xu et al. 2012).

Cao and co-workers have designed the biofilm based systems using filamentous bamboo which showed better chemical oxygen demand reduction compared to control systems. Pollution removal efficiencies were found 11.2–74.3%, 2.2–56.1%, 20–100% for permanganate index, ammonia nitrogen, turbidity, and total bacteria respectively. Xu et al. (2012) have developed various lab scale biofilm based system for river bioremediation. The systems were developed using various bio-filler such as Elastic filler and AquaMats® ecobase. In terms of pollution load removal were found 84.41–94.21% and 69.66–76.60% for ammonia nitrogen and permanganate index respectively. As stated in the Tables 10.1 and 10.2, range of lab and field scale microbial treatment technologies have gain particular attention in river bioremediation processes that are based on biofilms such as bio-filters and periphyton based remediation technologies.

#### 10.6.2.1.1 Bio-filters in River Bioremediation

Bio-filters are the static bed biofilms packed with different substrates which find their application for the remediation of different effluents (Qiu et al. 2010; Loupasaki and Diamadopoulos 2013). Several research findings have suggested the use of bio-filters for the river bioremediation (Jing et al. 2012; Gao et al. 2010; Chang et al. 2019). Bio-filters provide higher surface platform for the microbial interactions and nutrient load reduction (Qiu et al. 2010; Jing et al. 2012). Substrate selection is the important aspect for the efficient treatment system in bio-filter technologies (Liu et al. 2014; Yang et al. 2018). Microbial communities are the key mediator of contaminants removal in biofilters (Faulwetter et al. 2009; Du et al. 2018).

Recent research studies have developed various optimized biofilters as mentioned in the (Table 10.1). Chang et al. (2019) have constructed tidal-operated biofilters with optimization of the biofilm carriers. They have utilized Ceramsite, magma rock, stringy carriers and biological sphere as biofilm carriers. These systems have shown efficient result in ammonium and phosphorus reduction. Systems constructed from ceramsite and lava rock proved efficient in ammonium and phosphorus removal. However, fibrous carrier-packed biofilters gained improved overall nitrogen reduction.

Gao et al. (2010) developed lab scale immobilized biofilters for the bioremediation of Songhua River, China. They have utilized activated carbon filter as the biofilm support material. It was concluded in this study that the major microbial community found on filters were safe for its application in drinking water treatment processes. Likewise, Jing et al. (2012) developed double-layer biofilters as an emerging design in biofilters. These systems were filled with coal fly ash and ceramic granules, the systems achieved more than 80% of chemical oxygen demand, 85% of ammonium and 60% of total nitrogen removal efficiency in treatment of highly polluted river water having high total nitrogen, phosphorus, biochemical and chemical oxygen demands values.

### 10.6.2.2 Periphyton Based Technologies

Periphytons are the group of aquatic organisms such as algae, microbes, protozoans, metazoan and epiphytes which have ability to colonize under submerged conditions into various surface water matrices (Azim 2009; Wu et al. 2014). Periphyton assemblages have higher affinity towards inorganic N and P (Kangas and Mulbry 2014), metal ions (Soldo and Behra 2000) and organic complexes (Shangguan et al. 2015; Wu et al. 2010). Furthermore, they have ability to withstand range of abiotic ecological factors which prevail in flowing rivers such as variations in temperature, availability of oxygen and nutrients (Shangguan et al. 2015; Liu et al. 2016). Due to these properties, periphyton finds its application in various bioremediation technologies.

Wu et al. (2014) have reviewed various *in situ* treatment technologies for the surface water bioremediation using periphytons. As depicted in (Table 10.1), Liu and co-researchers have developed hybrid floating treatment bed where interactive periphyton communities have assembled with floating beds exhibiting better treatment efficiencies in lab-scale systems.

## 10.7 *In Situ* Emerging Integrated Systems for the River Bioremediation

Most of the river bioremediation techniques are limited to the lab scale due to various environmental challenges and other factors affecting their application for on-site river remediation. Remediation technologies which are solely dependent on either plants or microorganisms alone have limited application at river sites having higher pollution loads. Therefore, the emerging technologies must have to focus on the integrated approaches for remediation of actual polluted river sites. These integrated techniques have supremacies in upholding the constancy and durability of the remediation efficiency, and should be designed to have less treatment period, space along with costs. However, there have been only a few reports concerning the application of integrated eco-engineering in remediation of polluted rivers.

