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APPLICATIONS OF NEW TECHNOLOGIES FOR ENVIRONMENTAL CLEANING: A REVIEW

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ABSTRACT

Environmental pollution has become a major global concern, requiring innovative technologies for effective remediation. This review discusses recent advancements in environmental cleaning, including bioremediation, nanotechnology, advanced oxidation processes (AOPs), artificial intelligence (AI), green chemistry, and membrane filtration techniques. These technologies offer sustainable solutions for treating soil, water, and air pollution. This paper provides a comprehensive evaluation of their mechanisms, applications, advantages, limitations, and future potential. The integration of multiple technologies for enhanced efficiency is also examined, emphasizing the need for further research and policy development for large-scale implementation.

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Keywords: Environmental remediation, bioremediation, nanotechnology, oxidation processes, artificial intelligence, pollution control, sustainable technologies, green chemistry.

1. Introduction The rapid expansion of industrial activities, urbanization, and agricultural practices has resulted in widespread environmental contamination (Kuppusamy et al., 2016). The accumulation of hazardous pollutants in soil, water, and air poses serious health risks to both humans and ecosystems (Ghosh & Mohan, 2020). Conventional pollution control methods, such as physical and chemical treatments, often require high energy inputs, generate secondary waste, and may not be effective in completely eliminating pollutants. These challenges have led to the exploration and development of advanced environmental cleaning technologies that offer cost-effective, sustainable, and efficient solutions (Singh et al., 2021).

New technologies, including bioremediation, nanotechnology, and artificial intelligence, have revolutionized the field of environmental remediation by providing targeted and adaptive solutions (Kumar et al., 2019). Moreover, the integration of multiple techniques enhances pollutant degradation and improves overall treatment efficacy. This review provides a detailed overview of cutting-edge technologies for environmental remediation, their mechanisms, applications, advantages, and limitations. It also highlights future perspectives on improving the scalability and effectiveness of these technologies for real-world environmental challenges.

2. Bioremediation Technologies Bioremediation uses microorganisms and plants to break down pollutants in soil and water (Singh et al., 2021). Strategies include:

- **Microbial Remediation:** Genetically engineered bacteria enhance pollutant degradation (Kumar et al., 2019).
- **Phytoremediation:** Plants such as *Brassica juncea* and *Helianthus annuus* accumulate contaminants (Ali et al., 2013).
- **Enzymatic Bioremediation:** Enzymes such as laccases and peroxidases degrade persistent organic pollutants (Megharaj et al., 2011).

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3. Nanotechnology-Based Solutions Nanomaterials have revolutionized environmental cleaning by providing highly efficient adsorption and catalytic degradation (Khin et al., 2012). Key applications include:

- **Water Purification:** Nano-adsorbents remove heavy metals and pharmaceuticals from wastewater (Zhang et al., 2019).
- **Air Filtration:** Carbon-based nanomaterials capture airborne pollutants (Nowack et al., 2012).
- **Soil Remediation:** Nanoscale zero-valent iron (nZVI) degrades chlorinated hydrocarbons (Sodha et al., 2020).

4. Advanced Oxidation Processes (AOPs) AOPs generate reactive radicals to break down pollutants (Oturan & Aaron, 2014). Techniques include:

- **Photocatalysis:** Titanium dioxide (TiO2) and UV light degrade organic contaminants (Wang et al., 2016).
- **Fenton Process:** Iron-catalyzed oxidation for wastewater treatment (Kumar & Pal, 2018).
- **Electrochemical Oxidation:** Electro-Fenton processes for industrial effluent treatment (Sharma et al., 2021).

5. Artificial Intelligence in Environmental Cleaning AI enhances monitoring and decision-making in pollution control (Xu et al., 2021). Applications include:

- **Predictive Modeling:** AI-driven simulations optimize remediation strategies (Sharma et al., 2020).
- **Automated Detection:** AI-powered drones monitor air and water pollution (Tripathi et al., 2022).
- **Machine Learning for Waste Treatment:** AI-driven wastewater treatment plants improve efficiency (Singh & Joshi, 2020).

