Journal of Tecnologia Quantica, 1(3) - June 2024 135-145

Journal of Tecnologia Quantica
E - ISSN 3048-1740 | P - ISSN 3062-6757

Ultra-Sensitive Quantum Sensor for Detection of Pollutants in Water

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Received: Dec 06, 2024	Revised: Dec 22, 2024	Accepted: Dec 25, 2024	Online: Dec 25, 2024

ABSTRACT
Water pollution by hazardous substances, such as heavy metals and industrial chemicals, is a global problem that threatens the sustainability of ecosystems and human health. Early detection of these pollutants is essential to prevent further damage. This study aims to evaluate the effectiveness of ultra-sensitive quantum sensors in detecting pollutants in water at very low concentrations. The method used in this study is laboratory and field experiments, by comparing the performance of quantum sensors and conventional sensors in detecting heavy metals and other chemicals in water. The results show that quantum sensors have a much higher sensitivity compared to conventional sensors, with the ability to detect contaminants up to lower concentrations. Quantum sensors can detect lead (Pb) at 0.1 ppb, while conventional sensors can only detect at 0.4 ppb. In conclusion, quantum sensor technology can provide a more efficient and sensitive solution for water quality monitoring, and it has great potential to be implemented in a wider range of environmental monitoring systems. Further research is needed to overcome cost constraints and improve the integration of these technologies in water monitoring in the field.

Keywords: *Pollution Detection, Quantum Sensors, Water Quality*

Journal Homepage https://journal.ypidathu.or.id/index.php/ijnis

How to cite: Fathoni, M., Zaki, A & Razak, F. (2024). Ultra-Sensitive Quantum Sensor for Detection of Pollutants in Water. *Journal of Tecnologia Quantica,* 1(3), 135-145. https://doi.org/10.70177/quantica.v1i3.1677
Published by: Yayasan Pendidikan Islam Daarut Thufulah

INTRODUCTION

Water quality is a very important global issue in supporting the sustainability of life on earth. Polluted water can have a devastating impact on ecosystems, human health, as well as the agricultural and industrial sectors (Sharma, 2021). Therefore, it is important to have an efficient and accurate detection system in place to monitor the presence of pollutants in the waters. However, pollutant detection is often hampered by the limitations of existing sensor technologies, especially in terms of sensitivity and accuracy at the very small particle level (Chandra, 2022).

In recent decades, sensor technology has undergone significant developments, with an emphasis on increasing sensitivity and accuracy in detecting chemicals or contaminants at low concentrations. Among the different types of sensors being developed, sensors based on quantum technology have emerged as one of the innovative solutions (Liu, 2022). Quantum technology, with the basic principles of particle physics, offers advantages in terms of more sensitive detection, even at the molecular and atomic levels. Quantum sensors, thanks to their quantum properties such as superposition and interference, are capable of measuring very small changes in the environment, including in the detection of chemicals dissolved in water (Gottscholl, 2021).

In the context of pollutant detection in water, ultra-sensitive quantum sensors can identify substances present in very low concentrations. This provides a huge advantage compared to traditional sensor technologies that often require a larger amount of pollutants to produce the detected signal (C. Li, 2022). With the ability to detect even contaminants with micro or nano concentrations, quantum sensors offer the potential to monitor water quality with a higher degree of precision. This will pave the way for more efficient monitoring of hazardous substances such as heavy metals, pesticides, or industrial chemicals that are difficult to detect with conventional methods (Wu, 2022).

Quantum properties such as interference and optical measurements also allow quantum sensors to perform measurements in a non-invasive manner, which is important in testing water quality without damaging or altering ambient conditions (Deka, 2022). In water detection, a non-invasive approach reduces the potential for measurement errors that can arise from direct interaction between the sensor and the water sample. This technique allows for continuous monitoring without disturbing existing aquatic ecosystems, making quantum sensors a highly efficient tool for real-time water quality monitoring (Kalkal, 2021).

Research on the use of quantum sensors for the detection of pollutants in water is still in its infancy, but it is already showing promising results. Several laboratory experiments and field applications have shown that these sensors have the potential to replace traditional detection methods that are more expensive and time-consuming (Wang, 2021). However, there are challenges in terms of integrating quantum technology into existing water quality monitoring systems, especially in terms of improving sensor design and processing of very large and complex data (El-Malla, 2022).

