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Open Access Journal of Microbiology & Biotechnology
ISSN: 2576-7771

# Nanotechnology in Water Quality: Assessment Application for Microbial Detection and Control

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**Mini Review**
**Volume 9 Issue 4**
**Received Date:** October 11, 2024
**Published Date:** November 18, 2024
DOI: 10.23880/oajmb-16000308

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## Abstract

Evaluation of water quality is critical for assuring the safety of drinking water, especially with the increasing incidence of microbiological pollutants. Traditional microbial detection and control methods, while successful, are time-consuming and may lack the sensitivity needed to detect infections at low concentrations. Nanotechnology has emerged as a significant tool in this field, providing novel approaches to quick pathogen identification and efficient disinfection. This review provides an overview of the latest developments in nanotechnology for assessing water quality, with a focus on nanosensors and nanomaterials. Nanosensors, such as gold nanoparticles, quantum dots, and magnetic nanoparticles, detect pathogens with great sensitivity and specificity. Furthermore, nanoparticle-based disinfection systems that use materials such as silver, zinc oxide, and titanium dioxide nanoparticles have shown high antibacterial activity. Nanocomposite membranes loaded with nanoparticles improve water filtration by both eliminating and inactivating microorganisms. Despite the potential of these technologies, issues including cost, scalability, and environmental safety must be addressed. This review indicates that nanotechnology has the potential to transform water quality monitoring and treatment by making it more efficient and accessible, especially in areas where clean water is rare.

**Keywords:** Nanotechnology; Water Quality Assessment; Nanoparticles; Nanosensors

## Abbreviations

AuNPs: gold nanoparticles; LFAs: Lateral Flow Assays; QDs: Quantum Dots; MNPs: Magnetic Nanoparticles; PCR: Polymerase Chain Reaction; ZnO NPs: Zinc Oxide Nanoparticles; ROS: Reactive Oxygen Species; $TiO_2$ NPs: Titanium Dioxide Nanoparticles; GO: Graphene Oxide.

## Introduction

Giri [1] asserts that the increasing human population, industrialisation, agricultural practices, and the effects of climate change have elevated water quality to the status of a major worldwide concern. Particularly in developing countries where clean water is rare, contaminated water sources pose a significant risk to public health. According to Martínez-Santos [2], waterborne infections can be caused by microbial pathogens such as *Escherichia coli, Vibrio cholerae*, and *Cryptosporidium*, which are common contaminants in water sources. Culture and biochemical processes, which are the gold standards for microbial identification, can be labour-intensive, slow, and even unable to detect trace amounts of contamination. In response to these challenges, nanotechnology has shown promise as a tool for microbial management and water quality assessment by offering new, sensitive, and inexpensive methods [3]. When it comes to measuring water quality, nanotechnology is essential, especially for the detection and control of microbiological illnesses. Nanoparticles of many types, including polymeric, semiconductor, and metallic ones, are utilised because of their unique properties that help in the detection of microbes in water samples. One way to help identify pathogens is by combining polymeric nanoparticles with biofunctionalities and fluorescent agents [4]. Nanopore sequencing tools like the MinION also make it possible to track different kinds of bacteria in freshwater in real time, which is great for learning about potentially dangerous infections and their concentrations [5]. The development of DNA conjugates based on nanoparticles has also reduced diagnostic time significantly and provided a dependable way for detecting pathogens [6]. Rose and Grimes [7] and Mubeen, et al. [8] found that these advancements promote public health by increasing germ identification and providing new ways to combat antibiotic resistance. This review study examines recent advances in the use of nanotechnology for microbial identification and control in water quality assessments.

## Nanotechnology for Microbial Detection in Water

According to Tovar-Lopez [9], nanotechnology-based microbial detection technologies have revolutionised water quality monitoring. These approaches enable the highly sensitive and precise detection of infections at extremely low concentrations. As a result, various types of nanosensors and nanomaterials have been developed.

## Nanosensors for Pathogen Detection

To address the limitations of traditional techniques, which can be time-consuming and require specialist laboratory settings, nanosensors have emerged as an important tool for the rapid detection of diseases. These miniaturised devices, which incorporate biological probes, signal transducers, and enhancers, enable sensitive and specific pathogen identification in a variety of settings, including field situations [10]. Magnetic nanoparticle-urease sensors are one recent breakthrough that has the ability to identify bacteria quickly and correctly [11]. Nanomaterial integration also increases biosensor performance, allowing for real-time monitoring and enhanced diagnostic capabilities [12]. The ability of nanosensors to produce timely data is critical for epidemic management, and this capability extends to virus detection [13]. According to Mustafa, et al. [14], the incorporation of nanotechnology into pathogen detection systems has marked a significant advancement in public health and safety.

