Type of Manuscript : Review article

Role of Microorganism as Bioremediation

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Abstract

Through agriculture, industry, and everyday life, harmful chemicals have been discharged into the world's air, soil, and water. Depending on their fixations, these substances can have ruinous outcomes on environments, just as cause serious harm to people and different living beings close by. This chemical has been removed by the process of bioremediation,it is a biological mechanism of recycling wastes into another form that can be used and reused by other organisms.Nowadays, the world is confronting the issue of various natural contamination. Bioremediation has been viewed as a domain of well disposed, modest and effective methods for natural reclamation. Since microorganisms comprise a key factor of this innovation, information on the nature and molecular components of their resistance to expanded overwhelming metal fixations is essential. Microorganisms are basic for a key alternative for conquer challenges.Microorganisms survive in all places in the biosphere because their metabolic activity is astonishing; then come into existence in all over a range of environmental conditions.The nutritional capacity of microorganisms is totally changed, so it is utilized as bioremediation of natural pollutants.Bioremediation is profoundly associated with corruption, eradication, immobilization, or detoxification of chemical waste and physical hazardous materials from the including through the exhaustive and movement of microorganisms. Microorganisms are the significant players in checking such burdens and reusing components by mineralizing or parceling poisons, even in situations poor in supplements or lacking accessibility of significant electron contributors and acceptor.The aim of this review article to discuss the importance of microorganisms in bioremediation.

Keywords: *Detoxification;chemical;microorganisms;ecosystem;environment*

Introduction

Microorganisms in nature have consistently separated the waste, and people have consistently (intentionally or unconsciously) utilized them in farming, household, and mechanical activities[1] and it also plays a vital role in bioremediation.Bioremediation refer to the process of the utilization of microorganisms to corrupt contaminants that present natural and human dangers.

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Bioremediation forms normally include the activities of a wide range of organisms acting in equal or succession to complete the degradation process.Both in situ (in place) and ex situ (evacuation and treatment in other place) remediation approaches are used. The adaptability of organisms to degrade a huge amount of contaminants that makes bioremediation an innovation that can be applied in various soil conditions [2]. The in situ approaches can reduce disruptive engineering practices, bioremediation is still not a common practice[3]. From an ecological perspective, bioremediation relies upon the different associations between three factors:substrate (toxin), life forms, and condition.The usage of bioremediation as a biotechnological procedure involve the microorganisms for illuminating and expelling threats of numerous contaminations through the biodegradation from the environment[4].Microorganisms act as a most important pollutant to excavate the tool in soil, water, and sediments;

mostly due to their advantage over other remediation procedural protocols. Microorganisms restore the natural surroundings and prevent further pollution. Bacteria are broadly microbial creatures, and in this manner it makes biodegradation and bioremediation as important one. There are barely few toxic microorganisms, so there is likely a life form ready to separate any given substrate, when furnished with the correct conditions (anaerobic versus aerobic environment, sufficient electron donors or acceptors, etc.)[5]. Bacteria like streptococcus aureus, Acinetobacter baumannii, Enterococcus faecalis,can help management of bioremediation [6,7,8,9]viruses cannot act as bioremediation[10].

Few Previous articles were referred to,in that role of bioremediation is to enhance the microorganisms with appropriate nutrients and other chemical compounds that will empower them to destroy the contaminant .In order to work the bioremediation system with microorganism it requires the the optimum levels of nutrients and other chemicals essential for their metabolism [11],some bacteria acts as a bioremediation that remove the pollutants,contaminant from the environment. Bacteria that can oxidize aromatics including benzoate, chlorobenzoate, and toluene, coupling the reaction with the decrease of oxygen, chlorate, or nitrate. Due to the high concentration of benzene contamination, especially in ground and surface water, D. aromatic is especially useful for in situ bioremediation of this substance[12]. The new version of bioremediation applications primarily use bacteria, with comparatively few attempts to use fungi. Fungi have important roles ,its participation in the cycling of elements through decomposition and transformation of organic and inorganic materials. These qualities can be converted into applications for bioremediation that separate natural mixes and decrease the dangers of metals. It is able to oxidize a diverse amount of chemicals and survive in harsh environmental conditions such as low moisture and high concentrations of pollutants. Therefore, fungi are potentially an extremely powerful tool in soil bioremediation [13,14,15]. The first Fungi which helps to degradation of organic pollutants is P. chrysosporium . Various research has shown that it has strong potential for bioremediation in pesticides, PAHs, dioxins, carbon tetrachloride, and many other pollutants. Among fungal systems, the P. chrysosporium has selected to demonstrate as bioremediation.Other notable species of white rot fungi include Pleurotus ostreatus and Trametes versicolor.[16]

