Pollution, 5(3): 555-568, Summer 2019
DOI: 10.22059/poll.2019.272339.558
Print ISSN: 2383-451X Online ISSN: 2383-4501
Web Page: https://jpoll.ut.ac.ir, Email: jpoll@ut.ac.ir

Review on Bioremediation: A Tool to Resurrect the Polluted Rivers

Shishir, T. A.[1*], Mahbub, N.[2], and Kamal, N. E.[1]

1. Department of Mathematics and Natural Sciences, BRAC University, Dhaka, Bangladesh
2. Department of Pharmacy, East West University, Dhaka, Bangladesh

Received: 26.12.2018 Accepted: 17.2.2019

ABSTRACT: The term bioremediation describes biological machinery of recycling wastes to make them harmless and useful to some extent. Bioremediation is the most proficient tool to manage the polluted environment and recover contaminated river water. Bioremediation is very much involved in the degradation, eradication, restriction, or reclamation varied chemical and physical hazardous substances from the nearby with the action of all-inclusive microorganisms. The fundamental principle of bioremediation is disintegrating and transmuting pollutants such as hydrocarbons, oil, heavy metal, pesticides and so on. Different microbes like aerobic, anaerobic, fungi and algae are incorporated in bioremediation process. At present, several methods and approaches like bio stimulation, bio augmentation, and monitoring natural recovery are common and functional in different sites around the world for treating contaminated river water. However, all bioremediation procedures it has its own pros and cons due to its own unambiguous application. Above all, utilization of bioremediation as a tool to resuscitate the polluted river will endow us considerably minimal contaminated, safe as well as fumigated and shipshape rivers.

Keywords: Bioremediation; Biodegradation; Polluted River; Water Treatment, Contamination.

INTRODUCTION

United Nations Educational Scientific and Cultural Organization (UNESCO) claims water encompasses three-fourth of the earth plane but unfortunately only 0.3% to 0.5% of all the water resources are considered fresh or safe for human and animals ("Earth's Freshwater | National Geographic Society" 2012). Therefore, in spite of having immense quantity of water on earth, a very small proportion can be directly used, on contrary rest of the polluted water are causing severe health and environmental complexities. In the 21st century, water is turning out to be a priceless scarce resource. Polluted water is a tremendous problem to natural resources, as well as to major tactical disputes linked to the sustainable growth of a country's economy and its long-term stability (Saeijs & Van 1995; Linton 2004; Sivakumar 2011). Demand for water in industry, agriculture, home have enlarged rapidly with the worldwide population outburst and swift financial development causing the shortage of fresh water more and more critical (Azevedo et al. 2000; Kuylenstierna et al. 1998). Moreover, worsening of water quality at the same time is aggravating the scarcity of water based

* Corresponding Author Email: shishirbd4@gmail.com

resources therefore, quality associated water unavailability has recently been emerged as a matter of huge apprehensiveness at international, regional as well as at local levels, particularly in developed and developing countries (Zeng et al.2013; Azevedo et al. 2000; Delpla et al. 2009). Therefore, water associated resources fortification, balanced utilization and well-organized restoration of contaminated water has become one of the most vital conundrums of the current world.

In broad spectrum, three types of approaches have been brought into play to bring back the quality of water in polluted rivers termed as physical, chemical and biological method. First of all, physical methods take account of artificial aeration (Zhang et al. 2010; Ouellet et al. 2006), water diversion (Liu et al. 2014), sediment dredging (Mulligan et al.2001) and mechanical algae subtraction (Wang et al. 2012). These methods are very straightforward and old-fashioned and cost a lot of human, material, monetary resources along with time. Physical methods emphasis on treatment based on indications overlooking the source of the pollution in many cases and results in the incomplete removal of the contaminants from the water body proficiently. Secondly, chemical methods include chemical oxidation, chemical precipitation, enhanced flocculation, and algae removal using chemicals (Wu et al. 2015). These methods are designed to eliminate pollutants like suspended solids, dissolved nitrogen and phosphorus thereby augmenting the limpidity of water. However, this procedure utilize huge amount of chemicals including coagulants (e.g. iron and aluminum salts), precipitants (e.g. lime), oxidizing agents (e.g. hydrogen peroxide) etc. The major advantage of chemical methods is no need for long-term maintenance and appropriate for emergency treatment. On the other hand, it is unavoidable that these methods produce secondary pollutants; thus, concealed hazards for the ecosystem persist (Margeta et al. 2013). Last but not the least, biological methods includes plant purification technology (Sun et al. 2009), combinatorial biotechnology (Sheng et al. 2013; Bosso et al. 2015; Ravikumar et al. 2017), bioremediation technology (Hashim et al.2014; Hechmi et al., 2016; Mani et al. 2017;Stocking et al., 2000), biofilm technology (Boltz et al. 2017; Chen and Stewart 2000), and artificial wetland technology (Zheng et al. 2016) which all are eco-friendly and designed to boost the self-refinement the quality of the river water, and reestablishing river's ecosystem. However, these methods are to some extent costly in their implementation though they are very effective. Therefore, more research are required to overcome the cost related issues and technical difficulties in near future to save the rivers worldwide.

Bioremediation technology, invented by George M. Robinson is outlined as the process of degrading organic wastes biologically under meticulous conditions using microorganisms (Vidali 2001). According to the definition, bioremediation process utilizes of living microbes to degrade the ecological pollutants into less noxious forms. This technique utilizes naturally present bacteria, fungi as well as plants to terminate or depollute substances which are threat to human health as well as the environment. The microbes used in the process are mostly native to the polluted area or sometimes collected from somewhere else to introduce into the polluted site (Qiu et al. 2012). Amongst all the approaches described above, bioremediation is found most appropriate for its advantages including large efficiency of degradation ability, very low energy depletion, absence of secondary pollution, no complexity in technical process, long-term viability, and no additional constructions are required (Stocking et al. 2000). Therefore, it has been extensively and effectively executed in many countries for a number of purposes. For example, an experiment found that addition of two varieties of microbial population into comprehensively contaminated river could proficiently recover water quality by reducing COD and BOD up to 70% (Sheng et al. 2012).

In this review, different techniques used in bioremediation and the microorganisms used to remediate the river water pollutants have been sketchily discussed.