In terms of integration, various physical and chemical approaches are also integrated as a pre-treatment for remediation of the heavily polluted rivers sites for instances, artificial aeration and dredging (Fang et al. 2016; Sheng et al. 2013). Polluted rivers are deficient in dissolved oxygen content. Artificial aeration is prudent choice to oxygenate the polluted river artificially for the growth enhancement of aerobic microorganisms for river restoration and purification (Liu et al. 2019; Dong et al. 2012; Wu et al. 2019; Gao et al. 2018). Various case-studies of on-site river bioremediation technologies have conducted by various research groups as described in (Table 10.2).

Sheng et al. (2013) constructed on-site eco-engineered integrated systems on the Dihe River, China. In this study, ecological floating beds were planted with candocks and *Ipomoea aquatic Forsk.* For the microbial growth enhancement and improvement of water quality, photosynthetic bacterial reagents and *Bacillus subtilis* powder were used. In addition to that biological aerated filters were combined with the treatment process, biofilms were developed on slag and coal cinder. Furthermore, artificial aeration was selected for microbial growth enhancement. This eco-engineered system has proved to be applicable for onsite river water treatment in terms of efficiency and stability.

Fang and co-researchers have integrated the plant based systems with dredging as a pre-treatment for heavily eutrophicated the Shuangqiao River, China. They have designed on-site multi-pond constructed wetlands planted with range of plant species for instances, submerged hydrophytes, floating-leaved plants and emergent plants for bank site treatment of various wastewaters shown enhanced treatment effectiveness (Fang et al. 2016). Jones and co-workers have investigated In-situ phytoremediation potential of Water hyacinth (*Eichhornia crassipes*) of highly polluted British river (Nant-Y Fendrod, a tributary of the River Tawe).

Bank-side study using an *in situ* treatment pods was carried out within the dynamic environment of the Nant-Y Fendrod River itself intended to evaluate the heavy metal removal proficiency of the real field scale system. The treatment system was fabricated with two 1000 litre bulk vessels. Each treatment vessels were affixed with 50 plants. Data indicated that the removal of around 21 heavy metals together with antimony for the first time, in a single experiment was reported. Data indicated reliable results for heavy metal removal from the actual river site (Jones et al. 2018).

Microbial nano-bubble systems are currently emerging technologies for river bioremediation (Sun et al. 2018; Wu et al. 2019) as depicted in (Table 10.2). In these systems, artificial aeration in form of the micro-nano bubble can produce minor bubbles with diameters in micrometres and nanometres which have ability of self-sustenance and lesser rising time compared to ordinary aeration proved to be efficient for an on-site river remediation technology.

In an another study for on-site river bioremediation, the Council of Scientific and Industrial Research-National Botanical Research Institute designed and engineered a subsurface-flow constructed wetlands systems near Haridwar, India, in order to combating urban drains that is being discharged into Ganga directly (Rai et al. 2013, 2015). These wetland systems encompass a surface area of nearly 79.17 m$^2$ and are composed of two compartments; a four-sided planted sector having length, width and diameter around 57.8 m, 56.65 m and 51.8 m respectively. While a settling reservoir has 57.8 m length, 53.5 m width and 51.8 m diameter. The packing materials of constructed wetlands utilized were gravels (0.75 m thickness) of variable dimensions extending from 6 to 25 millimetres thickness. Selection of configuration was done on the basis of pollutants load and hydrodynamics of 0.065 million of litres per day urban runoffs (Rai et al. 2013, 2015). The movement of wastewater from the settling tank was mediated 15 cm below the pebbly layer using hollow tubes. The flow rate was regulated by inlet valve. The macrophytes utilized in wetland configuration are, *C. esculenta, P. australis, T. latifolia, A. sessilis, P. hydropiper,* and *P. stratoites.* These systems are doing well in terms of overall biochemical and chemical oxygen demands, total nitrogen and total phosphorus removal for on-site river water treatment.

## 10.8 Concluding Remarks

Large numbers of treatment methods are available in the field of river bioremediation, but for the proper method selection, it is very crucial to do an advance analysis of the contaminated riverine environments and the types of pollutants present at such sites. It is significant to integrate eco-engineered bioremediation technologies in order to develop better river restoration systems. Single eco-engineering practises are limited to the lab scale applications, whereas, *in situ* applications would require working with several approaches simultaneously. Integrated remediation technologies have advantages in upholding the steadiness and durability of the remediation effectiveness. Bacteria and plants assisted remediation can be superior option for the specific contaminated site having comparatively low pollution loads. Various eco-based technologies such as constructed wetlands, biofilters, periphyton, islands, floating beds, microalgal, ecotanks, micro-nano bubble technology and bio-rack based remediation technologies account for an ecofriendly and sustainable approach for the restoration of polluted river ecosystems.

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