The main differences between the previous article and this article is that they discussed only about the role of microorganisms in bioremediation but this review article concentrates on techniques followed during the bioremediation that helps to remove the pollutants from the environment. Aim of this review article is to emphasize all about current knowledge on the role of microorganisms in bioremediation and the techniques in bioremediation.

Materials and Method

Review of scientific literature was done in preparation of manuscript. This system and data base searched for relevant articles from PUBMED and GOOGLE SCHOLAR. About 50 articles were collected and analysed and reviewed .Databases of the journal were searching for articles based on the keyword bioremediation microorganism techniques ,cross references were also included .

Biological treatment of man-made waste has successfully been implemented for decades. Municipal and waste water and agriculture and agricultural waste are treatment in bioreactor as activated sludge in water ponds or in fluidized bed reactor containing an active biofilm of microorganism[17].Bioremediation use the characteristic feature of microorganism for transformation,mineralisation or complexation by coordinating those capacities towards natural and inorganic ecological contamination.

Discussion

Microorganism in bioremediation

Microorganisms act against the pollutants only when they have access to a variety of material compounds to help them generate and nutrient to build more cells [18].Besides bacteria they are also efficient in heavy metal bioremediation. Microorganisms have developed the capabilities to protect themselves from heavy metal toxicity by various mechanisms such as adsorption,uptake,oxidation. Some bacteria like Alcaligenes faecalis ,Bacillus pumilus,Brevibacterium iodonium,Staphylococcus ,Acinetobacter baumannii are gaseous methyl mercury [19,20,21,22]. As a bioremediator, there are biological agents which are used to clean the

contaminated site in the area. Bacteria, archaea and fungi are some of typical prime bioremediator[23]. Some of microorganisms can be biomediator which can be used as mouthwash[24,25].Bioremediator also consist of pesticides that kill the unwanted soil microorganism that causes toxicity to environment[26]. The bacteria which performs more antibacterial activity in orange peel has bioremediation [27,28,29] . Finally it is ecocompatibile as well as economically feasible [30].Figure 1 depicts the process of bioremediation which involves microorganisms and other substrates.