Bioremediation Schemes

Contemporary molecular biology and ecological knowledge offers us numerous prospects for more competent biotic processes to achieve notable accomplishments for the cleanup of contaminated river water. Bioremediation is used to maintain contaminated river to a harmless state, or to a level which is underneath concentration limits authenticated by supervisory authorities (Crawford and Crawford 2005). Bioremediation utilizes naturally occurring microbes, fungi or plants where some of them are native and some of them are introduced to degrade the organic pollutants. Introduction of microbes to a contaminated site to augment remediation process is known as bio augmentation whereas, when nutrients and other factors are provided to enhance the environment for the indigenous microorganisms is called bio enhancement (Kharayat 2012). Pollutant substances are distorted by living organisms through different reactions taking place as a part of microbes' metabolic actions. Biodegradation basically occurs due the actions of multiple organisms which enzymatically deal with the pollutants and turn them into innocuous products (Vidali 2001). However, effectiveness of bioremediation largely depends on many environmental settings that permit microbial activity as well as growth; therefore its utilization frequently includes the tweaking of environmental boundaries to enhance the microbial growth along with degradation to progress at a faster rate (Boopathy 2000). However, every silver lining has a cloud, in the same way like other technologies, bioremediation has some inadequacies as well, for example some pollutants like high aromatic hydrocarbons and chlorinated organics are invulnerable to microbial action. Therefore these compounds are metabolized either very slowly or sometimes not at all, which makes the prediction of the rates of cleanup for a bioremediation triticale (Megharaj et al. 2014). Auspiciously bioremediation processes are usually more cost-effective than conventional methods like incineration, chemical treatment and others. Moreover, many pollutants are treatable on site which reduces the risks for cleanup personnel to exposure, or hypothetically wider exposure due to transportation accidents. In addition, bioremediation is completely natural attenuation process as a result public acceptance is higher than other technologies due to fewer side effects. Bioremediation systems can be operated both under aerobic conditions as well as anaerobic condition. Though most of the processes take place in aerobic environment but running a process in anaerobic settings can be used to degrade recalcitrant molecules by microorganisms (Vidali 2001).

Microbes in Bioremediation Processes

Microbes are present in abundance at almost all environment and can grow along with adaption at varieties of conditions like at freezing temperatures as well as utmost heat, can adapt in desert conditions or even in water, can survive in aerobic conditions in addition to anaerobic conditions, even in the presence of harmful compounds and in waste stream (Crawford and Crawford 2005). Due to their high abundance and adaptability, microbes are used to treat polluted rivers to degrade polluting compounds. Microbes used in bioremediation uses natural microorganisms, either indigenous or added from outside which uses pollutants for their carbon as well as energy source (Pieper and Reineke 2000). However, selection of microbes varies depending on the chemical nature of the contaminant along with the survival capacity of microbes in those particular conditions (Das, S. 2014). As a result, microbes used in river bioremediation are classified into different classes.

Aerobic: These microbes function in the presence of oxygen and degrade a wide variety of pollutants including hydrocarbons, alkanes, and polyaromatic substances. Moreover, many of these microbes are found to use the pollutants as their energy and carbon source (Passatore et al. 2014).

Anaerobic: Microorganisms those function in the absence of oxygen are getting immense interest to be used for bioremediation of PCBs (polychlorinated biphenyls) in river deposits though they are not used as frequently as aerobic ones (Lovley 2001).

Ligninolytic fungi: Fungi those who have the potential to degrade toxic substances of river are used to bio remediate polluted river. One of the examples is *Phanaerochaete chrysosporium* fungus which has ability to patch up a diverse range of persistent toxic pollutants. However, these ligninolytic fungi needs substrates for signifying their activity and commonly used substrates include corn cobs, straw, saw dust etc. (Field et al. 1993; Pointing 2001).

Methylotrophs: Microorganisms, mostly aerobic microbes those feed on methane for their energy and carbon source are known as methylotrophs and initially secret enzyme methane monooxygenase for initiating aerobic degradation of pollutants. These microbes uses long range of substances as substrates and active in contrast to a wide range of pollutants like 1,2-dichloroethane and chlorinated aliphatic trichloroethylene (Babel et al. 1999; Hard et al. 1997).

Microorganisms used in bioremediation are predominantly bacteria as well as fungi which are nature's original recyclers with their ability to transmute natural and artificial substances into sources of energy and nutrition for their own growth, bring to mind that costly physical or chemical treatment procedures might be swapped with biological processes which are of low cost and environmental friendly. Therefore, microbes correspond to a promising and largely unexploited resource for new environmental biotechnological approach to treat polluted river water around the world. Researchers are continuously thriving to verify the bioremediation prospective of different microorganisms and the findings propose that further investigation of microbial diversity will show the way to discover more organisms with unique potentials to be useful in bioremediation (Bamforth and Singleton 2005).

Bioremediation technologies

Cost effectiveness of bioremediation puts it into the major interest compared with other remediation with conventional techniques along with its permanent solution to pollution due to the complete mineralization of contaminants (Crawford and Crawford 2005). Moreover, it is a non-invasive practice that keeps the ecological unit intact and has the potential to deal with very minor concentration of pollutants whereas the cleanup by physical and chemical approaches would not be practicable. However, bioremediation exhibits some major drawbacks like the processes might be time-consuming and less predictable than conventional methods which confine the appliance of these techniques. Nevertheless, the major approaches for bioremediation of river water can be the following: (i) Monitoring natural recovery (MNR), (ii) Bio stimulation, (iii) Bio augmentation. More than one technique can be applied to enhance the capability of bioremediation and bring about the desired effect.

1. Monitoring natural recovery (MNR)

Monitoring natural recovery involves leaving pollutants in the place and allowing ongoing natural processes in river water to degrade or restrain the pollutant in situ to lessen its bioavailability (Sharma et al. 2009). This technique does not require any action therefore it is reflected as the result of a deliberate, meticulous decision considering the detailed site assessment and characterization. MNR involves several processes like natural deposition, sorption to other active compounds, and removal of contaminants from site of pollution by erosion, dispersion and mostly pollutants can be converted to less toxic form (Margesin and Schinner 2001).

MNR is found least expensive response action compared with other physical and chemical methods. Though this process requires long-term monitoring then again MNR is deliberated as the most operative for low menace sites with low intensity of contamination, where both human and environmental health risks are not severe (Perelo 2010).

2. Bio stimulation

Bio stimulation is the dilapidation of contaminants in anaerobic pathway using anaerobic microbes thereby requires additional electron acceptor other than oxygen. For instance, degradation of benzene in contaminated sediments from river requires Fe (III), sulfate, nitrate as electron acceptor (Margesin and Schinner 2001). Then again, contaminants are not always readily available to the organisms due to their complex structures but degradation potential largely depends on the availability of the contaminants therefore surfactants are applied as potential agents to boost solubility of the contaminants. These surfactants can be either bio surfactants like bile salt or synthetic like sodium dodecyl sulfate, have demonstrated their potential to enhance bioavailability for degradation (Tyagi et al. 2011). However, these surfactants are not always found to potentiate degradation, they might lead to opposite effect like inhibiting the degradation, posing toxic effects to the degrading microbes and even surfactants themselves can be contaminant substrate (Andreolli et al. 2015).

