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THE ROLE OF BACTERIA IN REDUCING THE IMPACT OF ENVIRONMENTAL POLLUTION: BETWEEN RISKS AND BENEFITS /A REVIEW ARTICLE

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Abstract:
The objective of this article is to study the impact of environmental pollution on air, water, and soil quality with a focus on the role of environmental bacteria in bioremediation of pollutants. The research also addresses the ability of some strains of bacteria to remove heavy metals and petroleum hydrocarbons and degrade toxic substances, resulting in improved environmental quality. Outcomes: Empirical studies reveal that environmental pollution leads to significant health and environmental problems, such as a rise in respiratory disease as a result of air pollution, water pollution that affects aquatic life, and soil pollution that decreases crop output. Other bacterial strains such as *Pseudomonas, Bacillus, and Streptomyces* have also been shown to have an enormous capacity to biodegrade harmful organic toxicants and adsorb heavy metals such as lead, cadmium, and mercury. Bioremediation has also been proven useful in improving water and land contamination quality and thereby constituting a safe green technology option to regular chemical technology. Conclusions: The research indicates that environmental bacteria bioremediation is a sustainable and efficient means of reducing environmental pollution. It is possible to improve these practices through genetic engineering to make bacteria more efficient in removing pollutants. Research and technology support in this field is also required to make applications of bacteria in programs of environmental remediation, resulting in a cleaner and greener

Keywords: Environmental Pollution, Bioremediation, Metals, Improving Environmental Quality

1-INTRODUTION

Environmental Pollution Definition and Types:

Environmental pollution is the release of materials or energy into the environment in a manner that leads to undesirable modifications in ecosystems or in injury to the health of living organisms and natural resources (Mackenzie *et al.,* 2021). Pollution occurs due to pollutants, either anthropogenic or natural, to a concentration above the ability of the environment to neutralize the impacts, leading to air, water, and land deterioration and climate change.

Types of Environmental Pollution

Environmental pollution is classified into various principal types based on its origin, nature, and effect on the environment and living organisms:

1- Air Pollution : Air pollution occurs when harmful materials such as gases and particulates are emitted into the atmosphere, causing health consequences and environmental impact such as acid rain and climate change (Seinfeld & Pandis, 2016). The major cause of this type of pollution includes industrial and transportation emissions and combustion of fossil fuels.

2- Water Pollution : Water pollution is where chemical, biological, or physical materials are deposited into water bodies, contaminating water and making it unfit for use by human beings or aquatic organisms (Chapman, 2020). Sources include industrial waste disposal, oil spills, pesticides, and household waste.

3- Pollution of Soil : Soil contamination occurs when toxic substances get deposited on the ground, rendering the soil barren and unable to support agriculture or contaminate groundwater (Alloway, 2013). Chemical spills from industries, excessive use of pesticides and fertilizers, and dumping of solid wastes are some of the reasons behind this contamination.

4- Noise Pollution : Noise pollution results from loud, intrusive sounds that produce negative impacts on human health and animal life (Basner et al., 2014). Transportation noise comes from noise, machinery, and heavy music, causing stress as well as physical and psychological disturbances.

5- Light Pollution : Light pollution is a consequence of the excessive and uncontrolled use of artificial light, which interferes with the natural biological cycles of living things and prevents the stars from being visible at night (Falchi *et al.,* 2016). It is found most commonly around industrial areas and large cities.

6- Radioactive Pollution : Radiation contamination results from unwanted exposure to electromagnetic or nuclear radiation. It is one of the most dangerous contaminations due to its health impacts, which include genetic mutations and cancer (Møller & Mousseau, 2013). Nuclear testing or leaking of radioactive fuel from nuclear energy facilities can activate the contamination.

Bacteria as Environmental Microorganisms: Ecological Functions in Interactions

Bacteria are one of the most widespread organisms in the environment, found in soil, water, air, and other organisms. Bacteria play a vital function in ecological processes in nutrient cycling, biodegradation, nitrogen fixation, and environmental pollutant decomposition. All these processes are essential in maintaining ecological balance and ensuring natural ecosystems' sustainability (Madigan *et al.*, 2021).

1- The Bacterial Role in Ecological Interactions

A- Bacteria and Nutrient Cycles :

Bacteria have a key function in major nutrient cycles such as the carbon, nitrogen, sulfur, and phosphorus cycle and convert organic and inorganic substances into a form that other organisms can use.

Carbon Cycle: Bacteria decompose dead organic matter and cycle organic carbon to carbon dioxide (CO_2) through aerobic respiration, or to other carbon compounds in anaerobic conditions, such as methane (CH_4) by *methanogenic* bacteria (Conrad, 2020).