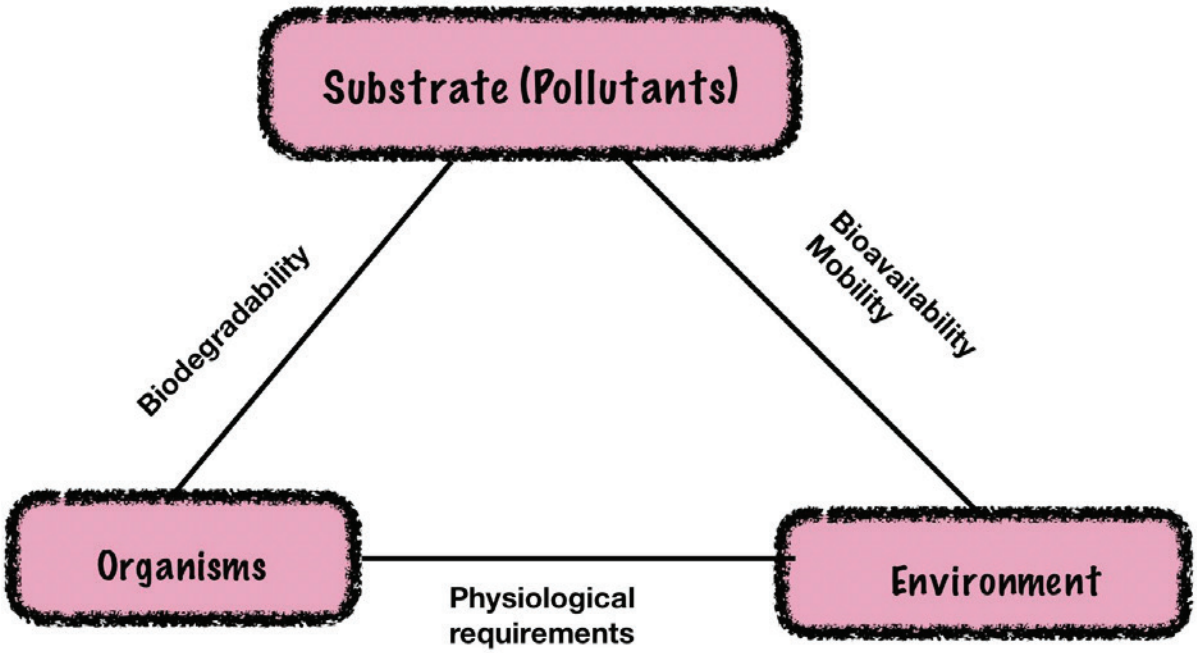

Figure 1 Bioremediation process

Factor affecting microbial bioremediation

Microbial and pollutants are not uniformly spread in the environment.The controlling and optimising of bioremediation process is complex system due to many factor.These factor included capable of degrading the pollutants,availability contaminants to microbial population and environment factor (type soil,temperature,PH,the pressure of oxygen and nutrient.

Biological factor-Major biological factor included is mutation,horizontal gene transfer,enzyme activity,interaction,its own growth until,critical biomass is reached,population size and composition[31],n6-adenosine methylation bacteria is also one of biological factor that affect the bioremediation[32]

Environment factor- Physicochemical bioavailability of pollutants contaminants,concentration, solubility, chemical structure and toxicity[33]. The environment factor microorganisms is a metabolic is a metabolic characteristic of microorganism.This mechanism only succeeds when the microorganism grows in the optimum temperature and PH.some of leaves like laures nobies can be used as bioremediation[34]

Availability of nutrition-The appropriate quality of nutrient is a favourable strategy for increasing the metabolic activity of microorganism and thus biodegradation rate in cold environment [35]. Biodegradation in aquatic environments is limited by the availability[36]. The artificially well-developed mixture of bacterial strain along with inorganic nutrients such as

phosphorus and nitrogen is pumped into the ground or applied to oil spill areas as required for treatment. This increases the rate of bioremediation at the target site.

Principle of bioremediation

The aim of bioremediation is enhanced by the giving the optimum level of nutrient and other essential chemicals that is required to degrade.It is effective,when it has suitable environment that allow the growth to the microorganism and is allow them to perform the microbial activity.There are several parameter that require for the growth of microorganism [37]. The principle of bioremediation is based on the process of degradation.Degradation is the process of removal of unwanted organic toxicity refers to harmless or naturally occurring compounds like carbon dioxide,water,inorganic compounds which are safe for human,animal plant and aquatic life. Many mechanism and pathway have been executed for the biodegradation of wide variety of organic compound in absences or in presences of oxygen

Biostimulation

Biostimulation is widely used to stimulate the nature occurring microbial communities providing them with nutrients and other needs to break down contaminants. Biostimulation can be achieved through change in PH,moisture,aeration or addition of electron acceptors,donors such as phosphorus,nitrogen,oxygen carbon.It is potentially useful for the treatment of less frequently encountered contaminants spill such as pesticides,particularly herbicides[38]. Biostimulation is dependent on the organisms and which requires the environment for their comfort which makes them easier to alter in a way that will have the desired bioremediation effect.

Bioattenuation

It is also called as naturally attenuation is the eradication of pollutants concentration from the surrounding. It is carried out in biological processes; it may include physical phenomenon and chemical reaction. Terms such as biotransformation are included within the more general attenuation[39]. The processes involved are largely due to biodegradation by soil microorganisms and to some extent by interaction with soil matrices. This procedure is frequently considered as a"do nothing" arrangement, yet it requires consistent checking of the contaminant in soil. The time required for natural attention relies upon site conditions and the particular contaminant.

Due to persistent nature and lack of appropriate degrading microorganisms, natural attenuation of a pesticide in some soils takes a long duration.