3. Bio augmentation

The most appropriate technology for bioremediation of polluted river water is the bio augmentation which is the introduction of microorganisms into the contaminated river water with pollutants degrading capabilities to assist indigenous microbes as well as speed up the degradation process (Herrero and Stuckey 2015). PAHs degradation is found successful using this technique though this process has both negative and positive debate (Bamforth and Singleton 2005). Bio augmentation approaches may become fruitful notably in the remediation of man-made impurities in cases when suitable bacteria with the suitable catabolic pathways are not present in the polluted river water. Microbial reductive dehalorespiration is an auspicious means for the reclamation and degradation of halogenated compounds like PCBs, PCDD/Fs and chlorinated ethylene which are toxic as well as carcinogenic (Hendrickson 2001). Specific dehalorespiration organisms use chlorinated compounds for their source of energy by substituting halogen with hydrogen in anaerobic environment. Dehalococcoides strains have found to be very effective against these halogenated contaminants (Lendvay et al. 2003). Moreover, Diaz et al. found microbes with ability to degrade petroleum and tolerate high salinity which can be used to treat river near sea with high salinity like mangroves. However, bio augmentation techniques has some drawbacks as well, for example this process can be inhibited by numerous factors like redox, pH, presence of toxic contaminants to bio augmentation microbes, concentration of contaminants, bioavailability of the pollutants and absence of co-substrates (El Fantroussi and Agathos 2005). Therefore, microbes' selection must be most prioritized for successful bio augmentation keeping the indigenous microorganisms in mind. To avoid all the complexities, three standards have been developed through series of experiment for the selection of microorganisms for bio augmentation process. These standards include the relative abundance of the source microbial populations in the target environment, tolerance to co-contaminants and the ability to degrade target contaminants (Van et al. 2004).

Last of all, bio augmentation approach is worthwhile when the restrictive elements of biodegradation is absent as well as the expression of catabolic genes within the native microbes so that the deficient genetic information can be filled by the introduced microbes.

Bioremediation of Contaminants in River Water

Bioremediation triggers the improvement of water quality of river with the employment of microbes, results in inferior gathering of slime or organic matter in river bed, higher infiltration of oxygen and overall improvement of the environment. An efficacious bioremediation have to deal with optimization of nitrification to keep low ammonia concentration, optimization of denitrification to reduce leftover nitrogen, enhancement of carbon mineralization, maximization of sulphide oxidation, maintenance of stable and various microorganisms' community in river and capitalize on the productivity of shrimp and secondary crops (Boopathy 2000).

1. Bioremediation of Organic Detritus

Industrialization and marine transportation has great impact on people's life. However, these modernizations have negative effects in the ecosystem which are becoming more and more apparent with time. Pollutants from these sources contain dissolved and suspended organic matter, comprehending carbon chains which are very much accessible by microbes and algae (N. Das and Chandran 2011). Microbes degrading the organic detritus mainly of genus Bacillus must be capable of efficaciously clean up carbonaceous wastes from water. Some examples of these microbes include like *Bacillus subtilis*, *Bacillus cereus*, *Bacillus licheniformis*, *Bacillus coagulans*, and of the genus *Phenibacillus*, like *Phenibacillus polymyxa*, are bacteria appropriate for bioremediation of organic waste (Cerqueira et al. 2011; Guo et al. 2010). However, these microbes are not naturally present in prerequisite amounts in the river water, therefore certain Bacillus strains are appended into the water in adequate quantities to make an impact competing with naturally persistent microbes for the available organic matter, like percolated or left-over feed and shrimp feces (Jacques et al. 2008). These Bacillus are constructed, amalgamated with sand or clay and disseminated to be deposited in the river (Obed Ntwampe 2014). Moreover, Lactobacillus are also used along with Bacillus to speed up the breakdown of organic matters and yields a number of enzymes that rupture pollutants like proteins and starch into small particles, which are then utilized as energy source by other microbes present in that environment (Shrivastava et al. 2013; Singh and Sarma 2010).

2. Bioremediation of Nitrogenous Compounds

Nitrogenous compound (e.g., ammonia and nitrite) in excess amount in river water lead to worsening of water quality and trigger toxicity to fish and shrimp. The large amount of ammonia is from fish excretion, hominid waste and sediments generated from the mineralization of organic substances.

Nitrification process as follows:

$$NH_4^+ + 11/2\ O_2 \rightarrow NO_2^- + 2H^+ + H_2O$$

$$NO_2^- + 11/2\ O_2 \rightarrow NO_3^-$$

Microbiological nitrification is considered as the most appropriate method for the confiscation of ammonia with the use of ammonia oxidizers under five genus named *Nitrosomonas*, *Nitrosovibrio*, *Nitrosococcus*, *Nitrolobus* and *Nitrospira*, and nitrite are oxidized by three genuses known as *Nitrobacter*, *Nitrococcus* and *Nitrospira* (De Oliveira et al. 2016). In addition, some of the heterotrophic nitrifies produce low levels of nitrite and nitrate with the usage of organic sources of nitrogen such as ammonia (Martinez-Porchas et al. 2014). Nitrification procedure alters the pH slightly acidic to facilitate the bioavailability of soluble substances along with the production of nitrates (Hlihor et al. 2017). Additionally, anaerobic bacteria grow in the region where nitrates accumulation creates anaerobic region and these microbes produce nitrogen gas reducing nitrate (Sun et al. 2009).

Biochemical pathways of nitrification are as follows:

$NO_3 \rightarrow NO_2 \rightarrow NO \rightarrow N_2O \rightarrow N_2$

Though nitrification species are limited and less diversified in number but at least 14 genuses of bacteria are found to reduce nitrate. *Pseudomonas*, *Bacillus* and *Alkaligenes* are the most prominent among all the species having denitrification capabilities (Focht and Verstraete 1977). Recently, work of Nduwimana et al. confirmed that the bioremediation of water using a combination of Nitrobacteria and grass plant species, *Lotium perenne* improve waste water quality (Pan et al. 2007).

3. Bioremediation of Hydrogen Sulphide

Sulphur is considered important since organic Sulphur converted to sulphide in aerobic conditions and consecutively gets oxidized to sulphate by microorganisms which are highly soluble in water and disappears at a higher rate from sediments with time. Moreover, sulphate can be used for microbial metabolism instead of oxygen under anaerobic conditions and lead to the production of hydrogen sulphide gas by a cycle of microbes mediated reductions (Szabõ 2007).

$SO_4^{2-} + 4H_2 + 2H^+ \rightarrow H_2S + 4H_2O$

Organic materials in water stimulate H_2S production which is highly soluble in water and causes lessening of benthic fauna gill damage and other complaints in fish (Rowan et al. 2009). On the other hand, unionized H_2S is tremendously toxic to fish at lower concentrations which even occurs in normal water as well as contaminated river water (Bonn and Follis 1967).

