Sustainable Management of Emerging Contaminants in Wastewater: Monitoring, Governance, and Advanced Treatment Technologies in the Global South

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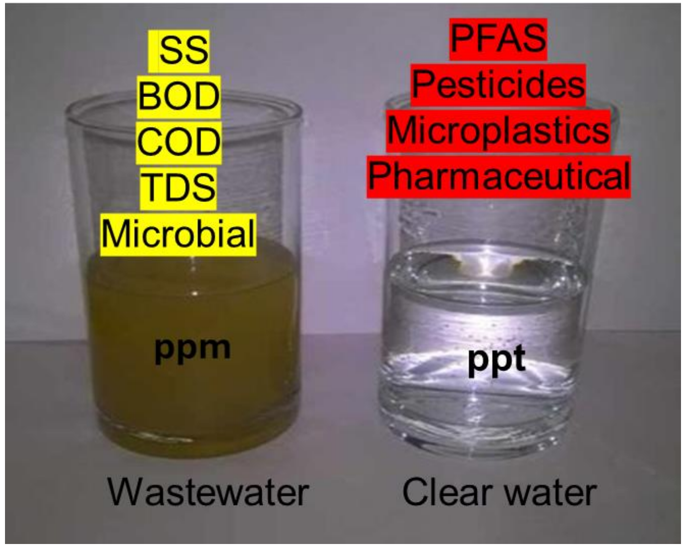
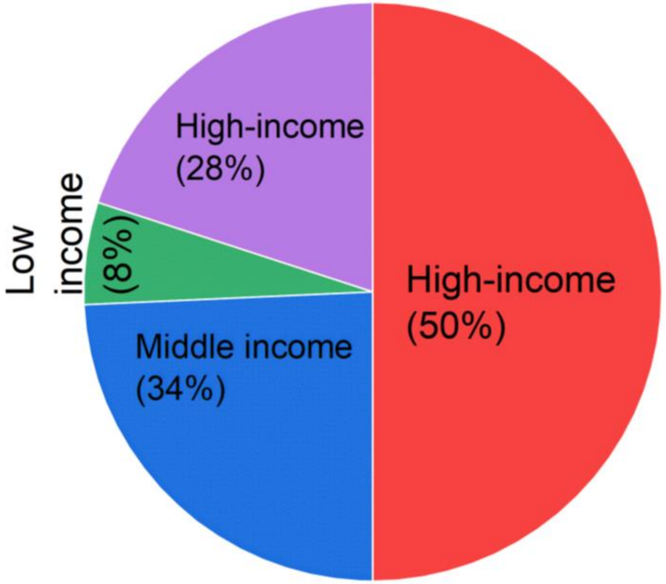
Emerging Contaminants (ECs)



People's Perception of Safe water are based on *subjective values*:

- Color,
- Odour,
- Taste and
- Suspended Impurities



Worldwide Wastewater Treatment

UNSD 2030 ?

ECs: emerging and non-regulated

- Persistent, Toxic, low concentration

e.g. PPCPs, EDCs, Pesticides, micro plastics, ARB, ARG

- worldwide output: 1 million to 500 million tons each year[1]
- India: Pharmaceutical ~10 µg/L and PFAS ~100 ng/L in surface water

[1]Khan, S et. al. (2022) *Environmental Research,*

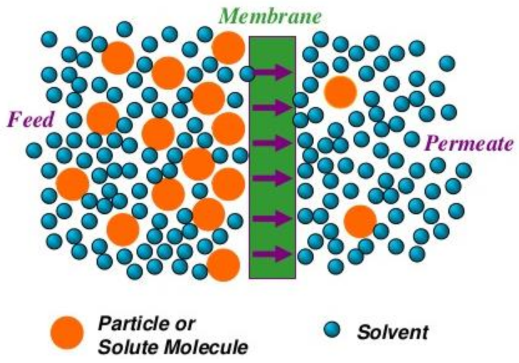
PPCPs: Pharmaceutical and Personal care compounds
EDCs: Endocrine Disrupting Compounds
ARBs: Antibiotic Resistance Bacteria
ARGs: Antibiotic Resistance Genes

Major EC Concentrations in Indian Waters

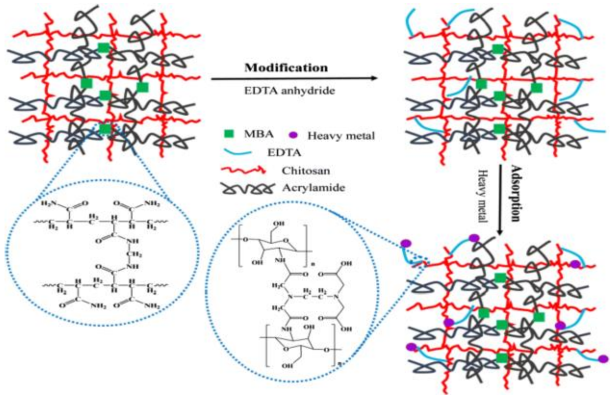
- **Pharmaceutical residues:** Reported up to **10 µg/L** in major rivers (Yamuna, Ganges, Godavari)[1]
- **PFAS contamination: Exceeding 100 ng/L** in surface and drinking water sources[2]
- **Pesticide contamination:** Organophosphate levels up to **50 µg/L** in agricultural runoff[3]
- **Microplastic pollution:** Found in **over 80% of sampled rivers**[4]