Nitrogen Cycle: Nitrogen fixation: Certain bacteria, such as *Rhizobium and Azotobacter*, fix atmospheric nitrogen (N_2) to a usable form like ammonium (NH_4^+), which enriches plant nutrition (van Kessel *et al.*, 2015).

Nitrification: Nitrosomonas and Nitrobacter oxidize ammonium to nitrate (NO_3^-) and enhance plant uptake of nitrogen.

Denitrification: *Pseudomonas* bacteria convert nitrate to nitrogen gas (N_2), releasing it into the atmosphere, decreasing nitrate accumulation in soil and groundwater.

Sulfur Cycle: Bacteria play an important role in oxidizing sulfur to various forms, influencing energy production in some ecosystems (Muyzer & Stams, 2008).

Phosphorus Cycle: Phosphorous bacteria make the degradation of insoluble phosphates possible and convert them into soluble forms that plants can use for growth.

B- Bacteria and Biodegradation

Bacteria break down complex organic matter into simpler forms, a process that plays an important role in recycling nutrients in the ecosystem. Certain bacteria involved in biodegradation include:

Cellulolytic bacteria such as *Cellulomonas*, which break down cellulose in dead plant material, *Proteolytic* bacteria such as *Proteus*, which break down proteins into amino acids, Microbial bacteria specifically employed to break down contaminants such as *Pseudomonas and Alcanivorax,* which break down organic contaminants such as petroleum and pesticides (Ghosal *et al.,* 2016).

C- Bacteria and its application in bioremediation of environmental pollutants

Bacteria can be used to take a pivotal role in the remediation of environmental pollutants by the mechanism of bioremediation. This includes:

Heavy metal elimination: Some bacteria, such as Bacillus and Pseudomonas, accumulate heavy metals like lead (Pb) and mercury (Hg) and reduce their toxicity (Gadd, 2010).

Oil decomposition: Microorganisms such as *Alcanivorax and Pseudomonas aeruginosa* are employed to degrade hydrocarbon molecules in contaminated water and soil (Prince *et al.,* 2018).

Wastewater treatment: Microorganisms such as *Nitrosomonas and Nitrobacter* oxidize ammonium to nitrate during wastewater treatment, reducing the extent of pollution.

D- Bacteria and Plant and Other Organism Interactions

Plant growth is stimulated by bacteria through the provision of symbiotic relationships, such as:

Nitrogen-fixing bacteria (Rhizobium) dwelling in the root of legumes and playing their role in fixing nitrogen for the plant.

Plant growth-promoting bacteria (PGPR) such as *Bacillus subtilis*, which develop the plant with the secretion of plant hormones such *as auxins* (Backer *et al.,* 2018).

Bacteria are perhaps the most important microorganisms in the world as they play fundamental roles in biogeochemical cycling, biodegradation, bioremediation, and plant growth promotion. Understanding such roles guarantees the balance of the ecosystem and application of bacteria to practical environmental, agricultural, and industrial purposes.

Effects of Pollution on Bacteria: What the Pollutants (Heavy Metals, Oil, Chemicals) Do to the Bacteria

Bacteria are among the organisms most susceptible to pollution in the environment, as pollutants such as heavy metals, oil, and chemicals hinder their form and bioprocesses. The pollutants disrupt their diversity, reproductive process, and efficiency in environmental processes such as biodegradation and nutrient cycling. In some cases, bacteria are able to develop resistance to such contaminants and are able to adapt to them, and they can be useful in environmental cleaning processes (Rocha *et al*., 2018).

1- Response of Bacteria to Heavy Metals

A- Mechanisms of Toxicity: Among the most toxic metal contaminants to bacteria are heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg), and chromium (Cr). They are toxic to bacteria in the following manners: Inhibition of enzymes: Heavy metals inhibit bacterial enzymes by binding at active sites such as thiol groups (-SH) and leading to interference with the normal biological function (Bruins *et al.,* 2000).

Oxidative stress: Some metals, such as cadmium and mercury, lead to the production of reactive oxygen species (ROS), which damage bacterial DNA, proteins, and cell membranes (Wang & Chen, 2019).

Effects on cell membranes: Heavy metals interfere with the permeability of the bacterial cell membrane, potentially leading to the loss of essential ions and nutrients required for cell survival.

B- Bacterial resistance to heavy metals

Some bacteria have sophisticated defense mechanisms against heavy metals, such as:

Active pumping (Efflux pumps): Some bacteria use protein pumps to eject heavy metals from the cell.

