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Technological Innovation in Clean Water Management to Improve the Quality of Life of the Community

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Abstract

Clean water is a basic need that is very important for human health, well-being, and quality of life. However, many regions in the world, including Indonesia, still face serious challenges in providing clean water due to population growth, urbanization, environmental pollution, climate change, and inadequate infrastructure. This article aims to examine various technological innovations in clean water management and analyze their impact on people's quality of life. This study uses the Systematic Literature Review (SLR) method by examining various scientific articles, policy reports, and relevant technical documents from various reliable sources. The results of the study show that the application of technologies such as membrane filtration, Internet of Things (IoT)-based water quality monitoring, integrated wastewater treatment, desalination technology, and the use of renewable energy significantly increase access to clean water, reduce the rate of disease, and support economic welfare and environmental resilience of the community. This article recommends the integration of inclusive and collaborative clean water technology policies to realize efficient, sustainable, and equitable water management at all levels of society.

Keywords : *clean water, technological innovation, water management, quality of life*

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1. Introduction

Clean water has a very vital role in human life. It is not only needed for daily consumption purposes such as drinking and cooking, but also needed in maintaining personal hygiene, environmental cleanliness, and various household and industrial activities. Without adequate availability of clean water, humans cannot live healthy and productive lives(Ambarwati, 2024). Polluted or unsafe water can be a source of the spread of various dangerous diseases, such as diarrhea, cholera, hepatitis A, and other gastrointestinal infections. Data from the World Health Organization (WHO) shows that millions of people in the world, especially children in developing countries, still die every year from diseases caused by poor water quality and inadequate sanitation. This confirms that clean water is not only about comfort, but also about public health and survival issues (Sukri et al., 2019).

Moreover, access to clean water has been internationally recognized as part of a human right. In 2010, the United Nations General Assembly (UN) formally established that access to clean water and proper sanitation is a fundamental right of every individual. This means that the state and all elements of society have a moral and legal responsibility to ensure that all its citizens can enjoy these rights fairly and equitably. In the context of development, clean water is one of the important indicators to measure the quality of life and welfare of the community. This is reflected in the Sustainable Development Goals (SDGs), especially in the sixth goal which targets the availability and management of clean water and sustainable sanitation for all (Maziyya & Nurhamsyah, 2025). The availability of clean water is also closely related to other sectors such as education, food security, and gender equality. For example, in some rural areas, children, especially girls, have to travel long distances to fetch water, which ultimately interferes with their chances of attending school and developing optimally.

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Therefore, the provision of clean water is not just a technical issue, but also part of a major effort to create social justice, improve public health, and build the foundations for inclusive and sustainable economic and social development. Initiatives and innovations in clean water management should be seen as long-term investments that have a far-reaching impact on current and future generations. Increasing access to clean water means providing greater opportunities for people to live healthier, more prosperous, and more dignified lives (Manurung, 2021).

Although water is an abundant natural resource, the availability of clean water that is suitable for consumption is still a serious problem in various regions, both in developing and developed countries. In many areas, especially in remote areas, rural areas, and densely populated urban areas, people still have difficulty accessing clean water for their daily needs. This limited access not only impacts health, but also affects productivity, education, and overall quality of life of people (Sudarmanto & Hermawan Setiabudi, 2023). In Indonesia, despite numerous government programs aimed at expanding the clean water network, there is still a large gap between urban and rural areas in terms of the availability of safe drinking water infrastructure and services. This problem is exacerbated by various interrelated factors. First, rapid population growth has led to a significant increase in water demand, while clean water sources remain limited. Second, the high rate of urbanization is often not balanced by the development of adequate clean water infrastructure. This causes great pressure on the existing water supply system, especially in slum and densely populated areas. Third, environmental pollution, both from domestic, agricultural, and industrial waste, also worsens the quality of available water sources. Many rivers and lakes are heavily polluted due to sewage disposal without prior treatment, making the water unfit for consumption even after simple filtration (Waluyo et al., 2022).

