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Bioremediation and Waste Management for Environmental Sustainability

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Agricultural practices, industrial manufacturing, and lifestyle of human beings have raised the accumulation of hazardous compounds into the surrounding. It has drastically increased health issues and environmental concerns. Therefore, there is an urgent need for eco-friendly approaches to solving these multiple issues at a time. Contrary to the harmful chemical methods, bioremediation has emerged as an eco-friendly substitute for sustainable development. Bioremediation utilizes living microbiomes for cleaning environment and their sustainability. As advancement in science and technology, researchers have developed various bioremediation techniques but because of nature and type of pollutant, there is no single 'silver bullet' which can be applied to restore the polluted environment. The ever-increasing population and our reckless acts are turning the Earth into a huge garbage dump. The indiscriminate exploitation of resources making this condition worsen. Moreover, it is a major cause of climatic irregularities, environmental destructions, biodiversity shrinking, disease outbreaks, and agricultural issues. The present waste management efforts are proving insufficient to handle this situation.

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Nevertheless, several of them are known to generate toxic by-products. Therefore, besides limiting waste generation, the present scenario requires an efficient, feasible, and environmental-friendly approach for its management. Bioremediation is well recognized and widely accepted alternative to clean environment without harming the nature [1]. Further, it can be used under in-situ conditions with cost-effectiveness as the cost of excavation, transportation, treatment, etc is reduced due to its on-site application. Although, this process has its own limitations as it is less efficient to non-biodegradable compounds; requires metabolic specificity of the source organism, modern technologies are needed, and slower in comparison to the other alternatives. But still it has proven itself an important claimant for this scenario [2].

Bioremediation either eliminate the contaminants or reduce their concentration to a significant level. Plants, fungi, and bacteria are the most important contributor to this process and can be classified under phytoremediation, mycoremediation, and remediation. Further, myco-remediation and micro-remediation techniques entail several sub-processes to enhance the on-site removal of the contaminants viz. bio-stimulation, bio-augmentation, and bio-sparging, etc. (Figure 1). The bio-stimulation process invigorates the indigenous microorganisms by supplying additional nutrients and growth factors, while bio-augmentation is the addition of exogenous microorganisms in an ecosystem to degrade the contaminants. On the other side, pressurized air is used in bio-sparging to deliver oxygen and/or nutrients to a certain zone for enhancing microbial activity. In recent past, the bioremediation field has undergone extensive research and advancements. Several technologies are in use to accomplish and monitor the bioremediation processes viz. nanotechnology, genetic engineering, biochemical engineering, spectroscopy, spectrometry and chromatography. Nowadays, bioluminescence-based assays have

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attracted scientific attention for the eco-toxicological assessment of pollutants. Microbial biosensors have also explored as a sensitive and reliable technique for identifying and tracking the contaminants within an ecosystem [3].

Excessive use of agrochemicals, especially pesticides are dangerous for environment, biodiversity and human health. Due to the indiscriminate use of pesticides during1940-1960, that period is also called the "pesticide era". Besides, polluting the surface and sediments, they are also known to reduce microbial diversity. There are huge number of publications on bioremediation and waste management for environmental sustainability (Figure 2). The previous reports have proven the pesticide degradation ability of fungi and bacteria [4]. Fungal and bacterial enzymes viz. oxidoreductase, esterase, peroxidases, hydrolases are the key elements that accelerate the agrochemical's biodegradation. Heavy metals are another serious threat to biodiversity and human health due to their bioaccumulation property and persistent nature [5]. They are present in both soluble (ionic) and insoluble (colloidal) forms in the soil. Further they may be classified as essential and non-essential metals. Essential heavy metals *viz*. copper, zinc, manganese, and nickel are considered toxic only under very high concentration. While non-essential heavy metals viz. lead, mercury, chromium, cadmium, and arsenic are extremely dangerous to the living organisms and therefore, require special attention. The available technologies for managing heavy metal pollution involves chemical washing/flushing, leaching, adsorption, dilution, and immobilization by reducing their solubility. Moreover, chelating compounds nitrilotriacetic acid, aminopolycarboxylic acids and ethylenediaminedisuccinic acid can also be used for extracting the heavy metals. However, despite taking the various precautionary measures and use of such diverse technologies, heavy metal toxicity is remaining a threat for mankind. Therefore, in recent years, various bioremediation approaches have been tested for removing heavy metals.

Environmental issues are becoming an increasing obstacle for man due to globalization and rapid industrialization. The waste water from industries is highly alkaline and has high biological and chemical oxygen demand as well as total dissolved solids. The waste water consists of effluents from the textile industries and heavy metals. In order to produce best quality products, a number of dyes and auxillary chemicals are used which in turn has become a critical concern for the environment [6].