Bioaugmentation

Another bioremediation approach is termed bioaugmentation,where organism selected for high degradation abilities are used to inoculate the contaminated situ[40].It is also used to ensure that insitu microorganism can totally remove and alter these contaminants to ethylene and chloride which are non toxic[41]. Because of having diverse metabolic profiles to change into less complex and harmless end product[42].The potential of the microorganism and important features is to enable the cells to be functionally active and persistent under the desired environmental conditions. Based on the prior knowledge of microorganism communities inhabiting the target site ,competent microbes should be selected.The stresses that hamper microbial development may remember variances or limits for temperature, water content, pH, exhaustion of supplements, and furthermore possibly poisonous toxin levels in the debased found that organisms having the capacity to corrupt the natural contaminations in societies neglected to do likewise in regular frameworks. The recommended potential explanations behind bioaugmentation disappointment were: issues concerning the adjustment of the vaccinated microorganisms; insufficiency of substrate; rivalry among presented and indigenous biomass; utilization of other natural substrates in inclination to the toxic; and predation.

Genetically Engineered Microorganisms

Genetically engineered microorganism whose genetic material has been already changed by applying genetic engineering technique inspired by natural otherwise artificial genetic exchange microorganism. It has improved the utilization and elimination of hazardous unwanted waste under laboratory condition creating genetically modified organism[43]. Genetically Engineered microorganisms have potential for

bioremediation application in soil ground water etc .

Advantage of bioremediation

Bioremediation is eco friendly and sustainable[44] and it is relatively ease in implementation[45]. Effective way of remediating natural ecosystems from the number of contaminants and acts as an environment friendly option.Bioremediation is a natural process and accepted by the public as a waste treatment process for contaminated material such as soil. There is an increase in number and release of harmless products due to degradation of microbes. The residues for the treatment are usually harmless products such as carbon dioxide, water, and cell biomass.Bioremediation is useful for the complete destruction of a wide variety of contaminants. Many hazardous compounds can be transformed into harmless products. This reduces the chance of future liability associated with the treatment and disposal of contaminated material.

Disadvantage of bioremediation

It is difficult to extrapolate from bench and pilot scale studies and the biological process is often specific -important site factors required for success include the pressure of metabolically capable microbial population and appropriate level of nutrients and contaminants. Research is expected to create and build bioremediation advancements that are reasonable for destinations with complex blends of contaminants that are not equally dispersed in the earth. It might be available as solids, fluids, and gases. Organic procedures are exceptionally explicit. Significant site factors required for progress incorporate the nearness of metabolically able microbial populaces, reasonable natural development conditions, and suitable degrees of supplements and contaminants.

Conclusion

Through agriculture, industry, and daily life, harmful chemicals have been released into the earth's air, soil, and water. Depending on their concentrations, these substances can have destructive consequences on ecosystems, as well as cause severe damage to humans and other organisms nearby. Soil pollution is of special importance because of its impact on surface, groundwater and air contamination and can easily spread and be consumed by humans.Biodegradation is a very fruitful and attractive option to remediating,cleaning,managing and recovering techniques for solving pollutants' environment through microbial activity .The advantage is the use of technology and its increasing popularity through time.It relies on stimulating the growth of certain microbes that use contaminants like oil, solvents, and pesticides as a source of food and energy. These microbes consume the contaminants, converting them into small amounts of water and harmless gases like carbon dioxide

Acknowledgement: We thank saveetha dental college for the support to carry on the study

Conflict of Interest : Nil

Source of Funding : Self

Ethical Clearance: Not Required

ReferenceS

1. Litchfield C. Thirty Years and Counting: Bioremediation in Its Prime? [Internet]. Vol. 55, BioScience. 2005. p. 273. Available from: http://dx.doi.org/10.1641/0006-3568(2005)055[0273:tyacbi]2.0.co;2
2. Sylvia DM. Principles and Applications of Soil Microbiology [Internet]. Prentice Hall; 2005. 640 p. Available from: https://books.google.com/books/about/Principles_and_Applications_of_Soil_Micr.html?hl=&id=tLjwAAAAMAAJ
3. Alleman BC, Leeson A. In Situ and On-site Bioremediation: Papers from the Fourth International In Situ and On-Site Bioremediation Symposium, New Orleans, April 28-May 1, 1997 [Internet]. 1997. 752 p. Available from: https://books.google.com/books/about/In_Situ_and_On_site_Bioremediation.html?hl=&id=nhNSAAAAMAAJ
4. Strong PJ, Burgess JE. Treatment Methods for Wine-Related and Distillery Wastewaters: A Review [Internet]. Vol. 12, Bioremediation Journal. 2008. p. 70–87. Available from: http://dx.doi.org/10.1080/10889860802060063
5. Vidali M. Bioremediation. An overview [Internet]. Vol. 73, Pure and Applied Chemistry. 2001. p. 1163–72. Available from: http://dx.doi.org/10.1351/pac200173071163
6. Ashwin KS, Muralidharan NP. Vancomycin-resistant enterococcus (VRE) vs Methicillin-