The photosynthetic bacteria breaking H_2S at pond bottom is extensively used in river to maintain a satisfactory environment (Barbosa et al. 2001). These types of bacteria have bacteria-chlorophyll for absorbing light to cause photosynthesis under anoxic environment (Wätzlich et al. 2009). These are purple and green Sulphur bacteria growing in anaerobic condition, decompose organic matter such as H_2S, NO_2 and other unsafe wastes of river by reducing electrons from H_2S using lower energy than H_2O excruciating photo-autotrophs and therefore require decreased light strengths for photosynthesis (Baykara et al. 2007).

The general reaction of this photosynthesis is as follows:

$CO_2 + 2H_2S \rightarrow (CH_2O) + H_2O + 2S$

$S + CO_2 + 3\ H_2S \rightarrow (CH_2O) + H_2SO_4$

$CO_2 + NaS_2O_3 + 3H_2O \rightarrow 2(CH_2O) + NaS_2O_4 + H_2SO_4$

Rhodospirillaceae family have the capability to grow in both aerobic and anaerobic conditions like heterotrophic bacteria therefore, they can be used to efficiently mineralize waste at river ground (Jayamani 2015). Interestingly, this family can grow and survive in dark without consuming lunar energy (Singh and Radhika, 2001). Some of the essential Photosynthetic bacteria are *Amoebobacter*, *Chlorobium*, *Chloropseudomonas*, *Chromatium*, *Clathrochloris*, *Ectothiorhodospira*, *Lamprocystis*, *Pelodictyon*, *Prosthecochloris*, *Rhodomicrobium*, *Rhodopseudomonas*, *Rhodospirillum*, *Thiocapsa*, *Thiocystis*, *Thiodictyon*, *Thiopedia*, *Thiosarcina*, *Thiospirillum* etc. (Idi et al. 2015).

4. Bioremediation of Petroleum

Production, appliance and release of several petroleum products and oil slick happening bring about the petroleum contamination, one of the main contaminations in aquatic environment. Therefore, controlling it has become one of the major research focuses to environmental experts which can be done using regular microorganisms present in most environments those can degrade and transmute petroleum. These microorganisms are capable of enzymatically degrade petroleum hydrocarbons whereas some of them degrade large chain alkanes, aromatics, and in some cases both paraffinic and aromatic hydrocarbons (Megharaj et al. 2011). Short chain alkanes ranging C10 to C26 are considered most readily degradable, however low molecular weight aromatics like benzene, xylene and toluene found in petroleum and very toxic in nature are conveniently biodegraded by number of aquatic microorganisms (Bezza and Chirwa 2015; Martinez-Porchas et al. 2014; M. Wu et al. 2016). Moreover, substances structure is one of the major determinants of biodegradation since more complex structures are more resistant to biodegradation therefore a small number of microbes can degrade those complex structures resulting in lower biodegradation rate in comparison with simpler hydrocarbons present in petroleum (Boopathy 2000). Petroleum biodegradation in the river water is carried out by various bacterial residents like different Pseudomonas species, widely distributed in the seas. These Pseudomonas bacteria along with other naturally produced by plants, algae, and living organisms are apparently use hydrocarbons, other substrates like carbohydrates and proteins in river water to improve the water quality (Margesin and Schinner 2001). As soon as an environment is polluted with petroleum, the hydrocarbon degrading bacteria multiplies rapidly, specifically when aquatic environment is adulterated with petroleum hydrocarbons; there is an upsurge of bacterial inhabitants having the capability of hydrocarbon utilization (Atlas 1995). Some of the competent petroleum degrading Cyanobacteria are *Oscillatoria salina*, *Plectonema terebrans* and *Aphanocapsa sp*. (Zinicovscaia and Cepoi 2016; Vijayakumar 2012).

5. Bioremediation of Heavy Metal Contamination

Immobilization of heavy metals is the basic principle of remediation of heavy metal-contaminated river along with affecting the pattern of heavy metals by some group microbes with capacities of synchronization of the surface of the cell wall of microorganisms (Malik 2004). These microbes form covalent or ionic bond with metal ions to absorb heavy ions (Kang et al. 2016). The absorbing capacity of the microbes of absorbing metal is sometimes greater than artificial chemical adsorbent. For example, *Rhizopus nigricans* can absorb 135.8 of Cr (IV) per gram of bacterial weight (Bai and Abraham 2001). Heavy metal morphology is deteriorated by biological efficiency and these heavy metals are altered by microbial life activity, which is achieved by morphological alteration of microbes specific for heavy metals, eventually results in relieve of the pollution of heavy metal. A research demonstrates that the cashmere of cyanobacteria and algae can eliminate heavy metals in wastewater. Some of the sulphate reducing bacterium produces H_2S, by reducing heavy metals such as ZnS, CdS and CuS which have very low water solubility to deposit and controls the heavy metal contamination (Subashchandrabose et al. 2013;

Zinicovscaia and Cepoi 2016). Biological methylation proposed by Frankenberger accelerates cultivation, management and addition of supplement to make heavy metal selenium volatile to decrease the toxicity produced (Dungan and Frankenberger 1999).

6. Bioremediation of Eutrophication

Eutrophication or algal bloom largely depends on presence of carbon, nitrogen and phosphorus in the aquatic environment, which are the indispensable factors for growth of algae as well as the eutrophication in river water where water current is absent due to blockage or deposition of huge amount of pollutants (Khan and Ansari 2005). Phosphorus is every so often considered as the limiting factor for eutrophication since the overall concentration of phosphorus in the still water 0.086mg per liter indicates the threshold of eutrophication, as well as the available content of nitrogen in algae is more than phosphorus (Kharayat 2012; Jiang et al. 2010). Eutrophication is eliminated using advanced technology that removes nitrogen, phosphorus and other organic carbon sources. Mechanical dredging is also applied in some cases. Moreover, water flushing and bioremediation are found effective against eutrophication as well (Shan et al. 2009). Bioremediation of eutrophication involves the usage of microbes to remove phosphorus and nitrogen from contaminated water. Pinar et al. found *Klebsiella oxytoca* very effective for the removal of nitrogen from water (Shawabkeh et al. 2007). In addition, *Phormidium bohneri* a photoautotrophic microorganism removes both nitrogen and phosphorus under certain conditions using solar energy (Chevalier et al. 2000). The principle behind the removal of nitrogen is nitrification and denitrification of nitrogen sources like ammonia, nitrates etc. whereas phosphorus removal is accomplished by absorption by microbes under both aerobic and anaerobic condition (Shan et al. 2009). Compared with conventional methods, microbial treatments are more stable, cheaper and easier with better results which make it the superior choice for treatment of eutrophication and exercised widely to eradicate phosphorus and nitrogen in water.