In addition, climate change also has a significant impact on the availability of clean water. Changes in rainfall patterns, rising global temperatures, and the occurrence of natural disasters such as floods or droughts make water supply uncertain and difficult to predict. Water sources such as springs, shallow wells, and lakes began to dry up or deteriorate due to seawater intrusion and sedimentation. This situation is further exacerbated by uneven and inadequate water management infrastructure, especially in areas that are geographically difficult to reach or have challenging topography (Lismawati, 2021). Budget limitations, lack of appropriate technology, and lack of community participation in maintaining water resources are also major obstacles in ensuring sustainable access to clean water. With the complexity of existing problems, a multidisciplinary and collaborative approach is needed between the government, the private sector, the community, and academia to find appropriate and sustainable solutions. Technological innovations, strict regulations on pollution, and public education on water conservation are important steps in overcoming the increasingly threatening clean water availability crisis. Without concrete and systematic efforts, the gap in access to clean water will continue to widen and bring serious consequences for the health, environment, and socio-economic development of the community (Mustapa et al., 2023). In the midst of increasing challenges in the provision of clean water, technological innovation plays a crucial role as an effective and sustainable solution. Modern technology allows the process of water treatment, distribution, and monitoring to be carried out in a more efficient, accurate, and resource-efficient way. Various innovations have been developed to overcome the limitations that were previously obstacles in clean water management, both in urban and rural areas. This technology-based approach not only offers technical convenience, but also opens up opportunities to expand access to clean water to communities previously isolated or unreached by conventional services (Audah et al., 2019).

One of the innovations that is widely used is membrane-based filtration technology, such as reverse osmosis (RO) and ultrafiltration. This technology is able to filter microscopic particles, heavy metals, and pathogenic microorganisms from raw water so that it produces water that is safe for consumption. In addition, advances in the field of Internet of Things (IoT) have also contributed greatly to real-time water quality monitoring systems. With sensors connected via the internet network, water quality can be monitored in terms of pH, turbidity level, chemical content, and other parameters automatically. This allows for early detection of

potential contamination and quick and precise decision-making. On the other hand, wastewater treatment has also undergone a major transformation thanks to the adoption of biotechnology-based technologies and environmental engineering (Fadylah et al., 2024). Technologies such as biofilters, constructed wetlands, and modern biological reactors allow domestic and industrial wastewater to be reprocessed into usable water without polluting the environment. In addition to reducing waste, the system also contributes to water conservation by providing alternative water sources. No less important, the use of renewable energy such as solar power to drive water pumps and filtration systems is an efficient solution in areas that are not yet accessible by electricity or have energy limitations. This technology can be integrated on a small or large scale, depending on the needs and characteristics of the local area (Sepri & Fauzi, 2022) .

The application of these technologies not only improves the technical system of water management, but also encourages community involvement in maintaining and managing water resources in a participatory manner. Through training and the introduction of appropriate technologies, communities can be empowered to operate and maintain water systems independently. In the long term, this approach not only addresses technical problems, but also strengthens community resilience to water crises, creates equity in access to clean water, and accelerates the achievement of sustainable development goals. Therefore, the integration of technological innovations in water management strategies should be a top priority in public policy and development planning, both at the local and national levels. The application of technology in clean water management provides various tangible benefits that have a direct impact on people's lives. One of the most important benefits is its ability to expand access to clean water, especially in areas previously difficult to reach by conventional distribution systems. Through technologies such as seawater desalination, rainwater harvesting based on filtration systems, and water purification using portable devices or community-scale systems, people in remote or disaster-affected areas can now enjoy clean water without having to rely on supplies from city centers. Technology allows the construction of a water treatment system that is modular and adaptive to geographical conditions and local needs, so that it is more flexible in responding to the very diverse water problems in each region.

The next very significant benefit is the improvement of public health. Clean water is the main prerequisite for maintaining personal hygiene, preventing the spread of disease, and supporting proper sanitation. With the consistent availability of quality water, cases of diseases caused by the consumption of polluted water such as diarrhea, typhus, cholera, to skin infections and worms can be drastically suppressed. The technology also allows for regular monitoring of water quality, so that early detection of contamination can be addressed immediately before it causes wider health impacts. This is especially important in areas with dense populations and limited access to health services. In the long term, the existence of clean water helps increase people's productivity, reduce the burden of health costs, and extend life expectancy. Furthermore, the implementation of technology also supports community empowerment and environmental sustainability. With a technology system that is appropriate and easy to operate, local communities can be actively involved in the water management process—from installation, maintenance, to water quality monitoring. This approach creates a sense of belonging to water resources and builds community independence in managing their basic needs. In addition, many clean water management technologies are designed with environmentally friendly principles, such as the use of renewable energy (solar or wind power), wastewater recycling systems, and the use of local materials with a minimal carbon footprint. This technology helps to suppress the overexploitation of water resources and supports the conservation of natural water resources, so that the sustainability of the ecosystem is maintained.