Metal sequestration: Some bacteria produce proteins such as metallothioneins or extracellular polysaccharides to trap heavy metals and reduce their toxicity (Mirete *et al.,* 2016).

Bioreduction: Some bacteria, such as Pseudomonas and Bacillus, are able to reduce heavy metal ions to less toxic forms, for instance, the reduction of hexavalent chromium (Cr^{6+}) to trivalent chromium (Cr^{3+}) (Gadd, 2010).

2- The Effect of Oil Contamination on Bacteria

A- Toxicity and Action Mechanism : Oil is one of the most frequent contaminants in soil and water, and it affects bacteria in several ways:

Cell Membrane Damage: The hydrocarbon molecules in oil can disrupt the lipids that make up cell membranes, altering their permeability and killing or inhibiting bacteria (Prince *et al.,* 2018).

Inhibition of Cellular Respiration: Some of the petroleum components, such as polycyclic aromatic compounds (PAHs), block the electron transport chain during aerobic respiration, interfering with the ability of the bacteria to produce energy.

Oxidative Stress: Some petroleum fractions, such as benzene and toluene, trigger the formation of reactive oxygen species, which damage bacterial proteins and DNA (Van Hamme *et al*., 2003).

B- Bacteria's Adaptation to Oil Pollution

Although oil is harmful to the majority of bacteria, some species can degrade petroleum products and use them as a source of carbon and energy, including: *Pseudomonas aeruginosa, Alcanivorax borkumensis, Rhodococcus sp.*

These bacteria use enzymes such as monooxygenases and dioxygenases to degrade petroleum compounds and convert them into less harmful products (Das & Chandran, 2011).

3- Effect of Industrial Chemicals on Bacteria

A- Pesticides and Organic Compounds: Pesticides and organic contaminants such as phenols and organic solvents affect bacteria in the ways, inhibiting metabolic enzymes, thus preventing their growth and reproduction, disrupting DNA, which leads to mutations or cell death and impacting the composition of the bacterial community in soil and water, leading to decreased bacterial diversity and increased resistant species (Aktar *et al.,* 2009).

B- Chemical resistance in bacteria: Some bacteria have evolved to be able to break down toxic chemicals and convert them into harmless substances, such as: *Pseudomonas putida*, which breaks down phenol and

Sphingomonas*,* which breaks down complex aromatic compounds and *Dehalococcoides* that can degrade chlorinated solvents such as carbon tetrachloride (Van Agteren *et al.,* 1998).

Pollution directly affects bacteria, disrupting their fundamental processes and inducing profound changes in the population of bacteria. However, there are some bacteria that acquire resistance against such contaminants and emerge as crucial actors in environmental clean-up. Research on the influence of pollution on bacteria is instrumental in the calculation of anti-pollution planning and boosting bioremediation processes.

Bacteria as Source of Pollution Remediation

Bacteria are possibly the most active biological entities as far as environmental pollution remediation is concerned founded on the fact that they have the ability of degrading and converting dangerous pollutants into less poisonous or harmless elements through biodegradation and bioremediation processes. These processes rely on the presence of different populations of bacteria having mechanisms of adaptation in which they could live in the contaminated condition and can also bioremediate contamination effectively. With this, bacteria-based applications to bioremediate pollution may be highlighted with the following broad uses such as Oil-degrading bacteria and oil pollution remediation and Heavy metal-resistant bacteria and bioremediation role

Bacteria used to cleanse polluted water

1- Oil-degrading bacteria and remediation of oil pollution

A- Environmental impacts of oil pollution: Oil is an extremely hazardous environmental pollutant that causes severe damage to the ground, water, and living species. Crude oil consists of complex hydrocarbon molecules, such as polycyclic aromatic hydrocarbons (PAHs) and aliphatic hydrocarbons, which are biodegradation-resistant and cause injury to ecosystems.

B- Role of Oil-Degrading Bacteria: Some bacteria can use petroleum constituents as a carbon and energy source, which enables them to effectively degrade oil contamination. These bacteria include *Pseudomonas aeruginosa, Alcanivorax borkumensis, Rhodococcus sp., Bacillus subtilis*

C- Bacterial Pathways for Degradation of Oil: Oil-degrading bacteria rely on an array of enzymes to break down petroleum constituents and convert them to non-toxic substances:

Oxygenases: These add oxygen molecules to petroleum products and convert them into biodegradable materials.

Dioxygenases: They are used for the breakdown of the benzene rings of polycyclic aromatic hydrocarbons.