resistant Staphylococcus Aureus (MRSA) [Internet]. Vol. 33, Indian Journal of Medical Microbiology. 2015. p. 166. Available from: http://dx.doi.org/10.4103/0255-0857.150976

7. Girija ASS, Smiline Girija AS, Vijayashree Priyadharsini J, Paramasivam A. Plasmid-encoded resistance to trimethoprim/sulfamethoxazole mediated by dfrA1, dfrA5, sul1 and sul2 among Acinetobacter baumannii isolated from urine samples of patients with severe urinary tract infection [Internet]. Vol. 17, Journal of Global Antimicrobial Resistance. 2019. p. 145–6. Available from: http://dx.doi.org/10.1016/j.jgar.2019.04.001
8. Marickar RF, Geetha RV, Neelakantan P. Efficacy of Contemporary and Novel Intracanal Medicaments againstEnterococcus Faecalis [Internet]. Vol. 39, Journal of Clinical Pediatric Dentistry. 2014. p. 47–50. Available from: http://dx.doi.org/10.17796/jcpd.39.1.wmw9768314h56666
9. Smiline ASG, Vijayashree JP, Paramasivam A. Molecular characterization of plasmid-encoded blaTEM, blaSHV and blaCTX-M among extended spectrum β-lactamases [ESBLs] producing Acinetobacter baumannii [Internet]. Vol. 75, British Journal of Biomedical Science. 2018. p. 200–2. Available from: http://dx.doi.org/10.1080/09674845.2018.1492207
10. Pratha AA, Ashwatha Pratha A, Geetha RV. Awareness on Hepatitis-B vaccination among dental students-A Questionnaire Survey [Internet]. Vol. 10, Research Journal of Pharmacy and Technology. 2017. p. 1360. Available from: http://dx.doi.org/10.5958/0974-360x.2017.00240.2
11. Chandra R, Sobti RC. Microbes for Sustainable Development and Bioremediation [Internet]. CRC Press; 2019. 368 p. Available from: https://play.google.com/store/books/details?id=LnnEDwAAQBAJ
12. Salinero K, Keller K, Feil W, Feil H, Trong S, Di Bartolo G, et al. Soil Microbe Dechloromonas aromatica Str. RCB Metabolic Analysis [Internet]. Recent Advances in Microbiology. 2011. p. 120–47. Available from: http://dx.doi.org/10.1201/b12222-10
13. Bumpus JA. Fungi in Bioremediation edited by G.M. Gadd (2001). Pp. 481. ISBN 0-521-78119-1 (hardback). Cambridge University Press, Cambridge, U.K. Price ??80; $120 [Internet]. Vol. 16, Mycologist. 2002. Available from: http://dx.doi.org/10.1017/s0269915x02253070
14. Harms H, Schlosser D, Wick LY. Untapped potential: exploiting fungi in bioremediation of hazardous chemicals [Internet]. Vol. 9, Nature Reviews Microbiology. 2011. p. 177–92. Available from: http://dx.doi.org/10.1038/nrmicro2519
15. Shahzan MS, Sohaib Shahzan M, Smiline Girija AS, Vijayashree Priyadharsini J. A computational study targeting the mutated L321F of ERG11 gene in C. albicans, associated with fluconazole resistance with bioactive compounds from Acacia nilotica [Internet]. Vol. 29, Journal de Mycologie Médicale. 2019. p. 303–9. Available from: http://dx.doi.org/10.1016/j.mycmed.2019.100899
16. Manonmani HK. Bioremediation of Hexachlorocyclohexane Contaminated Soil: Field Trials [Internet]. Pesticides in the Modern World - Pesticides Use and Management. 2011. Available from: http://dx.doi.org/10.5772/20802
17. Lindsey B. Biodegradation and Bioremediation [Internet]. Scientific e-Resources; 2018. 336 p. Available from: https://play.google.com/store/books/details?id=rePEDwAAQBAJ
18. Fantroussi SE, El Fantroussi S, Agathos SN. Is bioaugmentation a feasible strategy for pollutant removal and site remediation? [Internet]. Vol. 8, Current Opinion in Microbiology. 2005. p. 268–75. Available from: http://dx.doi.org/10.1016/j.mib.2005.04.011
19. De J, Ramaiah N, Vardanyan L. Detoxification of Toxic Heavy Metals by Marine Bacteria Highly Resistant to Mercury [Internet]. Vol. 10, Marine Biotechnology. 2008. p. 471–7. Available from: http://dx.doi.org/10.1007/s10126-008-9083-z
20. Priyadharsini JV, Vijayashree Priyadharsini J, Smiline Girija AS, Paramasivam A. An insight into the emergence of Acinetobacter baumannii as an oro-dental pathogen and its drug resistance gene profile – An in silico approach [Internet]. Vol. 4, Heliyon. 2018. p. e01051. Available from: http://dx.doi.org/10.1016/j.heliyon.2018.e01051
21. Priyadharsini JV, Vijayashree Priyadharsini J, Smiline Girija AS, Paramasivam A. In silico analysis of virulence genes in an emerging dental pathogen A. baumannii and related species [Internet]. Vol. 94, Archives of Oral Biology. 2018. p. 93–8. Available from: http://dx.doi.org/10.1016/j.archoralbio.2018.07.001