Thus, the benefits of implementing technology are not only technical and short-term, but also include social, economic, and ecological aspects in the long run. Targeted and inclusive technologies will be key in creating a fair, adaptive and sustainable clean water management system for current and future generations. This article has been compiled with the main objective of providing a comprehensive understanding of the role of technological innovation in clean water management, as well as its implications for various aspects of

people's lives. Amid increasing pressure on water resources due to population growth, environmental pollution, and the impacts of climate change, the need for a more modern and efficient approach to managing clean water is urgent. Therefore, this study focuses on the identification and exploration of various types of technologies that have been and are being developed in water quality treatment, distribution, and monitoring. These technologies include membrane-based filtration systems, the use of the Internet of Things (IoT) for real-time water quality monitoring, desalination technology, biotechnology-based wastewater treatment, and the use of renewable energy in independent clean water systems. By evaluating the characteristics, advantages, and challenges of each technology, this article is expected to provide a clear picture of the potential for technological innovation in responding to the clean water crisis that occurred in various regions. In addition to examining the technological side, this article also aims to analyze the impact of the implementation of technology on the quality of life of the community, especially in health, social, and economic aspects. Effective water management technology is believed to make a significant contribution to reducing the number of diseases caused by polluted water, increasing community productivity, and creating a cleaner and more sustainable environment. Not only that, but wider access to clean water also contributes to reducing social inequality and improving welfare, especially in vulnerable communities and areas that have previously experienced water crises. This analysis will include case studies or field findings that show how changes in quality of life can occur once water technology is implemented, either individually, communityly, or regionally. Furthermore, this article also aims to provide strategic recommendations for various parties, ranging from the government, the private sector, non-governmental organizations, to local communities, in developing and implementing effective and sustainable technology-based clean water management. This recommendation will be prepared based on the results of the study and analysis conducted, taking into account socio-cultural factors, financial capabilities, infrastructure readiness, and public policy aspects that support innovation. It is hoped that the results of this article can be a useful reference in designing water policies, strengthening community capacity, and encouraging cross-sector collaboration in providing inclusive and equitable clean water solutions for all levels of society.

2. Method

This study uses the Systematic Literature Review (SLR) approach to examine various technological innovations in clean water management and their impact on improving the quality of life of the community. SLR is a systematic, transparent, and structured method for identifying, evaluating, and synthesizing research results that are relevant to the topic being researched. This approach was chosen because it was able to provide a comprehensive understanding of trends, findings, and gaps in research that had been conducted previously in the scope of the same topic. The SLR steps in this study are carried out in three main stages, namely literature identification, selection and evaluation, and data analysis and synthesis. In the first stage, literature search was carried out through several scientific databases such as Scopus, ScienceDirect, Google Scholar, and SpringerLink using keywords such as "water purification technology", "clean water management", "water innovation", "smart water systems", and "sustainable water access". The publication time range used is between 2013 to 2024, to ensure the relevance and novelty of the data. In the second stage, the article selection process was carried out based on inclusion and exclusion criteria. Inclusion criteria include journal articles or proceedings that discuss technological innovations in clean water management, are available in English or Indonesian, and have full access to the content of the article. Meanwhile, articles that are opinionated, do not go through a peer-review process, or are not relevant to the focus of the research are removed from the study list. From the results of the initial selection consisting of 150 articles, 30 main articles were obtained that met the criteria and became material for further analysis. The third stage is data analysis and synthesis. The selected articles were thematically analyzed to identify the categories of technologies used (e.g., membrane filtration, IoT monitoring, wastewater treatment, renewable energy), implementation objectives, geographical context, and impact on health, economy, and the environment. The data is then compiled in the form of a summary table and presented

narratively to illustrate the relationship between technological innovation and improving people's quality of life. In addition, the study also evaluates the weaknesses and potential for future technological development based on trends identified in the literature. With this SLR method, it is hoped that the research can make a valid and in-depth contribution to the scientific understanding of the importance of technological innovation in answering the challenge of clean water availability globally and locally.

3. Results and Discussion

Global and Local Clean Water Problems Overview

Clean water is one of the basic human needs that is very crucial for survival. However, both globally and locally, the problem of the availability of clean water is still a big challenge. According to data from the World Health Organization (WHO) and UNICEF, more than 2 billion people in the world still do not have access to safe drinking water services. In Indonesia, similar problems also occur, especially in remote, coastal and densely populated areas, where access to clean water often depends on water sources that are vulnerable to contamination and unfit for consumption. This inequality of access is not only a technical issue, but also concerns social justice and human rights, considering that clean water is part of the basic rights of every citizen (Susianto et al., 2023). The limited availability of clean water has serious multidimensional impacts, ranging from the health sector to social and economic. From a health perspective, the consumption of polluted water can cause various infectious diseases such as diarrhea, cholera, hepatitis A, and skin infections. Data from the Indonesian Ministry of Health shows that diarrhea cases are still one of the highest causes of death in toddlers in Indonesia, one of which is caused by poor water quality. The economic impact cannot be ignored, because people have to spend more money to buy water suitable for consumption or treat diseases caused by unhealthy water. Socially, women and children—who are generally responsible for water harvesting in many communities—are the most affected groups, both in terms of workload and the potential for dropping out of school due to running out of time to find water (Salni et al., 2024).