Production of Biosurfactants: Some bacteria such as *Pseudomonas* have the ability to produce compounds which emulsify oil, hence facilitating further with which its degradation can occur.

D- Applications of Bioremediation for Oil Pollution:

Bioremediation in Soil: Oil-degrading bacteria are used for the remediation of oil-contaminated soil through processes such as biostimulation and bioaugmentation.

Bioremediation in Water: Degrading bacteria are added to oil-contaminated water bodies to aid in the breakdown of spilled oil.

Application Example: *Alcanivorax borkumensis* was employed in the successful remediation of ocean oil spills due to its high potential in degrading petroleum compounds (Das & Chandran, 2011).

2- Heavy Metal-Resistant Bacteria and Their Role in Bioremediation

A- Impact of Heavy Metals on the Environment: Heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg), and chromium (Cr) are accountable for water and soil pollution, affecting human health and living organisms. These metals accumulate in living organisms, leading to serious health problems.

B- Heavy Metal-Resistant Bacteria: Some bacteria have developed resistance strategies that enable them to survive in heavy metal-polluted environments. The most prominent of these species are: *Pseudomonas putida, Bacillus subtilis, Cupriavidus metallidurans, Ralstonia eutropha,*

C- Mechanisms of Bacterial Resistance to Heavy Metals

Active Efflux Pumps: Bacteria use protein pumps to push heavy metals out of the cell.

Metal Sequestration: Some bacteria produce proteins such as metallothioneins to sequester heavy metals and reduce their toxicity.

Bioreduction: Some bacteria can reduce heavy metals to less toxic forms, for instance, reducing hexavalent chromium (Cr^{6+}) to trivalent chromium ($Cr^{\square+}$).

D- Applications of Heavy Metal Bioremediation

Decontamination of soil contaminated with heavy metals by using bacterial strains capable of heavy metal absorption and removal of heavy metals from contaminated water by bioremediation using resistant strain, applied example: *Cupriavidus metallidurans* has been used in the treatment of industrial wastewater containing heavy metals (Gadd, 2010).

3- Bacteria used in the cleaning of polluted water

A- Problem of water pollution: Water comes into contact with industrial, agricultural, and sewage pollutants, resulting in the spread of chemical and microbial contaminants. Bacteria can assist in the removal of organic and inorganic pollutants from water.

B- Bacteria utilized for water purification: Some bacteria have the ability to degrade and remove pollutants from water, e.g., *Nitrosomonas and Nitrobacter*, they oxidize ammonia to nitrate in wastewater treatment processes, and *Pseudomonas fluorescens,* they are able to degrade organic pollutants such as phenols and pesticides, and *Desulfovibrio desulfuricans, t*hey remove sulfates from polluted water.

C- Biological Water Treatment Technologies: Biological Wastewater Treatment: relies on the use of bacteria that degrade organic matter.

Biofiltration: Biofilms containing bacteria are used to filter water.

Algal-Bacterial Treatment: Algae are used in combination with bacteria to clean water polluted with excess nutrients.

Applied Example: *Nitrosomonas and Nitrobacter* were used in wastewater treatment plants to oxidize harmful ammonia to non-toxic nitrates (Wagner *et al.,* 2002).

Potential Risks of Bacterial Application in Bioremediation: Their Ecosystem and Human Health Impacts

Bacteria are one of the most promising tools in environmental pollution bioremediation, as they are used to remove oil pollutants, heavy metals, and decontaminate polluted water. However, the release of some bacteria into the environment is not safe and may affect ecosystems and human health. The risks include unexpected effects on ecological balance, the potential for spreading antibiotic-resistant genes, and potential health effects upon human exposure include:

A- Ecological Disturbance: Upon introduction of unnatural bacterial strains in the environment, they may compete with native organisms to cause ecological imbalance. Such a shift may result in displacement of Native Species: The bacteria used in bioremediation may reduce or eliminate native species, impacting the food web and growth of Certain Pathogenic Species: Some undesirable species are able to use the accessible nutrients due to the changed bacteria, which may lead to their unregulated growth.

B- Spread of Antibiotic Resistance Genes: Some bacteria used in bioremediation are intrinsically resistant to heavy metals or antibiotics, and this increases the likelihood of these genes being transferred to other bacteria in the environment by mechanisms such as Horizontal Gene Transfer (HGT), by which genes are exchanged between bacteria through plasmids or bacteriophages and Gene transfer between natural and engineered bacteria, which can give rise to antibiotic-resistant bacterial strains that are hard to manage applied example ,certain research has indicated that heavy metal-resistant Pseudomonas bacteria can harbor antibiotic-resistant genes, posing the risk of increased resistance dissemination in soil and water ecosystems (Silver & Phung, 2005).