As quantum technology matures, the ability to make smaller, cheaper, and easier to operate sensors will be an important factor in expanding the application of quantum sensors in various fields (Lee, 2021). In terms of water pollutant detection, the application of quantum sensors will open up new opportunities for more timely, accurate, and effective monitoring of water quality, which in turn will support more sustainable and responsive management of water resources to the growing threat of pollution (Suthar, 2021).

Quantum sensor technology for the detection of pollutants in water still faces various technical challenges that must be solved before it can be widely applied (Marciniak, 2022). One of the main obstacles is how to increase the sensitivity of sensors to be able to detect pollutants in very low concentrations, which are often undetectable by conventional sensors. In addition, current systems are still limited in terms of measurement accuracy on various environmental conditions that can affect water quality, such as changes in temperature, pH, or pressure (Tam, 2021).

The limitations in the integration of quantum sensors with existing water quality monitoring systems are also a significant obstacle (Ghiasi, 2021). Conventional sensor-based monitoring systems are often incompatible with new technologies based on quantum principles. Therefore, more research is needed on how to integrate quantum sensor technology into existing water monitoring infrastructure without changing the operational structure that is already in place (Kaur, 2022).

The ability of quantum sensors to detect contaminants under highly variable conditions is also still a challenge. In some experiments, although quantum sensors show superiority in terms of sensitivity, field conditions such as water currents, turbidity, and the influence of microorganisms can affect the detection results (Ganesan, 2022). More research is needed to understand how these factors can affect the performance of quantum sensors in the field and how to reduce or control their effects (Pejovic, 2022).

Another obstacle that remains unsolved is the cost and scalability of quantum sensor technology. The development of ultra-sensitive quantum sensors requires relatively expensive equipment and materials, as well as complex fabrication processes (Meinel, 2021). Along with that, the adoption of this technology on a larger scale for water monitoring in different locations or developing countries is still very limited. Therefore, one of the gaps that needs to be filled is how to reduce the production cost of quantum sensors while maintaining their quality and functionality (Sampaolo, 2021).

The data processing system for quantum sensors is also still in the development stage. Measurements with quantum technology generate very large and complex data, which requires advanced software for processing and analysis. Today, the biggest challenge is creating algorithms that can manage that data in an efficient and accurate way, and produce outputs that can be understood by operators or researchers in a short time (Ferrer-Cid, 2022).

Filling this gap is important because water pollution is a global problem that requires innovative and efficient solutions. With the ability of quantum sensors to detect contaminants at very low concentration levels, this technology offers the potential to improve existing detection systems. The utilization of quantum sensors can reduce testing costs, speed up the detection process, and enable real-time monitoring of water quality with a higher level of accuracy (Zhao, 2021).

Filling the gap in the development of quantum sensors will also contribute greatly to environmental sustainability (Mehaney, 2021). With more sensitive technologies that can detect pollutants in low concentrations, we can more quickly identify and address pollution problems before they adversely affect ecosystems and human health. Thus, quantum sensor technology can be an important tool in environmental protection efforts, especially in monitoring water quality in areas exposed to contaminants (Yuan, 2022).

This research aims to develop and test ultra-sensitive quantum sensors that are able to fill the gaps in the detection of pollutants in water. By exploring ways to improve sensitivity, accuracy, and data processing, this research is expected to provide a more effective and efficient solution in monitoring water quality in various conditions and environments (Worek, 2022).

RESEARCH METHODS

The design of this study uses an experimental approach to test the effectiveness of ultra-sensitive quantum sensors in detecting pollutants in water. The research will be carried out through a series of experiments in the laboratory and the field to measure the sensitivity of sensors to different types of contaminants present in water. The experiment will compare the performance of quantum sensors with conventional sensors in detecting contaminants in low concentrations. The variables to be measured include the level of sensitivity, detection accuracy, and measurement accuracy in various environmental conditions (Han et al., 2022).

The population in this study is water from various sources, such as rivers, lakes, and sewers, which are known to contain various types of contaminants, such as heavy metals, pesticides, and industrial chemicals. Water samples will be taken from several locations with varying levels of pollution, both in urban and rural areas, to provide a broader picture of the effectiveness of quantum sensors in various conditions. Water samples will be filtered to identify the types of contaminants present, and further analysis will be carried out to determine the concentration of pollutants in the water (Ji et al., 2021).

The main instrument in this study is an ultra-sensitive quantum sensor developed specifically to detect pollutants in water. The sensor uses quantum interferometry technology and optical measurements to identify changes in quantum structure caused by the presence of contaminants in the water. In addition, conventional water quality measuring devices are also used to compare detection results between quantum sensors and traditional sensors. Other testing instruments include spectrophotometers to measure contaminant concentrations and computer devices for data analysis and processing of test results (Gill, 2020).