Various challenges exacerbate this situation. Rapid urbanization has increased the pressure on water sources in urban areas, while domestic and industrial sewage pollution is worsening surface water and groundwater quality. On the other hand, climate change results in rainfall uncertainty and longer dry seasons, threatening the availability of seasonal clean water. Inadequate water management infrastructure and lack of investment in sustainable clean water systems further exacerbate the condition. In many areas, the piping system is damaged, does not reach the entire community, or is not equipped with adequate water treatment facilities. Therefore, the problem of clean water cannot be solved with a technical approach alone, but requires a comprehensive, integrated, and based solution on technological innovation and community participation (Dewantoro & Sitaresmi, 2022).

Development of Technological Innovation in Clean Water Management

As the need for clean water increases and environmental challenges become more complex, there has been a significant surge in the development of technological innovations for water management in various parts of the world. Global trends show that many countries are starting to shift away from conventional water management systems to a more modern, high-tech-based, efficient, and sustainable approach. In developed regions such as Europe and North America, water purification technology has integrated automation systems, artificial intelligence, and real-time monitoring using the Internet of Things (IoT). Meanwhile, in developing countries, including parts of Southeast Asia and Africa, simple but effective technologies such as biofilters, rainwater harvesting systems, and household-scale wastewater treatment continue to evolve as contextual solutions to infrastructure and cost constraints (Bachtiar et al., 2022). In comparison, conventional clean water management systems tend to be centralized, requiring large infrastructure and long-term investment. These technologies are often inflexible, slow in response to change, and less efficient in their use of energy and water. In contrast, modern technological innovations are more adaptive, decentralized, and energy-efficient. Examples are membrane technology for water filtration,

household-scale reverse osmosis units, or sensor-based water leak detection systems that allow for rapid monitoring and repair. In some smart cities, water management technology has even been integrated with a digital city management system, enabling real-time data-driven decision-making in water distribution and conservation. This comparison shows that the use of modern technology not only improves water efficiency and quality, but also expands the range of services, especially in areas that have not been served by conventional systems (Danial et al., 2024).

In addition, technological innovation in water management is also supported by the evolution of policies and government approaches that are increasingly pro-technology solutions. Governments in various countries are beginning to adopt policies that encourage collaboration between the public, private, and scientific sectors in the development of water technology. In Indonesia, for example, there are efforts to increase investment in clean water supply technology through government-business entity cooperation (PPP) schemes, as well as incentives for local innovations such as renewable energy-based water treatment technology. International institutions also provide support, both in the form of funds, training, and technology transfer. This approach shows that transformation in water management comes not only from technological developments themselves, but also from institutional support, policies, and paradigm shifts in water governance that are more participatory and sustainable ("Implementasi Peraturan Daerah Nomor 10 Tahun 2011 Tentang Pengelolaan Perusahaan Dan Pelayanan Air Bersih Dalam Rangka Meningkatkan Pelayanan Air Bersih Di Pdam Tirta Nauli Sibolga Kabupaten Tapanuli Tengah," 2023). Clean water management in the modern era no longer relies on a single approach, but rather utilizes various types of complementary technologies to address the challenges of water quality, quantity, and distribution. One of the main classifications is filtration and purification technology, which includes reverse osmosis (RO), ultrafiltration, and nano-filtration systems. This technology is designed to remove harmful particles, microorganisms, heavy metals, as well as harmful chemicals from raw water. Reverse osmosis, for example, has been widely used in households and on an industrial scale to produce high-quality drinking water. Nano-filtration is capable of filtering ions and small molecules with high efficiency, suitable for areas facing industrial waste pollution (Assamady et al., 2023) .