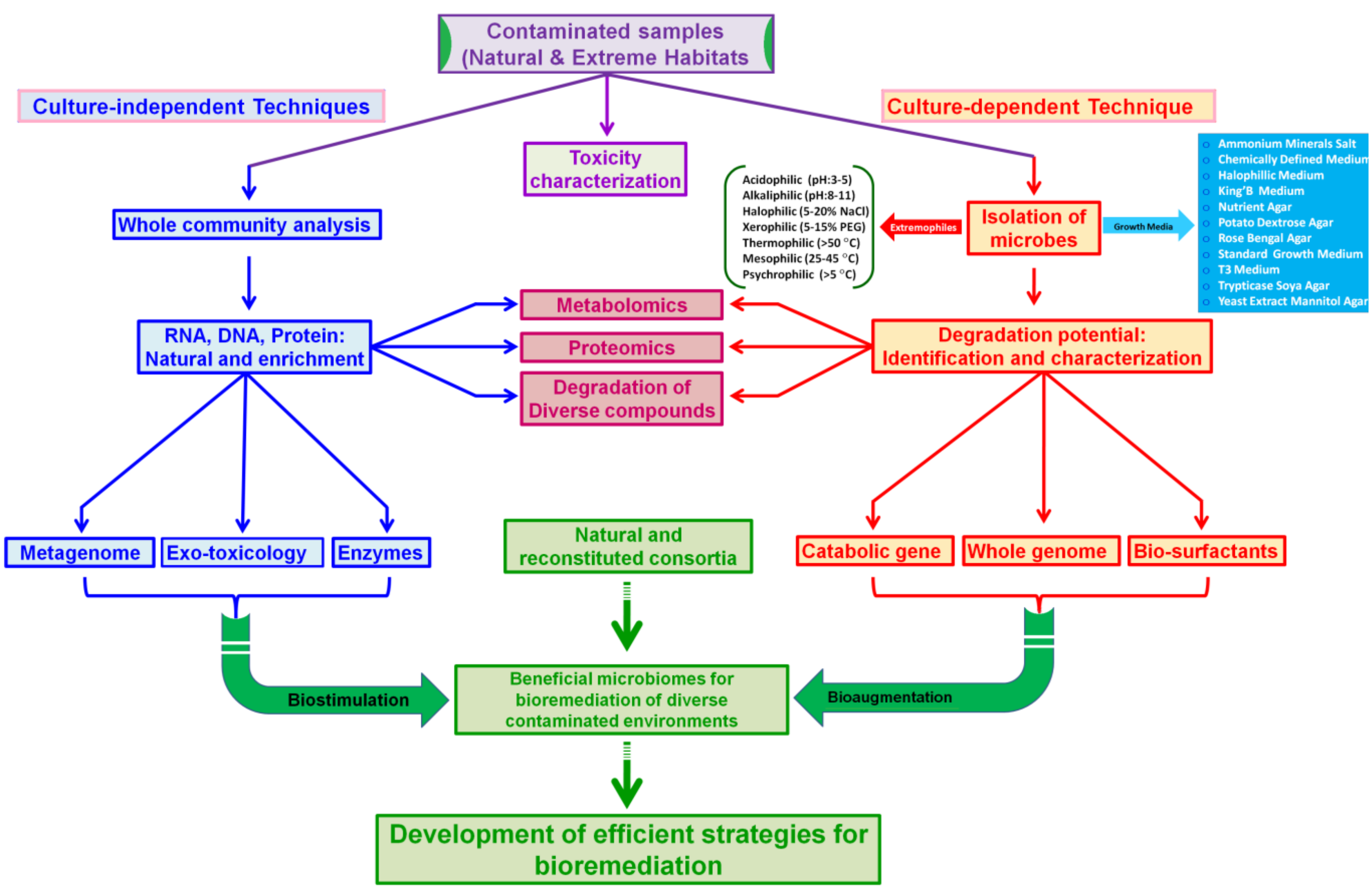

Fig 1: Schematic representation showing different approaches for bioremediation. Adapted with permission from Kaur [2].

Dyes are highly resistant to biological activity, light, ozone and other degradative environmental conditions. The azo dyes and related chemicals may induce mutagenesis leading to toxicity in aquatic plants and animals. Heavy metal contaminated wastewaters are the most hazardous among the other chemical industries. Heavy metals because of their solubility in the aquatic environment can be absorbed by microbiomes. After entering in the food chain, they get accumulated in human body in large concentrations. The ingestion of the heavy metals beyond the permitted concentrations can lead to serious health disorders [7, 8].