[1]Ranjan, N., et. al.,(2022). *Ecotoxicology and Environmental Safety*
[2]Koulini., et. al.,(2024). *Journal of Water Process Engineering*
[3]Behera, B. C et., al.,(2024). *IJCS*
[4]Neelavannan, K., & Sen, I. S. (2023).*ACS omega*.

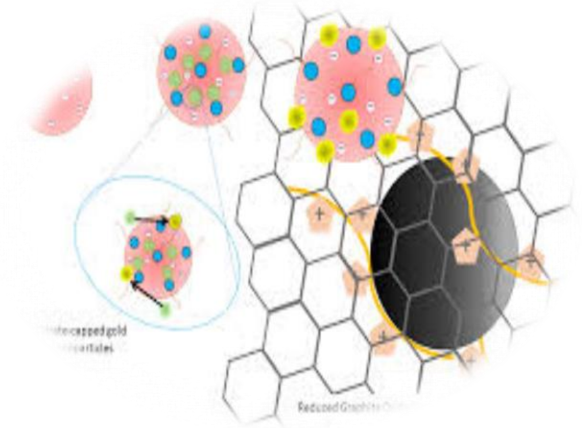
ADVANCED WASTEWATER TREATMENT SYSTEMS



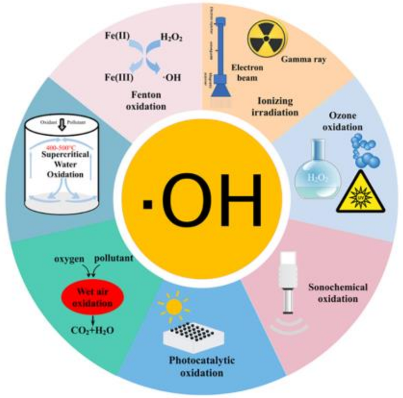
Membrane filtration



Adsorption



Nanoparticles



Advanced Oxidation Process (AOPs)

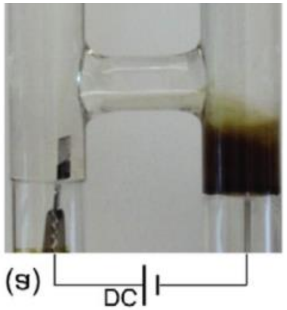
Adsorption
+ Cost-effectiveness
- Operational Challenges

Membrane technology
+ High treatment efficiency
- Chemical Compatibility

Nanotechnology
+ Selectivity
- Nanoparticles leaching

AOPs
+ Degradation method
- Chemical Requirements

PLASMA AS AN EFFECTIVE ADVANCED TREATMENT SYSTEM



Nanotechnolog
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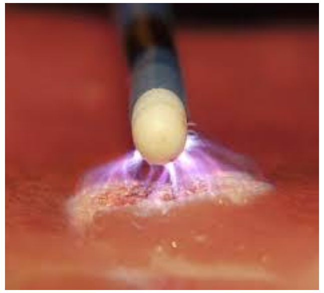
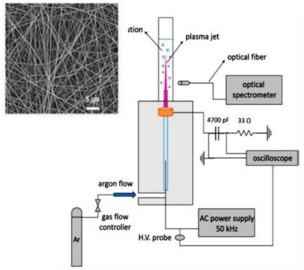
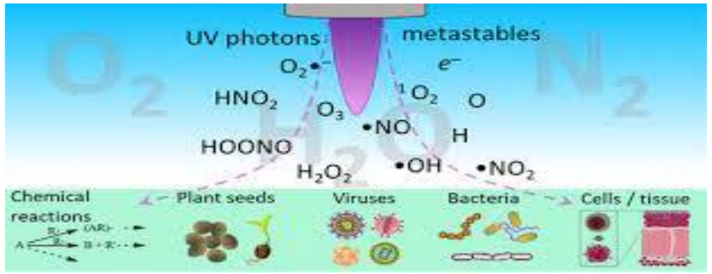


Biomedical

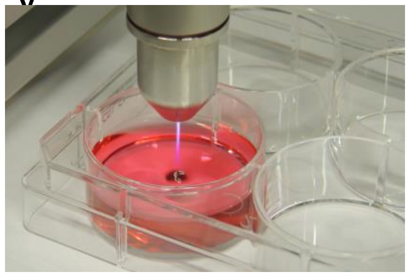
Agriculture



H_2 production



Reactive species formation and their interaction with contaminants[1]