7. Bioremediation of Pesticide

River water, to some extent is polluted by pesticides due to their excessive use in agriculture. However, fortuitously researchers have isolated many microorganisms like bacteria, fungi, algae and actinomycetes with the capability of degrading these pesticides among them bacteria is of most interest, with fungi in second position (Singh and Tripathi 2007). On the other hand, since herbicide is new in play, therefore isolation and use of microbes to degrade herbicide is active research area now a days (Cork and Khalil 1995). According to the research of Alian et al., napropamide into soil promotes the production of the pesticide degrading bacteria. Vinclozolin on soil also found to uninterruptedly tempt and screen pseudomonas of pesticide-degrading bacteria (Krol et al. 2000). It is of great interest that, this degrading gene of pesticide-degrading bacteria mostly presents in plasmids, and articulated in other bacterial strains over plasmid transfer. In the meantime, one bacteria strain was found able to carry manifold degrading plasmids, therefore mounting acceptances and augmenting capacities of biodegradation of pesticides in water (Shao and Behki 1996).

Advantages and Disadvantages of Bioremediation

1. Advantages of Bioremediation

Bioremediation is a widely accepted biological approach to treat contaminated water in river using microbes which have the ability to degrade the contaminant. Microbes are found to increases in number in the presence of pollutants but decreases when bio-degradative contaminants level declines. Bioremediation theoretically is expedient for the complete degradation of a wide range of pollutants and complete degradation of contaminants is possible in place of transferring them from one environment to another like, land to water or air. Many harmful compounds can be transformed to harmless products which in turn eradicate the chance of imminent accountability for treatment and dumping of polluted material and bioremediation residues are usually harmless products including carbon dioxide, water, and cell biomass. Moreover, bioremediation is possible in situ without hampering normal natural activities, eliminating the transportation issue and risk to human health as well as environment. Last but not the least; bioremediation is less expensive than other conventional technologies utilized for crackdown of dangerous waste.

2. Disadvantages of Bioremediation

There is no silver lining without cloud, similarly bioremediation deliberated as a boon in the midst of contemporary days regarding environmental issues, can also has some problematic issues as well. Some of them are as follows: bioremediation is limited to biodegradable compounds only; therefore, all pollutants cannot be treated using this technique. E.g. Plastic. On the other hand, though biodegradation is considered safe but bio degradative residues sometimes turn out to be more tenacious and noxious than the parent compound. Moreover, these processes are often extremely specific and depend largely on many parameters like environmental conditions, site factors, microbial populations, levels of nutrients and concentration of contaminants which make the process complicated. Then again, most of the process is still in research phages that make it challenging to insinuate full-scale field processes based on the result from bench and pilot scale studies. Longer time is required for bioremediation than other treatment options e.g. excavation, incineration etc. and unfortunately mixtures of contaminants are rarely treatable with single microorganism. Last of all, pollutants which are present in different forms such as solids, liquids and gases makes microbes selection problematic since microbes' survival depends on environmental conditions.

CONCLUSION

Bioremediation is a very productive and attractive choice using microbial activity to remediate, clean, manages and recovers polluted river water to normal. However, the speed of these processes are limited by competition with biological agents, insufficient amount of vital nutrient, unpleasant exterior abiotic environments like inappropriate aeration, humidity, altered pH, unfavorable temperature and lower bioavailability of the pollutant. As a result, bioremediation in natural condition is not much successful as expected which makes it to be less favorable however can be operative where environmental conditions facilitate microbial growth and activity. Moreover, microbes can be genetically engineered to enhance their potential to carry out remediation process of wide range of pollutants in diverse environmental conditions. Bioremediation has been employed in diverse river sites around the globe within fluctuating degrees of triumph and found the advantages are superior to those disadvantages therefore its popularity is increasing over time. Different species are discovered from different locations which are effective in contamination control system. Therefore, there is no doubt that with proper research in this field, bioremediation processes are going to pave a way to safe, fumigated and shipshape rivers.

REFERENCES

Andreolli, M., Lampis, S., Brignoli, P. and Vallini, G. (2015). Bioaugmentation and biostimulation as strategies for the bioremediation of a burned woodland soil contaminated by toxic hydrocarbons: A comparative study. *J. Environ. Manage.* https://doi.org/10.1016/j.jenvman.2015.02.007.

Atlas, R. M. (1995). Petroleum biodegradation and oil spill bioremediation. *Mar. Pollut. Bull.* https://doi.org/10.1016/0025-326X(95)00113-2

Azevedo, L. G. T. de, Gates, T. K., Fontane, D. G., Labadie, J. W. and Porto, R. L. (2000). Integration of Water Quantity and Quality in Strategic River Basin Planning. *J. Water Resour. Plan. Manag.* https://doi.org/10.1061/(ASCE)0733-9496(2000)126:2(85)

Bai R, S. and Abraham, T. E. (2001). Biosorption of Cr (VI) from aqueous solution by Rhizopus nigricans. *Bioresour. Technol.* https://doi.org/10.1016/S0960-8524(00)00107-3

Bamforth, S. M. and Singleton, I. (2005). Bioremediation of polycyclic aromatic hydrocarbons: Current knowledge and future directions. *J. Chem. Technol. Biotechnol.* https://doi.org/10.1002/jctb.1276

Barbosa, M. J., Rocha, J. M. S., Tramper, J. and Wijffels, R. H. (2001). Acetate as a carbon source for hydrogen production by photosynthetic bacteria. *J. Biotechnol.* https://doi.org/10.1016/S0168-1656(00)00368-0

Baykara, S. Z., Figen, E. H., Kale, A. and Nejat Veziroglu, T. (2007). Hydrogen from hydrogen sulphide in Black Sea. *Int. J. Hydrogen Energy*. https://doi.org/10.1016/j.ijhydene.2006.07.021

Bezza, F. A. and Chirwa, E. M. N. (2015). Production and applications of lipopeptide biosurfactant for bioremediation and oil recovery by Bacillus subtilis CN2. *Biochem. Eng. J.* https://doi.org/10.1016/j.bej.2015.05.007

Boltz, J. P., Smets, B. F., Rittmann, B. E., Van Loosdrecht, M. C. M., Morgenroth, E. and Daigger, G. T. (2017). From biofilm ecology to reactors: A focused review. *Water Sci. Technol.* https://doi.org/10.2166/wst.2017.061

Bonn, E. W. and Follis, B. J. (1967). Effects of hydrogen sulfide on channel catfish, Ictalurus punctatus. *Trans. Am. Fish. Soc.* https://doi.org/10.1577/1548-8659(1967)96[31:EOHSOC]2.0.CO;2