C- Impact on Soil and Water Nutrient Cycles: The microorganisms used in bioremediation can affect the biogeochemical cycles of such elements as carbon, nitrogen, and sulfur. The change in these cycles can lead to inadequate availability of essential nutrients in soil due to unbalanced consumption of certain compounds and increased nutrients in water, which lead to high biodegradation (eutrophication) and the production of toxic algal blooms, which consume oxygen and cause a deficiency of oxygen in water bodies.

Human Health Risks

A- Contact with Modified Bacteria

Some bacteria used in bioremediation may possess characteristics that would potentially make them unsafe to human health, including toxin production: Some bacteria used in the degradation of oil pollutants produce toxins that exhibit impacts on humans and animals and immune stimulation: Repeated exposure of humans to these bacteria might overstimulate the immune system and result in inflammation or an allergic response, certain strains of Bacillus bacteria can infect individuals upon exposure to them, particularly those with weak immune systems (Logan & De Vos, 2009).

B- Transmission of Bacterial Infections

Some environmental bacteria might be pathogenic if they infect the human body through:

Inhalation: Human workers in areas of pollution treatment may be exposed to bacteria-contaminated particles.

Direct Contact: Direct contact with bacteria can lead to infection, especially when there are skin breaks or open wounds.

Water Contamination: Some bacteria used in the treatment of contaminated water can form biofilms with pathogens that can affect human health.

Preventive Measures to Minimize Risks

A- Environmental Impact Assessment (EIA) before use: Environmental Risk Assessment (ERA) studies must be conducted prior to introducing new bacteria into the environment to establish whether they can cause environmental or health harm.

B- Use of Non-GMO Bacterial Strains: Natural bacterial strains must be used rather than genetically modified bacteria because natural bacteria have lower potential to harm the environment and lower ability to cause mass environmental disturbances.

C- Monitoring of Bacterial Effects Following Use: Dissemination and effect of bacteria used in bioremediation need to be monitored after use to prevent unintended consequences.

D- Mechanisms to Reduce the Dissemination of Resistance Genes: Use of bacterial strains that do not contain antibiotic resistance genes and genetic modification techniques that restrict the ability of bacteria to share genes with other bacteria in the environment.

CONCLUSION:

1- Environmental Pollution and its Impact on Health and Ecosystems: Pollution of the environment refers to releasing materials or energy into the surroundings in amounts greater than their level of neutralization, leading to a deterioration in the quality of air, water, and earth, and unhealthy effects on the life of animals. Environmental pollution has major classes that include pollution of the atmosphere, water pollution, land pollution, noise pollution, light pollution, and contamination due to radioactivity. This is even accelerated by human activity such as industrial activity, road traffic, and agriculture.

2- The Role of Bacteria in Environmental Processes and Bioremedies: Bacteria play a significant role in biogeochemical cycles such as the carbon, nitrogen, sulfur, and phosphorus cycles and in biodegradation and organic and inorganic substance transformation into forms available to other organisms. They also participate in nitrogen fixation, organic matter decomposition, and promotion of plant growth through symbiotic associations such as nitrogen-fixing bacteria and plant growth-promoting bacteria.

3- Bacteria, Biodegradation, and Applications in Ecoremediation: Bacteria are able to decompose complex organic compounds into simpler compounds, which aids in recycling nutrients within the ecosystem. They are also important in environmental cleanup (bioremediation), such as heavy metal removal, oil degradation, and wastewater treatment, through bacteria that are capable of detoxifying and converting pollutants into less harmful compounds.

4- The Impact of Environmental Pollution on Bacteria and Adaptation Mechanisms: Toxicants such as heavy metals, oil, and industrial chemicals harm bacteria by inactivating their enzymes, inducing oxidative stress, and destroying cell membranes. Bacteria possess defense systems such as active scavenging pumps, metal-binding protein production, and the ability to biochemically degrade toxicants into less toxic forms, which makes them essential for the clean-up of contaminated habitats.

5- The Need for Sustainable Environmental Strategies to Reduce Pollution: One of the most significant challenges to humanity and ecosystem stability is environmental pollution. The problem is addressed through developing green technologies, using clean sources of energy, improving waste management, and promoting biological solutions such as the utilization of bacteria in biodegradation and bioremediation to foster ecosystem sustainability and conserve natural resources.

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