In addition to filtration, Internet of Things (IoT)-based monitoring and management technologies are increasingly being adopted to ensure real-time water quality and distribution. Digital sensors can detect physical and chemical parameters of water such as pH, temperature, chlorine levels, and other contaminants directly from the location of the source or distribution network. The integrated automation system enables rapid response to water quality anomalies, reduces potential public health risks, and minimizes water leakage and wastage. This technology is particularly relevant for water management in urban and industrial areas, where the complexity of distribution systems demands high speed and accuracy in decision-making (Alya Fitri Nur Rahmadanti et al., 2023). Meanwhile, integrated wastewater treatment technology is an important solution in the water recycling cycle. Technologies such as biofilters, artificial wetlands, and biological reactors have proven effective in converting wastewater into usable water or even clean water. This system not only reduces environmental pollution, but also supports sustainability by reducing dependence on new water sources. Artificial wetlands, for example, work on the principle of natural ecosystems, utilizing aquatic plants and microorganisms to ecologically purify wastewater. Another innovation is the use of renewable energy in clean water systems, such as the use of solar and wind power to power water pumps, filtration systems, and desalination. This technology is particularly relevant for areas where conventional electricity is not reached, such as the interior and the archipelago. With renewable energy systems, people can access clean water independently without depending on primary infrastructure. Finally, desalination technology is an important solution for coastal areas and small islands experiencing a freshwater crisis. This technology works by separating salt from seawater through physical and chemical processes, such as thermal distillation and reverse osmosis. While it still has challenges in energy efficiency and operational costs, technological advancements have made desalination more affordable and environmentally friendly through integration with renewable energy sources. Overall, this classification of technologies shows

that a multi-innovative approach to clean water management is indispensable. The combination of these different types of technologies allows for a more sustainable, efficient, and inclusive water supply, especially in the midst of the climate crisis and increasing population pressures (Hikmarina et al., 2023) .

The Impact of Technology Implementation on People's Quality of Life

The application of technological innovations in clean water management has had a real impact on improving the quality of life of the community, especially in areas that previously experienced limited access to clean water. One of the most significant impacts is the increase in access to clean water in remote areas and difficult to reach by conventional infrastructure. Decentralized technologies such as portable filters, solar water purification systems, and the use of hydraulic and gravity pumps have opened up opportunities for rural communities and small islands to obtain clean water independently and sustainably. This reduces dependence on external water supply, speeds up the water distribution process, and increases people's sense of security and independence from their basic needs. Another impact that is no less important is the decrease in the number of waterborne diseases, such as diarrhea, cholera, typhus, and skin infections. Access to water that is safe to consume and used in daily activities directly reduces the risk of exposure to pathogenic microorganisms that are the main cause of water-based diseases (Gusri et al., 2024). Data from various studies show that clean water technology interventions contribute significantly to lowering the burden of disease, particularly among children and vulnerable groups. Apart from the health aspect, clean water technology also has a positive impact on the productivity and economic welfare of the community. When people no longer have to spend large amounts of time and money to get clean water or treat diseases caused by dirty water, they have more time and energy to work, go to school, or carry out other economic activities. This increases the productivity of individuals as well as the community as a whole. Furthermore, the implementation of clean water management technology also strengthens environmental and social resilience. Technology that supports water recycling, water use efficiency, and environmentally friendly waste treatment also reduce the burden on local water ecosystems. This practice maintains the sustainability of water resources for future generations and supports the Sustainable Development Goals (SDGs), especially point 6 (clean water and sanitation). From a social perspective, clean water technology is able to create positive changes in the dynamics of society, such as reducing access inequality, empowering women who were previously burdened with the task of finding water, and strengthening social cohesion in water-based community projects. Thus, the impact of the implementation of water technology is not only technical, but also touches on social, economic, and ecological aspects as a whole, making it one of the strategic keys in efforts to improve the quality of life of the community in a sustainable manner (Maharani et al., 2024) .

4. Conclusions and Suggestions

The availability of clean water is a fundamental need that greatly determines the health, welfare, and sustainability of people's lives. However, global challenges such as urbanization, environmental pollution, climate change, and limited infrastructure make the problem of clean water a multidimensional issue that requires innovative solutions. In this context, the use of modern technology has proven to be an effective approach to improve the efficiency, reach, and quality of clean water management. Various innovations, ranging from filtration technology, IoT-based monitoring systems, wastewater treatment, to desalination and the use of renewable energy, have shown a real contribution in expanding access to clean water, especially in remote and vulnerable areas. The implementation of technology not only has an impact on improving water quality, but also directly affects the quality of life of the community, including reducing the number of diseases, increasing economic productivity, and strengthening socio-environmental resilience. In addition, policy support, cross-sectoral partnerships, and active community participation are important factors in ensuring the successful transformation of technology-based water management. Therefore, the development and implementation of technological innovations in the water sector need to be

continuously improved as an integral part of the sustainable development strategy and equitable access to basic services in various regions.

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