Development of nano-based systems for aquatic ecosystem management

Umesh Daivagna[1]; Dr. Usha Nandhini S[2]; Subham Acharya[3]; Dr. Prabhu A[4]; Dr. Nidhi Srivastava[5]; Amit Kumar[6]; Puli Lavanya[7]

Received: 12 February 2025; Revised: 18 March 2025; Accepted: 03 April 2025; Published: 20 May 2025

Abstract

The detection of biomolecules has advanced quickly as a result of the biotechnology revolution. One way to effectively utilise these developments is through nanotechnology, which can be used to create continuous environmental monitoring systems. Although it has long been recognised that bacteria play a significant role in regulating a wide range of environmental processes, genomic research has only recently made it feasible to comprehend biological diversity in environmental systems. It will be essential to identify biological species through genetic analysis and evaluate the proteins that are being expressed in order to completely comprehend the interactions of biological systems in the environment. The capacity to perform biological analysis at incredibly low concentrations, beyond the detection limits of current biological sensors, will be necessary for this. Furthermore, it will be essential to measure a huge number of chemical and biological species at the same time and correlate these results across a wide range of length scales, from sub-micrometer to hundreds of kilometres, in order to completely comprehend environmental systems. Studies of the effects of combustion-generated nanoscale particles in ambient air on human cardiovascular health from a toxicological, epidemiological, and human health perspective are inconclusive when the bulk chemical composition of the particles is correlated with physiological response or health effects (health endpoints). As a result, measuring methods that differentiate the bulk particle interior from the chemical makeup and structure of particle surface layers are required.

1- Professor, ISME, ATLAS SkillTech University, Mumbai, Maharashtra, India.
Email: umesh.daivagna@atlasuniversity.edu.in, ORCID: https://orcid.org/0000-0002-3500-084X
2- Assistant Professor, Department of Biotechnology, Sathyabama Institute of Science and Technology, Chennai, India. Email: usha.biotech@sathyabama.ac.in, ORCID: https://orcid.org/0000-0003-0550-2758
3- Assistant Professor, Department of Agro-meteorology, Institute of Agricultural Sciences, Siksha 'O' Anusandhan (Deemed to be University), Bhubaneswar, Odisha, India. Email: subhamacharya@soa.ac.in, ORCID: https://orcid.org/0009-0002-8278-1359
4- Associate professor, Department of CS & IT, Jain (Deemed-to-be University), Bangalore, Karnataka, India. Email: prabhu.a@jainuniversity.ac.in, ORCID: https://orcid.org/0000-0003-0853-7980
5- Professor, Maharishi School of Pharmaceutical Sciences, Maharishi University of Information Technology, Lucknow, Uttar Pradesh, India. Email: nidhi.srivastava@muit.in,
ORCID: https://orcid.org/0000-0002-6661-5804
6- Centre of Research Impact and Outcome, Chitkara University, Rajpura, Punjab, India.
Email: amit.kumar.orp@chitkara.edu.in, ORCID: https://orcid.org/0009-0001-9561-2768
7- Centre for Multidisciplinary Research, Anurag University, Hyderabad, Telangana, India.
Email: pulilavanya2024@protonmail.com, ORCID: https://orcid.org/0009-0004-0880-2857
DOI: 10.70102/IJARES/V5I1/5-1-27

Targeting a particular molecule or chemical is the foundation of the majority of biological measurement methods currently in use. Measurement and sensing devices that can evaluate biological variety in the environment are necessary because the majority of microbial species are unknown.

Keywords: Nanotechnology, Environmental protection, Physical, Chemical, and biological properties.