Boopathy, R. (2000). Factors limiting bioremediation technologies. *Bioresour. Technol.* https://doi.org/10.1016/S0960-8524(99)00144-3

Bosso, L., Scelza, R., Testa, A., Cristinzio, G. and Rao, M. A. (2015). Depletion of Pentachlorophenol Contamination in an Agricultural Soil Treated with Byssochlamys nivea, Scopulariopsis brumptii and Urban Waste Compost: A Laboratory Microcosm Study. *Water, Air, Soil Pollut.* https://doi.org/10.1007/s11270-015-2436-0

Cerqueira, V. S., Hollenbach, E. B., Maboni, F., Vainstein, M. H., Camargo, F. A. O., Peralba, M. do C. R. and Bento, F. M. (2011). Biodegradation potential of oily sludge by pure and mixed bacterial cultures. *Bioresour. Technol.* https://doi.org/10.1016/j.biortech.2011.09.074

Chen, X. and Stewart, P. S. (2000). Biofilm removal caused by chemical treatments. *Water Res.* https://doi.org/10.1016/S0043-1354(00)00187-1

Chevalier, P., Proulx, D., Lessard, P., Vincent, W. F. and De La Noüe, J. (2000). Nitrogen and phosphorus removal by high latitude mat-forming cyanobacteria for potential use in tertiary wastewater treatment. *J. Appl. Phycol.* https://doi.org/10.1023/A:1008168128654

Cork, D. J. and Khalil, A. (1995). Detection, Isolation, and Stability of Megaplasmid-Encoded Chloroaromatic Herbicide-Degrading Genes within Pseudomonas Species. *Adv. Appl. Microbiol.* https://doi.org/10.1016/S0065-2164(08)70367-8

Crawford, R. L. C. and Crawford, D. L. (2005). Bioremediation: Principles and Applications. *Biotechnol. Res*. https://doi.org/10.2134/jeq1999.00472425002800030042x

Das, N. and Chandran, P. (2011). Microbial Degradation of Petroleum Hydrocarbon Contaminants: An Overview. *Biotechnol. Res. Int.* https://doi.org/10.4061/2011/941810

Das, S. (2014). Microbial Biodegradation and Bioremediation. *Adv. Appl Biotechnol.* . https://doi.org/10.1016/C2013-0-13533-7

De Oliveira, V. P., Martins, N. T., Guedes, P. D. S., Pollery, R. C. G. and Enrich-Prast, A. (2016). Bioremediation of nitrogenous compounds from oilfield wastewater by Ulva lactuca (Chlorophyta). *Bioremediat. J.* https://doi.org/10.1080/10889868.2015.1114463

Delpla, I., Jung, A. V., Baures, E., Clement, M. and Thomas, O. (2009). Impacts of climate change on surface water quality in relation to drinking water production. *Environ. Int.* https://doi.org/10.4324/9781315818948

Dungan, R. S. and Frankenberger, W. T. (1999). Microbial transformations of Selenium and the bioremediation of seleniferous environments. *Bioremediat. J.* https://doi.org/10.1080/10889869991219299

Earth's Freshwater | National Geographic Society. (n.d.). Retrieved December 1, 2018, from https://www.nationalgeographic.org/media/earths-fresh-water/

El Fantroussi, S. and Agathos, S. N. (2005). Is bioaugmentation a feasible strategy for pollutant removal and site remediation? *Curr. Opin. Microbiol.* https://doi.org/10.1016/j.mib.2005.04.011

Field, J. A., de Jong, E., Feijoo-Costa, G. and de Bont, J. A. M. (1993). Screening for ligninolytic fungi applicable to the biodegradation of xenobiotics. *Trends Biotechnol.* https://doi.org/10.1016/0167-7799(93)90121-O

Focht, D. D. and Verstraete, W. (1977). Biochemical ecology of nitrification and denitrification. *Annu. Rev. Microbiol. Ecol.* https://doi.org/10.1016/j.pec.2012.01.010

Guo, H., Luo, S., Chen, L., Xiao, X., Xi, Q., Wei, W., … He, Y. (2010). Bioremediation of heavy metals by growing hyperaccumulaor endophytic bacterium Bacillus sp. L14. *Bioresour. Technol.* https://doi.org/10.1016/j.biortech.2010.06.085

Hard, B. C. and Babel, W. (1999). Bioremediation of uranium mine drainage using methylotrophic sulfate-reducing bacteria. In *BIOREMEDIATION OF NITROAROMATIC AND HALOAROMATIC COMPOUNDS*.

Hard, B. C., Friedrich, S. and Babel, W. (1997). Bioremediation of acid mine water using facultatively methylotrophic metal-tolerant sulfate-reducing bacteria. *Microbiol. Res.* https://doi.org/10.1016/S0944-5013(97)80025-0

Hashim, S., Yuebo, X. and Kabo-Bah, A. T. (2014). Beneficial bacteria helpful to restore water bodies. *Orient. J. Chem.* https://doi.org/10.13005/ojc/300361

Hechmi, N., Bosso, L., El-Bassi, L., Scelza, R., Testa, A., Jedidi, N. and Rao, M. A. (2016). Depletion of pentachlorophenol in soil microcosms with Byssochlamys nivea and Scopulariopsis brumptii as detoxification agents. *Chemosphere*. https://doi.org/10.1016/j.chemosphere.2016.09.062

Hendrickson, E. R. (2001). Using a molecular approach to monitor a bioaugmentation pilot. *Sixth Int. Situ Site Bioremediation Symp.*

Herrero, M. and Stuckey, D. C. (2015). Bioaugmentation and its application in wastewater treatment: A review. *Chemosphere*. https://doi.org/10.1016/j.chemosphere.2014.10.033

Hlihor, R. M., Gavrilescu, M., Tavares, T., Favier, L. and Olivieri, G. (2017). Bioremediation: An Overview on Current Practices, Advances, and New Perspectives in Environmental Pollution Treatment. *Biomed Res. Int.* https://doi.org/10.1155/2017/6327610

Idi, A., Md Nor, M. H., Abdul Wahab, M. F. and Ibrahim, Z. (2015). Photosynthetic bacteria: an eco-friendly and cheap tool for bioremediation. *Rev. Environ. Sci. Biotechnol.* https://doi.org/10.1007/s11157-014-9355-1

Jacques, R. J. S., Okeke, B. C., Bento, F. M., Teixeira, A. S., Peralba, M. C. R. and Camargo, F. A. O. (2008). Microbial consortium bioaugmentation of a polycyclic aromatic hydrocarbons contaminated soil. *Bioresour. Technol.* https://doi.org/10.1016/j.biortech.2007.04.047

Jayamani, I. (2015). Assessing the biodegradation of toluene, ethylbenzene and RDX and the identification of the microorganisms involved using stable isotope probing and high throughput amplicon sequencing. *Biomed Adv. Res.*