Wastewater treatment is of major concern and one of the most important biotechnological processes used worldwide. The microbial communities from diverse habitats play a splendid role in biodegradation of diverse compounds in wastewater from engineered as well as natural systems. Microbes are capable of removing diverse pollutants from distinctive biological wastewater treatment system. There are different groups of microorganism used for treatment, in which filamentous fungi are getting attention due to their high efficiency. The treatment of wastewater with fungi is highly beneficial. The fungal treatment leads to conversion of wastewater organics into high-value potential fungal protein and valuable diverse biochemicals are highly resistant to inhibitory compounds additionally producing fungal biomass for animal feed and human diet [9]. Microbes can transform heavy metals from one oxidation state to another. They also pose capability of tolerating harmful effects of heavy metals. Microbes can convert insoluble toxic cations of heavy metals into less toxic soluble form [10]. Microbial communities have been shown to oxidize or decrease the concentration of SeO, AsO_2, Co (III), Fe(II), and Mn(II) making them less or non-toxic. The species of *Alcaligenes*, *Bacillus*, and *Pseudomonas* have been reported to cause reduction of Cr(VI), Hg(II) and Se(VI) and U(VI). Many studies have showed the potential ability of yeasts to accumulate different heavy metals and have been regarded as superior metal accumulators [11].

Population growth along with the rapid urbanization has led to new consumption patterns, which usually affect the waste stream by successively adding new types of waste. Electronics industry is the world's largest and fastest growing industry [12]. Polychlorinated biphenyls (PCBs) are used as coolants and lubricants in capacitors and transformers. The use of PCBs was in fact banned due to firm configuration and low bioavailability. PCBs cause serious health effects due to their toxic, mutagenic, and carcinogenic nature for the growth and development of plants, animal, and human beings [13]. Biomedical waste comprises any waste that has been generated during medical treatment, diagnosis, and/or immunization of the human as well animals. Moreover, it also includes the waste material produced through research activities involving human or animal trials. The rapidly growing healthcare sector and the

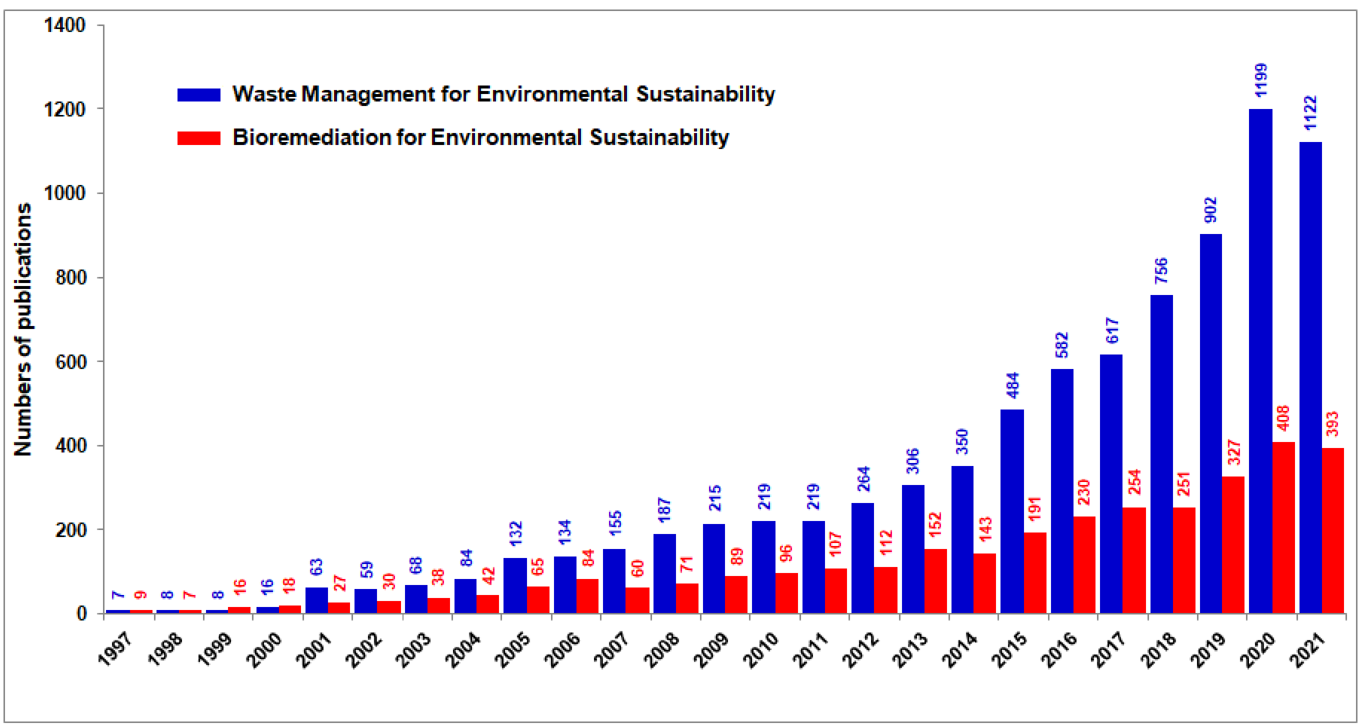

Figure 2: Numbers of publications related to Bioremediation and Waste Management for Environmental Sustainability [Source-PubMed].