Introduction

Nanotechnology is the creation and use of materials, instruments, and systems through manipulation of matter at the nanometer-length scale, including atoms, molecules, and supramolecular structures (Seidgar, 2021). The core of nanotechnology is working at these scales to produce larger objects with fundamentally unique molecular organization and characteristics (Ganesan *et al.*, 2024). These "nanostructures," which are among the tiniest things created by humans and have unique physical, chemical, and biological characteristics and phenomena, are constructed from basic building pieces (Pathak *et al.*, 2024). The objective of nanotechnology is to take use of these characteristics and effectively produce and use the structures (Kang, & Sohn, 2019). Nanotechnology has the potential to significantly impact environmental protection through the understanding and control of emissions from various sources, the development of new "green" technologies that reduce the production of undesirable byproducts, and the cleanup of existing waste sites and contaminated water sources (Rao and Tiwari, 2023; Thi and Dang, 2010). Nanotechnology can remove even the smallest contaminants from sources of water and air, in addition to continuously measuring and lowering environmental pollutants. Over the course of the next century, nanotechnology will significantly alter many existing technologies and make significant contributions to science and engineering (Wahab *et al.*, 2024). Nanoscale matter control is now urgent in a large number of logical fields, including programmatic experience, physical science, science, materials science, science, medication, and designing. Nanotechnology has as of now extraordinarily helped various natural and energy innovations, including waste cleanup, energy transformation, harmless to the ecosystem composite structures, and less waste and expanded energy productivity (Zhang and Goss, 2022; Yağız *et al.*, 2022). The sequestration, delivery, portability, and bioavailability of supplements and toxins in the common habitat are totally represented by multifaceted actual cycles including nanoscale structures (Kalita *et al.*, 2024). Wellbeing and biocomplexity issues are connected with processes at the limits among inorganic and natural frameworks (Das and Kapoor, 2024). Better comprehension of transport and bioavailability as well as the elements of cycles extraordinary to nanoscale structures in regular frameworks will bring about the formation of nanotechnologies that can stay away from or reduce natural effect (Zhao *et al.*, 2017). Nanotechnology might be unsafe to human wellbeing and the climate, very much like some other new innovation. To advance the dependable improvement of nanotechnology, research designated at fathoming and expecting such perils can bring down vulnerability and empower risk appraisal and the executives (Sengupta and Deshmukh, 2024).

Proposed Methodology

A superior oxidation procedure called photocatalysis is utilized in the treatment of water and wastewater, specifically for the oxidative evacuation of microorganisms and microbial microorganisms (He *et al.*, 2023). The majority of organic contaminants can be broken down by heterogeneous photocatalysis, according to published research. TiO2 is commonly used as a photocatalyst because of its well-known material qualities, low toxicity, high availability, and cost effectiveness (Moges *et al.*, 2020). Electrons in TiO2 will be photoexcited and move into the conduction band when exposed to ultraviolet light with the proper wavelength, which is between 200 and 400 nm. In figure 1 shows the photonic excitation below.

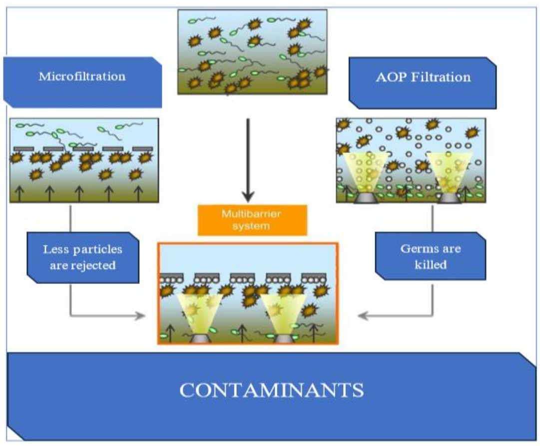

Figure 1: Photonic excitation.

Electron-hole pairs are produced by photonic stimulation, which sets off a convoluted series of oxidative-reductive processes (Madhura *et al.*, 2019). Therefore, a pretreatment process can be used to boost the biodegradability of highly decomposable compounds. Primarily, in polishing procedures like tertiary clarifying stages in municipal wastewater treatment plants, persistent substances like anti-microbials or other micropollutants can be photo catalytically taken out. However, the photon efficiency is rather poor due to the ultraviolet A radiation being only around 5% of sunshine, which limits its application on an industrial scale. Although a UV lamp is typically used to activate TiO2, sunlight and artificial light sources are equally acceptable. A new photocatalyst called KRONO Clean 7000 shifts the bandgap to a lower energy, allowing for the usage of a wider range of sunlight. Notwithstanding TiO2, tungsten trioxide, certain fullerene subsidiaries like Fullerol and C60 typified in poly(N-vinylpyrrolidone), and composites containing TiO2 have photocatalytic action when presented to noticeable light (Corsi *et al.*, 2018). They do, notwithstanding, produce 1O2, which is seldom costly and has a lower oxidation potential than TiO2. Extra techniques to work on the exhibition of TiO2 nanoparticles incorporate doping with respectable metals, which brings down the e−/h+ recombination, and delivering 25%-40% more proficient TiO2 nanotubes. Photocatalytic nanoparticles can be dismissed by immobilizing them on unambiguous materials utilizing proper covering methods, like wet substance covering or physical or compound fume statement. A useful multibarrier effect that combines chemical decontamination and mechanical filtration is achieved when a microfilter material is used as the substrate. Microfiltration membranes reject dirt particles and bigger microbes while chemically removing and degrading viruses, spores, and pollutants.