Jiang, Z. J., Fang, J. G., Mao, Y. Z. and Wang, W. (2010). Eutrophication assessment and bioremediation strategy in a marine fish cage culture area in Nansha Bay, China. *J. Appl. Phycol.* https://doi.org/10.1007/s10811-009-9474-1

Kang, C. H., Kwon, Y. J. and So, J. S. (2016). Bioremediation of heavy metals by using bacterial mixtures. *Ecol. Eng.* https://doi.org/10.1016/j.ecoleng.2016.01.023

Khan, F. A. and Ansari, A. A. (2005). Eutrophication: An Ecological Vision. *Bot. Rev.* https://doi.org/10.1663/0006-8101(2005)071[0449:EAEV]2.0.CO;2

Kharayat, Y. (2012). Distillery wastewater: bioremediation approaches. *J. Integr. Environ. Sci.* https://doi.org/10.1080/1943815X.2012.688056

Krol, W. J., Arsenault, T. L., Pylypiw, H. M. and Incorvia Mattina, M. J. (2000). Reduction of pesticide residues on produce by rinsing. *J. Agric. Food Chem.* https://doi.org/10.1021/jf0002894

Kuylenstierna, J., Najlis, P. and Björklund, G. (1998). Comprehensive Assessment of the Freshwater Resources of the World. *Water Int.* https://doi.org/EB.AIR/WG.5/2001/7

Lendvay, J. M., Löffler, F. E., Dollhopf, M., Aiello, M. R., Daniels, G., Fathepure, B. Z., … Adriaens, P. (2003). Bioreactive barriers: A comparison of bioaugmentation and biostimulation for chlorinated solvent remediation. *Environ. Sci. Technol.* https://doi.org/10.1021/es025985u

Linton, J. (2004). Global Hydrology and the Construction of a Water Crisis. *Gt. Lakes Geogr.*, *11*(2), 1–13.

Liu, Y., Wang, Y., Sheng, H., Dong, F., Zou, R., Zhao, L., … He, B. (2014). Quantitative evaluation of lake eutrophication responses under alternative water diversion scenarios: A water quality modeling based statistical analysis approach. *Sci. Total Environ.* https://doi.org/10.1016/j.scitotenv.2013.08.054

Lovley, D. R. (2001). BIOREMEDIATION: Anaerobes to the Rescue. *Science (80-.).* https://doi.org/10.1126/science.1063294

Malik, A. (2004). Metal bioremediation through growing cells. *Environ. Int.* https://doi.org/10.1016/j.envint.2003.08.001

Mani, P., Keshavarz, T., Chandra, T. S. and Kyazze, G. (2017). Decolourisation of Acid orange 7 in a microbial fuel cell with a laccase-based biocathode: Influence of mitigating pH changes in the cathode chamber. *Enzyme Microb. Technol.* https://doi.org/10.1016/j.enzmictec.2016.10.012

Margesin, R. and Schinner, F. (2001). Bioremediation (Natural Attenuation and Biostimulation) of Diesel-Oil-Contaminated Soil in an Alpine Glacier Skiing Area. *Appl. Environ. Microbiol.* https://doi.org/10.1128/AEM.67.7.3127-3133.2001

Margeta, K., Zabukovec Logar, N., Šiljeg, M. and Farkas, A. (2013). Water Treatment. *Water Treat.* https://doi.org/10.1016/B978-0-12-415923-5.00012-5

Martinez-Porchas, M., Martinez-Cordova, L. R., Lopez-Elias, J. A. and Porchas-Cornejo, M. A. (2014). Bioremediation of Aquaculture Effluents. In *Microbial Biodegradation and Bioremediation*. https://doi.org/10.1016/B978-0-12-800021-2.00024-8

Megharaj, M., Ramakrishnan, B., Venkateswarlu, K., Sethunathan, N. and Naidu, R. (2011). Bioremediation approaches for organic pollutants: A critical perspective. *Environ. Int.* https://doi.org/10.1016/j.envint.2011.06.003

Megharaj, M., Venkateswarlu, K. and Naidu, R. (2014). Bioremediation. In *Encyclopedia of Toxicology: Third Edition*. https://doi.org/10.1016/B978-0-12-386454-3.01001-0

Mulligan, C. N., Yong, R. N. and Gibbs, B. F. (2001). An evaluation of technologies for the heavy metal remediation of dredged sediments. *J. Hazard. Mater.* https://doi.org/10.1016/S0304-3894(01)00226-6

Obed Ntwampe, S. K. (2014). Biodegradation of Free Cyanide Using Bacillus Sp. Consortium Dominated by Bacillus Safensis, Lichenformis and Tequilensis Strains: A Bioprocess Supported Solely with Whey. *J. Bioremediation Biodegrad.* https://doi.org/10.4172/2155-6199.S18-004

Ouellet-Plamondon, C., Chazarenc, F., Comeau, Y. and Brisson, J. (2006). Artificial aeration to increase pollutant removal efficiency of constructed wetlands in cold climate. *Ecol. Eng.* https://doi.org/10.1016/j.ecoleng.2006.03.006

Pan, J., Sun, H., Nduwimana, A., Wang, Y., Zhou, G., Ying, Y. and Zhang, R. (2007). Hydroponic plate/fabric/grass system for treatment of aquacultural wastewater. *Aquac. Eng.* https://doi.org/10.1016/j.aquaeng.2007.09.001

Passatore, L., Rossetti, S., Juwarkar, A. A. and Massacci, A. (2014). Phytoremediation and bioremediation of polychlorinated biphenyls (PCBs): State of knowledge and research perspectives. *J. Hazard. Mater.* https://doi.org/10.1016/j.jhazmat.2014.05.051

Perelo, L. W. (2010). Review: In situ and bioremediation of organic pollutants in aquatic sediments. *J. Hazard. Mater.* https://doi.org/10.1016/j.jhazmat.2009.12.090

Pieper, D. H. and Reineke, W. (2000). Engineering bacteria for bioremediation. *Curr. Opin. Biotechnol.* https://doi.org/10.1016/S0958-1669(00)00094-X

Pointing, S. B. (2001). Feasibility of bioremediation by white-rot fungi. *Appl. Microbiol. Biotechnol.* https://doi.org/10.1007/s002530100745

Qiu, R. L., Guerif, J. and Zhang, R. D. (2012). Bioremediation of Contaminated Soil and Water. *Pedosphere*. https://doi.org/10.1016/S1002-0160(12)60028-9

Ravikumar, S., Baylon, M. G., Park, S. J. and Choi, J. il. (2017). Engineered microbial biosensors based on bacterial two-component systems as synthetic biotechnology platforms in bioremediation and biorefinery. *Microb. Cell Fact.* https://doi.org/10.1186/s12934-017-0675-z

Rowan, F. E., Docherty, N. G., Coffey, J. C. and O'Connell, P. R. (2009). Sulphate-reducing bacteria and hydrogen sulphide in the aetiology of ulcerative colitis. *Br. J. Surg.* https://doi.org/10.1002/bjs.6454

Saeijs, H. L. F. and Van Berkel, M. J. (1995). Global water crisis: the major issue of the 21st century, a growing and explosive problem. *Eur. Water Pollut. Control*.