continuous threat of pandemics have enormously increased the use of disposable medical and surgical items. They are mostly made up of synthetic polymers having a very slow rate of biodegradation. Therefore, any carelessness in their management leads to environmental pollution. The major proportion of the biomedical waste generated is of non-hazardous nature and therefore, can be tackled through the commonly used methods. Moreover, Patil, Mahamuni [14] converted organic biomedical waste into fertilizers. Further, Rajan and Robin [15] have reviewed the biomedical waste generation and management strategies in Ayurveda hospital of India. They have revealed that incineration and landfilling waste are the most preferred methods for managing the biomedical waste. Furthermore, bioremediation has also been explored by several researchers for this purpose [16, 17]. Microbes enzymatically attack and convert the pollutants to innocuous products. Microbes rely on the participation of various enzymes respectively for the remediation of recalcitrant and organo pollutants [18]. Bioremediation using microbial enzymes is considered eco-friendly, costeffective, innovative, and promising approach. Thus, applying microbial enzymes in bioremediation can be the apposite alternative for waste management to safeguard the environment and public health.

Extremophiles are capable of adjusting, and thriving in hostile habitats that were actually thought to be adverse or fatal for life to exist. The study of extremophiles is difficult due to complexity in reaching their ecological niches and isolating [19-21]. Microbes that thrive in extreme ecological habitats have evolved as a result of beneficial microbes for diverse potentials in environment and allied sectors [22]. Due to their unique physiological and enzymatic characteristics, extremophilic microbes are amazing bioresource for applications in bioremediation of diverse toxic pollutants [23, 24]. Extracellular polymeric substances have been revealed to be the most relevant structures for biosorption of metals and radionuclides with proved efficiency on species of psychrotolerant bacteria, *Pseudoalteromonas* [25] and acidophilic bacteria, *Acidithiobacillus ferroxidans* [26]. The regulatory mechanisms and chemical characteristics of the siderophores produced by the extremophilic microbes evidence the potential of these microbes as bioremediating agents for metal chelation [27]. The production of enzymes by extremophiles is another major mechanism involved in bioremediation. Diverse thermophiles, hyperthermophiles, and acidophiles including *Geobacillus stearothermophilus*, *Sulfolobus sulfataricus*, *Thermus thermophilus*, and *Thermus thermophilus* have been known to play a potent role in bioremediation through production of various extremozymes [28].

Nanotechnology is a highly promising discipline of technology and science which is emerging as novel trend in every sector [29]. The application of nanotechnology will redesign the future and change every aspect of lives for sustainability [30]. Nanotechnology is getting attentions in field of protecting environment from harmful compounds and thus managing environmental issues globally. Bioremediation is significantly a clean, green and sustainable technology and is in general recognized as 'environmentally appropriate. With the advent of bio-mimetic nanotechnology in the recent past, researchers have been drawn to intensively explore this hidden path. Nanotechnology can reduce expenditures that industries make to mitigate these pollutants by eco- friendly manners. The iron oxide nanoparticles synthesized from *Aspergillus tubingensis* could remove more than 90% of heavy metals from waste water [31]. Copper nanoparticles synthesized from *E. coli* were copper resistant and able to degrade azo dye and textile effluents. Additionally, the treatment of the industrial effluent with these nanoparticles showed reduction in the suspended solids in treated samples [32]. In this way, integrating nano-biotechnology together with bioremediation, it is possible to achieve an efficient, effectual and sustainable solution for a clean and green environment [33].

In conclusion, bioremediation is significantly a clean, green and sustainable technology and is in general recognized as environmentally appropriate. Various industrial and anthropogenic activities have resulted in increased contaminated sites due to unawareness about production, utilization and disposal of hazardous chemical substances. Academicians, government and scientists globally are strictly advocating tackling such contaminants that are putting the environment at risk. Bioremediation is thus an important strategy for sustainable development of our society with a minimal environmental impact.

CONFLICTS OF INTEREST

There are no conflicts of interest.

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