22. Girija SAS, Jayaseelan VP, Arumugam P. Prevalence of VIM- and GIM-producing Acinetobacter baumannii from patients with severe urinary tract infection [Internet]. Vol. 65, Acta Microbiologica et Immunologica Hungarica. 2018. p. 539–50. Available from: http://dx.doi.org/10.1556/030.65.2018.038

23. Norris RD. Handbook of Bioremediation [Internet]. CRC Press; 1993. 272 p. Available from: https://books.google.com/books/about/Handbook_of_Bioremediation.html?hl=&id=up9M7kvgWgIC

24. Shahana RY, Muralidharan NP. Efficacy of mouth rinse in maintaining oral health of patients attending orthodontic clinics [Internet]. Vol. 9, Research Journal of Pharmacy and Technology. 2016. p. 1991. Available from: http://dx.doi.org/10.5958/0974-360x.2016.00406.6

25. Selvakumar R, Np M. COMPARISON IN BENEFITS OF HERBAL MOUTHWASHES WITH CHLORHEXIDINE MOUTHWASH: A REVIEW [Internet]. Vol. 10, Asian Journal of Pharmaceutical and Clinical Research. 2017. p. 3. Available from: http://dx.doi.org/10.22159/ajpcr.2017.v10i2.13304

26. Lecomte J, St-Arnaud M, Hijri M. Isolation and identification of soil bacteria growing at the expense of arbuscular mycorrhizal fungi [Internet]. Vol. 317, FEMS Microbiology Letters. 2011. p. 43–51. Available from: http://dx.doi.org/10.1111/j.1574-6968.2011.02209.x

27. Vaishali M, Geetha RV. Antibacterial activity of Orange peel oil on Streptococcus mutans and Enterococcus-An In-vitro study [Internet]. Vol. 11, Research Journal of Pharmacy and Technology. 2018. p. 513. Available from: http://dx.doi.org/10.5958/0974-360x.2018.00094.x

28. Monfared AM, Rezaei A, Poursina F, Faghri J. Detection of Genes Involved in Biofilm Formation in MDR and XDR Acinetobacter baumannii Isolated from Human Clinical Specimens in Isfahan, Iran [Internet]. Vol. In Press, Archives of Clinical Infectious Diseases. 2019. Available from: http://dx.doi.org/10.5812/archcid.85766

29. Girija As S, Priyadharsini J V. CLSI based antibiogram profile and the detection of MDR and XDR strains of Acinetobacter baumannii isolated from urine samples. Med J Islam Repub Iran [Internet]. 2019 Feb 8;33:3. Available from: http://dx.doi.org/10.34171/mjiri.33.3