The research procedure begins with sampling water from various predetermined locations. Each sample will be tested using quantum sensors to detect different types of pollutants such as heavy metals (e.g., lead, mercury), pesticides, and industrial chemicals. The sensor will be set up to detect quantum changes that occur when pollutants interact with water (Mahendran et al., 2022). Testing will be conducted under a variety of conditions, including temperature and pH variations, to test the durability and reliability of the sensor under field conditions. The results from the quantum sensor will then be compared with the results obtained from conventional sensors to evaluate the performance of the quantum sensor in detecting pollutants at very low concentrations. The collected data will be analyzed using statistical software to assess the accuracy, sensitivity, and effectiveness of sensors under various conditions (Jiulin et al., 2021).

RESULTS AND DISCUSSION

The data obtained from this study shows the results of testing ultra-sensitive quantum sensors in detecting pollutants in various water samples. The following table summarizes the concentrations of pollutants detected in each water sample using both quantum sensors and conventional sensors. Quantum sensors show higher sensitivity in detecting heavy metals, such as lead (Pb) and mercury (Hg), at much lower concentrations than conventional sensors. For example, in a water sample with a lead concentration of 0.5 ppb, the quantum sensor successfully detected at a rate of 0.1 ppb, while conventional sensors only detected at 0.4 ppb.

Sample	**Pollutants**	**Quantum Sensor (ppb)**	**Conventional Sensor (ppb)**
Sample A	Lead (Pb)	0,1	0,4
Sample B	Merkuri (Hg)	0,02	0,1
Sample C	Pesticides	0,5	1,0
Sample D	Nitration	0,3	0,8

The recorded results show that quantum sensors have more sensitive detection capabilities in detecting the concentration of pollutants in water compared to conventional sensors. The main advantage of quantum sensors lies in their ability to detect small changes at the molecular level, which makes it possible to detect very low amounts of contaminants. This makes quantum sensors very effective for monitoring safer water quality with a higher level of accuracy, even in conditions of very low pollutant concentrations.

From the overall data obtained, quantum sensors show high consistency in detecting pollutants, especially heavy metals and other harmful chemicals. The sensitivity of this sensor is well tested in different water conditions, both at varying temperatures and under the influence of turbidity. Water samples contaminated with lead (Pb) and mercury (Hg) showed consistent results with significant differences in detection rates between quantum and conventional sensors. For example, a water sample containing 0.02 ppb of mercury was successfully detected using a quantum sensor, while a new conventional sensor could detect it at 0.1 ppb.

More precise measurements on quantum sensors may be related to the underlying principles of quantum physics, where the nature of interference and superposition allows sensors to detect very small fluctuations in the quantum field. In conventional sensors, the detection limit is often affected by factors such as the sensitivity of the tool, the type of electrode, or the data processing technique used. Therefore, quantum sensors' ability to capture more detailed and smaller information provides a significant advantage in pollutant detection at very low levels, which may have escaped conventional sensor detection.

The data obtained showed a close relationship between the sensitivity level of the sensor and the ability to detect contaminants in very low concentrations. Quantum sensors excel in this regard, by detecting pollutants that were previously undetectable by conventional sensors at low concentrations. This suggests that quantum sensor technology can fill gaps that exist in traditional detection systems, providing more precise information and allowing for faster intervention to prevent further contamination.

In a case study on the X river, quantum sensors successfully detected levels of heavy metal lead (Pb) below the threshold allowed by health regulations, which conventional sensors do not detect. The river water contained a lead concentration of 0.1 ppb, but conventional sensors only gave a result of 0.5 ppb, exceeding the safe limit. This shows that even though the water quality in the river is already at an unsafe level, conventional sensors fail to provide a precise indication of the presence of heavy metals at low concentrations.

This case study highlights the ability of quantum sensors to provide more accurate and sensitive results, even at very low levels of pollutants. In this case, the inaccuracy of conventional sensors in detecting low lead levels has the potential to delay the mitigation steps needed to reduce the impact of pollution. The use of quantum sensors in water quality monitoring in areas prone to pollution can help authorities take faster and more appropriate steps in pollution control.

Through this case study, it is evident that the incorporation of quantum sensor technology in water quality monitoring systems provides a significant advantage in detecting contaminants at lower concentrations than conventional methods can. These results emphasize the importance of applying quantum sensors as a more sophisticated tool in water quality monitoring, which allows for faster and more accurate detection of pollution, as well as providing greater opportunities in maintaining the sustainability of water resources.

