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Aptasensors for the Detection of Environmental Contaminants of High Concern in Water Bodies

Updesh Chauhan*

Department of Biotechnology, Shri Ramswaroop Memorial University, Lucknow, India

Introduction

Water bodies are essential to life on Earth, serving as sources of drinking water, habitats for aquatic life and critical components of ecosystems. However, the increasing industrial activities, agricultural practices and urbanization have led to the contamination of these water sources with various pollutants. The presence of environmental contaminants in water bodies poses significant threats to human health, aquatic life and the overall ecological balance. Traditional methods for detecting these contaminants often face limitations in terms of sensitivity, specificity and rapidity [1].

In recent years, aptasensors have emerged as a promising technology for the detection of environmental contaminants in water bodies. Aptasensors utilize aptamers—short, single-stranded nucleic acids that can specifically bind to target molecules. Their application in environmental monitoring is gaining attention due to their high sensitivity, specificity and versatility. This article provides a systematic review of the use of aptasensors for detecting environmental contaminants in water bodies, covering the introduction of aptasensors, a literature review of their applications, a discussion on their advantages and challenges and a conclusion summarizing the current state and future prospects.

Description

Aptasensors combine the selective binding ability of aptamers with a signal transduction system to detect target contaminants. Aptamers are selected from a random library of nucleic acids through a process known as SELEX (Systematic Evolution of Ligands by Exponential Enrichment). Once selected, these aptamers can bind to specific molecules with high affinity and specificity. The binding event is then transduced into a measurable signal, typically through optical, electrochemical, or piezoelectric means.

Applications in water contaminant detection

Heavy metals: Heavy metals such as lead, mercury and cadmium are common contaminants in water bodies due to industrial discharge and mining activities. Aptasensors have been developed for detecting these metals with high sensitivity. For example an aptasensor for lead detection that employed a gold nanoparticle-based colorimetric assay, achieving detection limits as low as nanomolar concentrations. Electrochemical aptasensor for mercury detection, which exhibited a high selectivity and sensitivity [2].

Pesticides and herbicides: Pesticides and herbicides are widely used in agriculture, but their runoff can contaminate water bodies, posing risks to both ecosystems and human health. Aptasensors for detecting pesticides such as atrazine and glyphosate have shown promising results. Aptasensor for atrazine detection based on Fluorescence Resonance Energy Transfer (FRET), which demonstrated high sensitivity and selectivity. Aptasensor for glyphosate using a lateral flow assay, providing a simple and rapid detection method. Pharmaceuticals and Personal Care Products (PPCPs) are emerging contaminants in water bodies due to their widespread use and incomplete removal during wastewater treatment. Aptasensors have been employed to detect various PPCPs, including antibiotics and hormones. A notable example is the work of aptasensor for detecting antibiotics such as tetracycline using a Surface Plasmon Resonance (SPR) technique. The aptasensor exhibited high sensitivity and was able to detect low concentrations of antibiotics in complex water matrices.

The presence of pathogenic microorganisms in water poses serious health risks. Aptasensors have been developed for the detection of bacterial and viral contaminants. For example, an aptasensor for the detection of E. coli using a fluorescence-based assay, which showed high specificity and rapid response. Another study focused on detecting norovirus using an electrochemical aptasensor, demonstrating the potential for sensitive and specific microbial detection Aptamers can be selected to bind specifically to target molecules with high affinity, leading to highly sensitive and selective detection. This is particularly important for detecting low concentrations of contaminants in complex water samples. Aptasensors can be designed to detect a wide range of contaminants, including heavy metals, pesticides, pharmaceuticals and microbial pathogens. The adaptability of aptamers to different targets makes them a versatile tool for environmental monitoring [3,4].

Aptasensor assays can be completed relatively quickly compared to traditional methods, such as chromatography or mass spectrometry. Additionally, aptasensors often require simpler and less expensive equipment, making them cost-effective for field applications. The small size of aptasensor components allows for the development of portable and handheld devices, which are useful for on-site monitoring and rapid assessment of water quality.

Challenges and limitations

Stability and robustness: Aptamers can be sensitive to environmental conditions, such as temperature, pH and ionic strength, which can affect their stability and performance. Ensuring the robustness of aptasensors under varying conditions is crucial for reliable field applications.

Matrix effects: Complex water matrices can interfere with aptasensor performance, leading to false positives or negatives. Overcoming matrix effects requires the development of aptasensors with improved selectivity and the use of appropriate sample preparation techniques.

Regulatory and standardization issues: The lack of standardized protocols for aptasensor development and validation can hinder their widespread adoption. Establishing regulatory guidelines and standardization procedures is essential for ensuring the consistency and reliability of aptasensor-based detections [5].

Scalability: The synthesis and functionalization of aptamers can be labor-intensive and costly. Scaling up the production of aptamers and aptasensor devices for large-scale environmental monitoring remains a challenge

Conclusion

Aptasensors represent a promising and innovative approach for detecting environmental contaminants in water bodies. Their ability to provide highly sensitive, specific and rapid detection makes them a valuable tool for

***Address for Correspondence:** Updesh Chauhan, Department of Biotechnology, Shri Ramswaroop Memorial University, Lucknow, India, E-mail: updeshchauhan11@gmail.com*

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environmental monitoring and pollution control. The systematic review highlights the significant advancements in aptasensor technology and its applications for detecting a wide range of contaminants, including heavy metals, pesticides, pharmaceuticals and microbial pathogens.

Despite the progress, there are still challenges that need to be addressed to fully realize the potential of aptasensors. Ensuring the stability and robustness of aptasensors, mitigating matrix effects and developing standardized protocols are essential steps towards enhancing their practical applications. Continued research and development in these areas will contribute to the successful implementation of aptasensors in environmental monitoring and provide a reliable means of safeguarding water quality. In conclusion, aptasensors offer a valuable addition to the toolkit for environmental contamination detection. Their ongoing development and refinement will play a crucial role in advancing water quality monitoring and ensuring the protection of public health and ecosystems.

Acknowledgement

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Conflict of Interest

None.

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