Results

The demographics of the respondents indicate that promotion plays a significant role in maintaining the effectiveness of nanomaterials in aquatic ecosystem management (mean = 4.87). There is a possibility that the water quality will decline if the problems are not managed. This study examines the effectiveness of nanomaterials in aquatic ecosystems in table 1.

Table 1: Descriptive statistics.

Descriptive Statistics					
	N	Ground water		Ocean water	
		Mean	Std. Deviation	Mean	Std. Deviation
nano-based systems be designed to minimize their potential environmental impacts	250	2.32	1.631	3.23	1.454
Nano-based systems interact with aquatic organisms	250	2.70	1.941	2.77	1.954
nano-based systems be used to develop more sensitive	250	4.76	.647	2.58	1.931
nano-based systems be used to develop sustainable and efficient methods for removing excess nutrients	250	4.55	1.189	4.85	.449
potential applications of nano-based systems for monitoring water quality	250	4.56	1.175	4.42	1.230
Nano-based systems be designed to detect and remove pollutants	250	4.09	1.081	3.97	1.376
policy and regulatory frameworks be developed to support the safe and sustainable use of nano-based systems	250	4.60	1.119	4.78	.849
potential risks and challenges associated with the use of nano-based systems in aquatic ecosystem management,	250	4.74	.877	4.86	.710
potential social and economic benefits of using nano-based systems	250	4.61	.917	4.35	1.180
nano-based systems be used to develop new materials and technologies for aquatic ecosystem management	250	4.30	1.481	4.56	1.115
nano-based systems be designed and synthesized to optimize their performance and efficiency in aquatic ecosystem	250	4.55	.957	4.28	1.297
physical and chemical properties of nano-based systems	250	4.61	.960	4.74	.945
Valid N (listwise)	250				

(Source: Primary Data/ Structured Questionnaire)

Since nanoparticles may spill and radiate into the climate, where they could gather for expanded timeframes, materials functionalised with nanoparticles embedded or saved on their surface convey a risk. There are right now no web based checking frameworks that convey precise constant estimation information on the number and nature of nanoparticles that are available in water in follow focuses, demonstrating an immense chance for development. Various public and worldwide regulation and guidelines are being ready to lessen the wellbeing risk. The powerlessness to adjust to mass activities and the way that they are presently habitually not serious with conventional treatment techniques address one more specialized limitation of nanoengineered water advances. Be that as it may, in the impending many years, nanoengineered materials have tremendous commitment for water upgrades, especially for vigorously degradable poisons, place of-purpose gadgets, and decentralized treatment frameworks.

Conclusion

Creative, state of the art water advancements are frantically required, particularly to ensure great drinking water quality, eliminate micropollutants, and help modern creation processes using water treatment frameworks that are deftly customizable. Novel water innovations that are effectively versatile to client explicit applications are conceivable with nanoengineered materials including photocatalysts, nanometals, nanoadsorbents, and nanomembranes. Most of them might be effortlessly included into standard modules and are viable with current treatment innovations. When contrasted with customary water advancements, one of the main advantages of nanomaterials is their ability to consolidate a few elements, making multipurpose frameworks like nanocomposite layers that take into consideration both molecule maintenance and contamination evacuation. Besides, due to their extraordinary properties, including a high response rate, nanomaterials consider expanded process productivity.

References

Corsi, I., Fiorati, A., Grassi, G., Bartolozzi, I., Daddi, T., Melone, L. and Punta, C., 2018. Environmentally sustainable and eco safe polysaccharide-based materials for water nano-treatment: An eco-design study. *Materials, 11*(7), p.1228. https://doi.org/10.3390/ma11071228

Das, A., and Kapoor, S., 2024. Comprehensive Review of Evidence-Based Methods in Preventive Cardiology Education: Perspective from Analytical Studies. *Global Journal of Medical Terminology Research and Informatics, 2*(4), 16-22.