SHAN, M., WANG, Y. and Xue, S. (2009). Study on bioremediation of eutrophic lake. *J. Environ. Sci.* https://doi.org/10.1016/S1001-0742(09)60027-9

Shao, Z. Q. and Behki, R. (1996). Characterization of the expression of the thcB gene, coding for a pesticide-degrading cytochrome P-450 in Rhodococcus strains. *Appl. Environ. Microbiol.*

Sharma, B., Short, R. and Gardner, K. H. (2009). Potential in situ approaches for remediation of contaminated sediments. In *In Situ and On-Site Bioremediation-2009: Proceedings of the 10th International In Situ and On-Site Bioremediation Symposium*. https://doi.org/10.1016/j.jaridenv.2006.02.009

Shawabkeh, R., Khleifat, K. M., Al-Majali, I. and Tarawneh, K. (2007). Rate of biodegradation of phenol by Klebsiella oxytoca in minimal medium and nutrient broth conditions. *Bioremediat. J.* https://doi.org/10.1080/10889860601185830

Sheng, Y., Chen, F., Sheng, G. and Fu, J. (2012). Water quality remediation in a heavily polluted tidal river in Guangzhou, South China. *Aquat. Ecosyst. Heal. Manag.* https://doi.org/10.1080/14634988.2012.687674

Sheng, Y., Qu, Y., Ding, C., Sun, Q. and Mortimer, R. J. G. (2013). A combined application of different engineering and biological techniques to remediate a heavily polluted river. *Ecol. Eng.* https://doi.org/10.1016/j.ecoleng.2013.04.004

Shrivastava, J. N., Verma, S. and Kumar, V. (2013). Bioremediation of Yamuna Water By Mono and Dual Bacterial Isolates. *Indian J. Sci. Res. Technol.*

Singh, A. L. and Sarma, P. N. (2010). Removal of arsenic(III) from waste water using Lactobacillus acidophilus. *Bioremediat. J.* https://doi.org/10.1080/10889861003767050

Singh, S. N. and Tripathi, R. D. (2007). Environmental bioremediation technologies. *Environ. Technol.* https://doi.org/10.1007/978-3-540-34793-4

Sivakumar, B. (2011). Water crisis: From conflict to cooperation—an overview. *Hydrol. Sci. J.* https://doi.org/10.1080/02626667.2011.580747

Stocking, A. J., Deeb, R. A., Flores, A. E., Stringfellow, W., Talley, J., Brownell, R. and Kavanaugh, M. C. (2000). Bioremediation of MTBE: A review from a practical perspective. *Biodegradation*. https://doi.org/10.1023/A:1011126414642

Subashchandrabose, S. R., Ramakrishnan, B., Megharaj, M., Venkateswarlu, K. and Naidu, R. (2013). Mixotrophic cyanobacteria and microalgae as distinctive biological agents for organic pollutant degradation. *Environ. Int.* https://doi.org/10.1016/j.envint.2012.10.007

Sun, L., Liu, Y. and Jin, H. (2009). Nitrogen removal from polluted river by enhanced floating bed grown canna. *Ecol. Eng.* https://doi.org/10.1016/j.ecoleng.2008.09.016

Szabõ, C. (2007). Hydrogen sulphide and its therapeutic potential. *Nat. Rev. Drug Discov.* https://doi.org/10.1038/nrd2425

Tyagi, M., da Fonseca, M. M. R. and de Carvalho, C. C. C. R. (2011). Bioaugmentation and biostimulation strategies to improve the effectiveness of bioremediation processes. *Biodegradation.* https://doi.org/10.1007/s10532-010-9394-4

Van Der Gast, C. J., Whiteley, A. S. and Thompson, I. P. (2004). Temporal dynamics and degradation activity of an bacterial inoculum for treating waste metal-working fluid. *Environ. Microbiol.* https://doi.org/10.1111/j.1462-2920.2004.00566.x

Vidali, M. (2001). Bioremediation. An overview. *Pure Applyed Chem.* https://doi.org/10.1351/pac200173071163

Vijayakumar, S. (2012). Potential Applications of Cyanobacteria in Industrial Effluents-A Review. *J. Bioremediation Biodegrad.* https://doi.org/10.4172/2155-6199.1000154

Wang, Z., Li, D., Qin, H. and Li, Y. (2012). An integrated method for removal of harmful cyanobacterial blooms in eutrophic lakes. *Environ. Pollut.* https://doi.org/10.1016/j.envpol.2011.09.003

Wätzlich, D., Bröcker, M. J., Uliczka, F., Ribbe, M., Virus, S., Jahn, D. and Moser, J. (2009). Chimeric Nitrogenase-like enzymes of (bacterio)chlorophyll biosynthesis. *J. Biol. Chem.* https://doi.org/10.1074/jbc.M901331200

Wu, J., Liu, J., Lin, L., Zhang, C., Li, A., Zhu, Y. and Zhang, Y. (2015). Evaluation of several flocculants for flocculating microalgae. *Bioresour. Technol.* https://doi.org/10.1016/j.biortech.2015.08.094

Wu, M., Dick, W. A., Li, W., Wang, X., Yang, Q., Wang, T., … Chen, L. (2016). Bioaugmentation and biostimulation of hydrocarbon degradation and the microbial community in a petroleum-contaminated soil. *Int. Biodeterior. Biodegrad.* https://doi.org/10.1016/j.ibiod.2015.11.019

Zeng, Z., Liu, J. and Savenije, H. H. G. (2013). A simple approach to assess water scarcity integrating water quantity and quality. *Ecol. Indic.* https://doi.org/10.1016/j.ecolind.2013.06.012

Zheng, Y., Wang, X. C., Dzakpasu, M., Ge, Y., Zhao, Y. and Xiong, J. (2016). Performance of a pilot demonstration-scale hybrid constructed wetland system for on-site treatment of polluted urban river water in Northwestern China. *Environ. Sci. Pollut. Res.* https://doi.org/10.1007/s11356-015-5207-y

Zinicovscaia, I. and Cepoi, L. (2016). *Cyanobacteria for bioremediation of wastewaters*. *Cyanobacteria for Bioremediation of Wastewaters*. https://doi.org/10.1007/978-3-319-26751-7