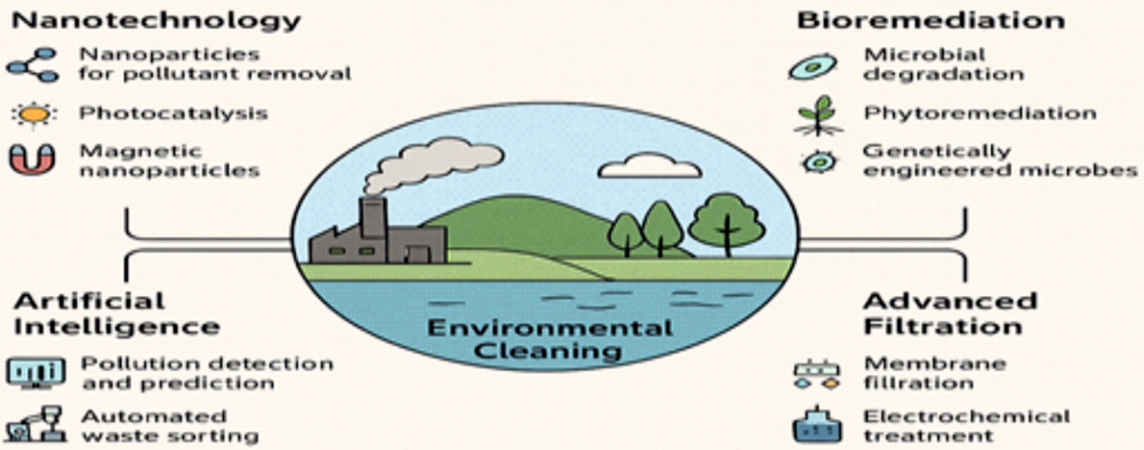

Table 1: Overview of Key Environmental Cleaning Technologies

Technology	Application
Nanotechnology	Removal of heavy metals and organic pollutants
Bioremediation	Degradation of contaminants by microorganismins and plants
Artificial Intelligence	Monitoring, prediction, and waste management
Advanced Filtration	Filiration of pollutants from water and air

Table 2: Selected Nanomaterials for Environmental Remediation

Nanomaterial	Uses
Nano-zero valent iron	Degradation of chiorinated compounds in soil
Titanium dioxide	Photocatalytic oxidation of organic pollutants
Graphene-based materials	Adsorption of heavy metals from water
Silver nanoparticles	Antimicrobial activity in water treatment

Figure: showing the application of recent technologies in environmental cleaning.

6. Membrane Filtration Technologies Membrane-based separation effectively removes contaminants from water (Alzahrani & Mohammad, 2014). Advanced membrane technologies include:

- **Reverse Osmosis (RO):** Desalination and heavy metal removal.
- **Nanofiltration:** Separation of microplastics and pharmaceutical residues (Gavrilescu et al., 2019).
- **Graphene Membranes:** Highly efficient pollutant removal with minimal energy consumption (Zhou et al., 2020).

7. Electrochemical Methods Electrochemical technologies are used for pollution remediation with minimal chemical input (Kumar et al., 2022). Key techniques include:

- **Electrocoagulation:** Effective removal of heavy metals from wastewater (Oturan & Aaron, 2014).
- **Electrochemical Advanced Oxidation:** Breakdown of persistent organic pollutants (Sharma et al., 2021).
- **Bioelectrochemical Systems:** Use of microbial fuel cells for pollutant degradation (Das et al., 2021).

8. Green Chemistry and Sustainable Approaches Green chemistry focuses on eco-friendly remediation strategies (Anjum et al., 2019). Examples include:

- **Bio-Based Adsorbents:** Chitosan, cellulose, and biochar for heavy metal removal (Zhou et al., 2020).
- **Enzyme-Based Detoxification:** Application of peroxidases and oxidases for wastewater treatment (Das et al., 2021).
- **Sustainable Catalysts:** Use of bio-derived catalysts for oxidation processes (Gavrilescu et al., 2019).

9. **Emerging Trends and Future Perspectives** The integration of multiple technologies can enhance environmental remediation (Tripathi et al., 2022). Research trends include:

- **AI-Assisted Bioremediation:** AI-optimized microbial consortia for enhanced pollutant degradation.
- **Nanotechnology-Enhanced Phytoremediation:** Improved heavy metal absorption using nano-fertilizers.
- **Hybrid AOP-Bioremediation Systems:** Combination of oxidation and biological degradation.
- Scalability and Policy Development: Ensuring global adoption through regulatory frameworks.

Conclusion

Emerging technologies provide promising solutions for environmental cleaning. While each technology has its strengths, integrated approaches offer superior efficiency. However, the deployment of these technologies on a larger scale still faces several challenges, including high costs, energy consumption, public acceptance, and regulatory approvals. Therefore, future research should focus on developing cost-effective, scalable, and energy-efficient remediation systems. Cross-disciplinary collaborations, industry participation, and international policy initiatives are essential to drive innovation and ensure effective implementation. As global environmental threats continue to rise, the adoption and evolution of advanced cleaning technologies are not just beneficial—they are imperative for sustainable development.

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