The use of nanomaterials in sensor design enables extraordinarily sensitive detection of biological molecules, including pathogenic microorganisms. These sensors are often made up of carbon nanotubes, magnetic nanoparticles, quantum dots, and gold nanoparticles (AuNPs). Abdel-Karim [15] and Medhi [16] discovered that nanomaterials can be used to immobilise specific antibodies, aptamers, or nucleic acid probes that identify bacteria' DNA, proteins, or surface antigens, increasing the sensitivity and speed of detection. The ability of gold nanoparticles (AuNPs) to amplify optical signals, such as colour changes, when attached to a target pathogen has made them a popular topic in the field of microbiology detection. To identify Escherichia coli in water samples with high sensitivity, lateral flow assays (LFAs) based on AuNPs have been used. When exposed to specific wavelengths of light, semiconductor nanocrystals known as quantum dots (QDs) emit fluorescence. According to Guruprasath, et al. [17], pathogen-specific antibodies or nucleic acid sequences can be linked to these nanocrystals, allowing fluorescence to identify water-borne illnesses. When paired with biosensors, magnetic nanoparticles (MNPs) have the ability to extract and concentrate dangerous bacteria from large volumes of water. Pathogens can be recognised after capture using techniques such as fluorescence-based assays and polymerase chain reaction (PCR) [17].

## Nanomaterials for Real-Time Water Quality Monitoring

Nanomaterials have been incorporated into multiple platforms to facilitate real-time assessment of microbiological water quality. These platforms comprise portable devices integrated with nanosensors that provide immediate, on-site detection of infections. A significant instance is the creation of smartphone-integrated nanosensors capable of detecting microbial pollutants in field environments, eliminating the necessity for specialised laboratory apparatus, as reported by Reddy, et al. [18].

## Nanotechnology for Microbial Control in Water

Olawade, et al. [19] stated that nanotechnology has shown immense potential in microbial control through nanomaterial-based disinfection techniques. These methods have been demonstrated to effectively eliminate pathogens from water, making it safer for consumption.

## Nanoparticle-Based Disinfection

According to Olawade, et al. [19], nanoparticles can interact with microbial cells due to their unique physicochemical features. This contact disrupts the cell membranes and finally kills the cells. Silver nanoparticles (AgNPs) are remarkable for their ability to destroy a wide variety of microorganisms. They work by releasing $Ag^+$ ions that bind to bacterial cell walls and membranes, causing structural damage and release of contents. Several water filtering systems have been modified using AgNPs to improve microbial management [20]. When exposed to light, zinc oxide nanoparticles (ZnO NPs) form reactive oxygen species (ROS), which have strong antibacterial capabilities. ROS can render waterborne pathogens inert by destroying microorganisms' DNA, proteins, and lipids. UV-assisted and sunlight-driven water disinfection systems using ZnO NPs are now being investigated [21]. Titanium dioxide nanoparticles ($TiO_2$ NPs) are widely used for photocatalytic water disinfection due to their ability to generate reactive oxygen species (ROS) when exposed to ultraviolet light. $TiO_2$-based photocatalysis effectively removes microbial pathogens and organic contaminants from water [22,23].

## Nanocomposite Membranes

Nanocomposite membranes impregnated with nanoparticles provide a dual approach to water filtration, physically eliminating pathogens while chemically inactivating them. These membranes were created employing a variety of nanomaterials, including silver, graphene, and carbon nanotubes, to improve their antibacterial and filtration efficacy [24]. For example, graphene oxide (GO)-based membranes have been demonstrated to successfully filter out microbiological pollutants while preventing biofilm formation, which is a key difficulty in typical filtering systems. Researchers have improved pathogen removal rates and increased the lifespan of filtration systems by incorporating nanoparticles into membrane technology [24].

## Conclusion

Nanotechnology presents considerable promise in enhancing water quality evaluation via swift microbial detection and efficient pathogen management. Nanosensors and nanomaterials have transformed pathogen detection, offering swift, sensitive, and economical methods. Simultaneously, nanoparticle-based disinfection methods and nanocomposite membranes have shown encouraging efficacy in eradicating microbiological pollutants from water. The incorporation of nanotechnology into water quality monitoring and treatment systems, despite existing hurdles, signifies a pivotal advancement in guaranteeing safe drinking water for everyone. Ongoing research and innovation in this domain will augment the efficacy and accessibility of nanotechnology-driven water quality solutions.

## Declaration

The Authors declare that there is no conflicting Interest.

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