30. Smitsman AW. The development of tool use: Changing boundaries between organism and environment [Internet]. Evolving explanations of development: Ecological approaches to organism–environment systems. 1997. p. 301–29. Available from: http://dx.doi.org/10.1037/10265-008

31. Boopathy R. Factors limiting bioremediation technologies [Internet]. Vol. 74, Bioresource Technology. 2000. p. 63–7. Available from: http://dx.doi.org/10.1016/s0960-8524(99)00144-3

32. Paramasivam A, Vijayashree Priyadharsini J, Raghunandhakumar S. N6-adenosine methylation (m6A): a promising new molecular target in hypertension and cardiovascular diseases. Hypertens Res [Internet]. 2020 Feb;43(2):153–4. Available from: http://dx.doi.org/10.1038/s41440-019-0338-z

33. Prasad R, Aranda E. Approaches in Bioremediation: The New Era of Environmental Microbiology and Nanobiotechnology [Internet]. Springer; 2018. 403 p. Available from: https://play.google.com/store/books/details?id=nx1-DwAAQBAJ

34. M MA, Geetha RV, Thangavelu L. Evaluation oEvaluation of anti-inflammatory action of Laurus nobilis-an in vitro study anti-inflammatory action of Laurus nobilis-an in vitro study [Internet]. Vol. 10, International Journal of Research in Pharmaceutical Sciences. 2019. p. 1209–13. Available from: http://dx.doi.org/10.26452/ijrps.v10i2.408

35. Singh SN, Tripathi RD. Environmental Bioremediation Technologies [Internet]. Springer Science & Business Media; 2007. 520 p. Available from: https://play.google.com/store/books/details?id=DY66MkyLriEC

36. Commentarii in epistulas Pauli [Internet]. 2013. Available from: http://dx.doi.org/10.1515/9783110313642

37. Kumar D, Kumar S, Shukla V, Kumar N. Adaptation Strategies of Plants Against Common Inorganic Pollutants and Metals [Internet]. Plant Adaptation Strategies in Changing Environment. 2017. p. 315–28. Available from: http://dx.doi.org/10.1007/978-981-10-6744-0_13

38. Kanissery RG, Sims GK. Biostimulation for the Enhanced Degradation of Herbicides in Soil [Internet]. Vol. 2011, Applied and Environmental Soil Science. 2011. p. 1–10. Available from: http://dx.doi.org/10.1155/2011/843450

39. Mulligan CN, Yong RN. Natural attenuation of contaminated soils [Internet]. Vol. 30, Environment International. 2004. p. 587–601. Available from: http://dx.doi.org/10.1016/j.envint.2003.11.001

40. Bioaugmentation [Internet]. SpringerReference. Available from: http://dx.doi.org/10.1007/springerreference_168354

41. Lyon DY, Vogel TM. Bioaugmentation for Groundwater Remediation: an Overview [Internet]. Bioaugmentation for Groundwater Remediation. 2013. p. 1–37. Available from: http://dx.doi.org/10.1007/978-1-4614-4115-1_1

42. Aziz CE, Wymore RA, Steffan RJ. Bioaugmentation Considerations [Internet]. Bioaugmentation for Groundwater Remediation. 2013. p. 141–69. Available from: http://dx.doi.org/10.1007/978-1-4614-4115-1_5

43. Ford CZ, Sayler GS, Burlage RS. Containment of a genetically engineered microorganism during a field bioremediation application [Internet]. Vol. 51, Applied Microbiology and Biotechnology. 1999. p. 397–400. Available from: http://dx.doi.org/10.1007/s002530051409

44. Shiomi N. Advances in Bioremediation of Wastewater and Polluted Soil [Internet]. BoD – Books on Demand; 2015. 284 p. Available from: https://books.google.com/books/about/Advances_in_Bioremediation_of_Wastewater.html?hl=&id=pmmQDwAAQBAJ

45. Ronald M. Atlas, Philp J. Bioremediation: Applied Microbial Solutions for Real-world Environmental Cleanup [Internet]. Amer Society for Microbiology; 2005. 366 p. Available from: https://books.google.com/books/about/Bioremediation.html?hl=&id=4g5SAAAAMAAJ