Ganesan, A., Sethuraman, P., and Balamurugan, S., 2024. The Impact of Geology on Environmental Management in Mining Operations. *Archives for Technical Sciences, 2*(31), 86–93. https://doi.org/10.70102/afts.2024.1631.086

He, J., Li, J., Gao, Y., He, X. and Hao, G., 2023. Nano-based smart formulations: A potential solution to the hazardous effects of pesticide on the environment. *Journal of Hazardous Materials, 456,* p.131599. https://doi.org/10.1016/j.jhazmat.2023.131599

Kalita, P., Barman, M., Chetia, A., Goyary, P., and Kumari, K., 2024. Mapping the Landscape of Literature on Use of AI in Libraries: A Bibliometric Analysis Using Scopus Database. *Indian Journal of Information Sources and Services, 14*(2), 24–27. https://doi.org/10.51983/ijiss-2024.14.2.04

Kang, J., Kim, J., and Sohn, M., 2019. Supervised learning-based Lifetime Extension of Wireless Sensor Network Nodes. *Journal of Internet Services and Information Security, 9*(4), 59-67.

Madhura, L., Singh, S., Kanchi, S., Sabela, M., Bisetty, K. and Inamuddin, 2019. Nanotechnology-based water quality management for wastewater treatment. *Environmental Chemistry Letters*, *17*, pp.65-121. https://doi.org/10.1007/s10311-018-0778-8

Moges, F.D., Patel, P., Parashar, S.K.S. and Das, B., 2020. Mechanistic insights into diverse nano-based strategies for aquaculture enhancement: a holistic review. *Aquaculture*, *519*, p.734770. https://doi.org/10.1016/j.aquaculture.2019.734770

Pathak, J., Singh, D.K., Singh, P.R., Kumari, N., Jaiswal, J., Gupta, A. and Sinha, R.P., 2024. Application of nanoparticles in agriculture: nano-based fertilizers, pesticides, herbicides, and nanobiosensors. In Molecular Impacts of Nanoparticles on Plants and Algae (pp. 305-331). *Academic Press.* https://doi.org/10.1016/B978-0-323-95721-2.00012-9

Rao, N., and Tiwari, M., 2023. Nature-Based Solutions for Coastal Resilience: Case Studies from Southeast Asia. *International Journal of SDG's Prospects and Breakthroughs*, *1*(1), 8-10

Seidgar, M. (2021). Applications of Fairy Shrimps in ornamental fish feeding. *International Journal of Aquatic Research and Environmental Studies*, *1*(2), 51-56. https://doi.org/10.70102/IJARES/V1I2/6

Sengupta, R., and Deshmukh, P., 2024. Multi-Stage Filtration Systems for Continuous Separation in Fine Chemical Production. *Engineering Perspectives in Filtration and Separation*, *2*(1), 13-16.

Thi, Q.N.T., and Dang, T.K., 2010. Towards Side-Effects-free Database Penetration Testing. *Journal of Wireless Mobile Networks, Ubiquitous Computing and Dependable Applications*, *1*(1), 72-85.

Wahab, A., Muhammad, M., Ullah, S., Abdi, G., Shah, G.M., Zaman, W. and Ayaz, A., 2024. Agriculture and environmental management through nanotechnology: Eco-friendly nanomaterial synthesis for soil-plant systems, food safety, and sustainability. *Science of the Total Environment*, p.171862. https://doi.org/10.1016/j.scitotenv.2024.171862

Yağız, E., Ozyilmaz, G., and Ozyilmaz, A. T., 2022. Optimization of graphite-mineral oil ratio with response surface methodology in glucose oxidase-based carbon paste electrode design. *Natural and Engineering Sciences*, *7*(1), 22-33. http://doi.org/10.28978/nesciences.1098655

Zhang, Y. and Goss, G.G., 2022. Nanotechnology in agriculture: Comparison of the toxicity between conventional and nano-based agrochemicals on non-target aquatic species. *Journal of Hazardous Materials, 439,* p.129559. https://doi.org/10.1016/j.jhazmat.2022.129559

Zhao, X., Cui, H., Wang, Y., Sun, C., Cui, B. and Zeng, Z., 2017. Development strategies and prospects of nano-based smart pesticide formulation. *Journal of agricultural and food chemistry*, *66*(26), pp.6504-6512. https://doi.org/10.1021/acs.jafc.7b02004