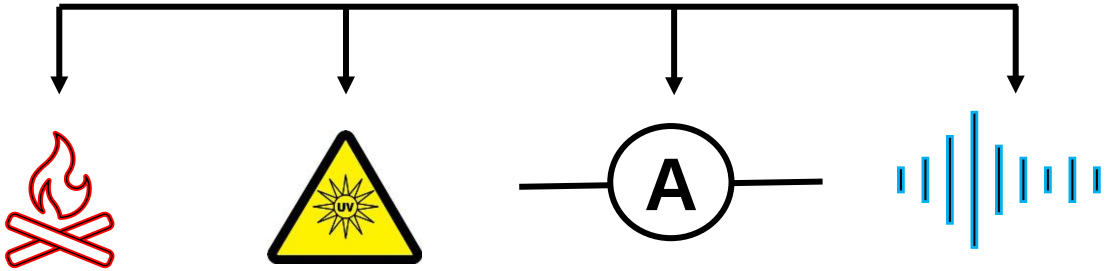
Sterilization

Analytics

Wastewater

Different applications of plasma technology

PLASMA



Heat

UV

Current

Sonic Waves

- Can degrade recalcitrant chemicals (e.g. PFOA)
- No additional chemicals needed
- No secondary waste generation

1. Gururani, P et al (2021). Cold plasma technology: advanced and sustainable approach for wastewater treatment. *Environmental Science and Pollution Research*,

REGULATIONS AND GUIDELINES

- **USA**

  US-EPA: CCL list from 2014

  Presently the CCL5 has 66 contaminants
- **European Union**

  European Chemicals Agency (ECHA) releases its ECs watchlist

  Presently monitors 53 compounds
- **Japan**

  Annual Water Quality Examination Plan

  Drinking Water Quality Standards (DWQS)
- **Australia and Canada**
- **Developing Countries** with some regulations

  Brazil, China and India

Limitations of the current international regulations

- Gaps in Policy intervention:

  USA major producer of ECs - not ratified to any significant conventions related to ECs

  Absence of enforceable regulatory authority
- Inadequate regulatory infrastructure for emerging contaminants
- Environmental behaviour and ecotoxicology:

  Manufacturer confidentiality practices
- Lack of link between science and policy

  Insufficient scientific evidence against ECs

- USEPA: epa.gov/ccl/contaminant-candidate-list-5-ccl-5
- EU: europa.eu/commission

Action Plan and Recommendations

Focus on three major dimensions of sustainability, i.e., economic, environmental and social

Targets

- 50% reduction in untreated wastewater by 2030
- 25% decrease in EC contamination by 2035

Strategies

- Deployment of cost-effective hybrid technologies.
- Capacity building for local governments and industries
- Incentives for private sector involvement

Source	Estimated Contribution
Pharmaceutical industries	10–20%
Hospitals & Healthcare	15–25%
Domestic Sewage	40–50%
Agricultural Runoff	10–20%
Landfills & Leachate	5–10%

Roadmap for EC Management in India: 2030 & 2035 Goals

1. **Expand centralized treatment capacity** CPCB (2021), NITI Aayog (2022)

- Implement decentralized wastewater treatment
- Increase wastewater reuse:

Expected Outcome: Untreated WW discharge **reduced from 26.5 BLD to ~13 BLD (~50% reduction)**

2 . National EC Monitoring Program with Real-Time Data Sharing

Current Status CPCB (2022), MoEFCC (2023):

- No centralized real-time EC monitoring in India
- Only 5% of cities have infrastructure for EC testing

Proposed Actions:

- Set up national EC monitoring stations at 50+ major rivers and 100+ WWTPs.
- Adopt sensor-based and AI-powered real-time monitoring technologies.
- Mandate data reporting from industries and STPs via an online National Water Quality Dashboard.

Proposed Scalable Framework

Strengthening Monitoring & Governance

- Nationwide EC surveillance programs with standardized methods
- Stricter discharge regulations for high-risk industries (pharma, textiles, tanneries)

Optimizing Treatment Strategies

- Hybrid treatment models: Combining biological, chemical, and physical processes
- Modular & decentralized EC removal units for high-impact industrial zones

Increasing Investment & Public-Private Partnerships (PPPs)

- Incentivizing private sector investment in EC treatment infrastructure
- PPP-driven pilot projects to test cost-effective, region-specific solutions

Conclusion & Call to Action

- The EC challenge in India & Global South requires immediate action
- Better monitoring, stricter policies, and scalable treatment technologies are key solutions
- Collaboration across academia, industry, and government is essential

  Call for investment in research & pilot projects to develop cost-effective EC removal strategies

Thank You

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