The results show that ultra-sensitive quantum sensors have much higher detection capabilities compared to conventional sensors in identifying pollutants in water, such as heavy metals and harmful chemicals. These sensors are capable of detecting contaminants at very low concentrations, even below the detection limits of traditional sensors. For example, quantum sensors can detect lead at a concentration of 0.1 ppb, while conventional sensors are only capable of detecting at 0.4 ppb. This advantage unlocks great potential for more accurate and efficient water quality monitoring, even in environments with low levels of contamination.

The results of this study are in line with several previous studies that have shown the potential of quantum sensors in environmental detection applications, but with significant differences in terms of implementation in the direct detection of water pollutants (Aslam, 2022). Previously, research on quantum sensors focused more on applications in the field of biomedicine or optical communication. Relevant research on water detection often uses sensors based on conventional techniques, which have limitations in terms of sensitivity and accuracy at low concentrations. The study fills in the gap by highlighting the application of quantum sensors for the detection of contaminants in water, which has not been widely explored in the previous literature (Yao, 2021).

The results of this study show that advances in quantum technology can provide new solutions in the challenge of water quality monitoring (Yayla, 2022). This discovery is an important step forward in bringing a more efficient and sensitive technology to detect contaminants on a smaller scale. This research is also a sign that quantum technology can be adapted to various fields other than physics and communication, especially in the field of the environment which requires advanced solutions to water pollution problems. The ability of quantum sensors to work at very low concentrations is also an indication that this technology could open the door to wider and more detailed monitoring in aquatic ecosystems (Dadkhah-Aghdash, 2022).

The implications of the results of this study are very large in the field of water quality monitoring, especially in an effort to maintain the sustainability of aquatic ecosystems and human health (Mishra, 2022). With the ability to detect pollutants at more sensitive levels, quantum sensor technology can be used to improve existing water monitoring systems, allowing for faster and more efficient monitoring. It also means that we can be more proactive in identifying and addressing pollution problems early, even before contaminants reach levels that could harm ecosystems or human health. Another implication is the potential for the development of cheaper and more accessible sensors for mass use, including in developing countries (Achard, 2021).

The results of this study can be understood by considering the basic principles of quantum technology that underlie the sensor (Zhang, 2021). Quantum sensors use physical phenomena that are highly sensitive to environmental changes at the molecular and atomic levels, such as quantum interference, which allows the detection of contaminants at very low levels. In addition, advances in quantum data processing and signal reinforcement allow these sensors to produce more accurate results despite the challenges of varying water conditions. Another factor influencing these results is the smaller and more efficient sensor design in processing information (Wu, 2021).

The next step is to test these quantum sensors under more varied field conditions to assess their performance in real-world situations, outside of a controlled laboratory setting. Further research is also needed to test the long-term durability of these sensors in a variety of different water conditions, as well as to better understand the influence of external factors such as temperature, pH, and turbidity on sensor performance (Balestra, 2022). In addition, further development should be focused on making more affordable sensors so that they can be implemented on a large scale, both in government monitoring systems and in the industrial sector. The measures will allow this technology to be widely accepted as a practical solution to the global water pollution problem (Y. Li, 2022).

CONCLUSION

The main finding of the study is that ultra-sensitive quantum sensors are capable of detecting pollutants in water at much lower concentrations compared to conventional sensors. The advantage of this quantum technology lies not only in its higher sensitivity, but also in its ability to work in more varied environmental conditions, such as temperature changes and turbidity of water. These results make a significant contribution to the development of a more accurate and efficient water pollution detection system.

The main contribution of this research lies in the application of the concept of quantum technology in the detection of water pollution. The quantum sensor method used in this study offers a new approach that can be adapted to monitor water quality in real-time with a higher degree of accuracy. This concept provides additional value in overcoming the challenges of detecting pollutants at low concentrations, which are often undetectable by conventional sensor technology, thus opening up opportunities for the development of more sensitive and fast monitoring systems.

Although the results show the great potential of quantum sensors in water pollution detection, there are several limitations that need to be overcome, such as the relatively high cost of sensor production and difficulties in integrating with existing monitoring systems. Further research needs to be focused on developing sensors that are more affordable and easy to integrate with existing infrastructure. In addition, testing quantum sensors in more diverse field conditions and on more complex water samples also needs to be carried out to ensure their reliability and efficiency in real-world applications.

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