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Research Paper

Circular Economy in Water and Waste Management: Sustainable Strategies for Conservation

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ABSTRACT: *The study navigates how circular economy (CE) principles can be applied to water and waste management to address critical issues like water scarcity and practicing sustainability at an age marked by consumption of water, ignoring the consequences of contaminated water. The purpose of this study is to examine recycling at a household (individual) level and industrial wastewater treatment practices to improve water use and reduce discharge of toxic waste. Adopting a circular approach in water management compels one to accept waste water as a reusable and recyclable resource. This paper focuses on analysing recent methods, economic factors, and technological advancements that influence CE adoption in water management and preservation strategies.*

The existing literature indicates that domestic water recycling techniques, such as utilising grey water for irrigation, may drastically reduce the need for freshwater and support sustainable water management at a large scale. However, when it comes to industry level, there are far more complex issues involved in the treatment of water due to existence of harmful contaminants in wastewater, such as heavy metals and chemical pollutants, which are usually not present in the wastewater discharged by households. In order to properly recycle industrial wastewater, support resource efficiency and minimise the environmental impact of industrial operations, treatment techniques such as improved filtration, biological treatment, and detoxification have proved to be efficient. However, the high cost and complexity imposed by these technologies often limits their wider adoption, especially for small and medium sized businesses and at places where water resources are scarce.

One can reduce the amount of impurities added to water during industrial processes, if the individuals build the habit of computing carbon footprint of the products they are willing to purchase, this will motivate the producers to manufacture eco- friendly products with low carbon footprints, this will help in preserving potable water. Whereas at the domestic level, rainwater collection and grey water reuse can be achieved with minimal investment.

This review paper also identifies a number of research gaps, such as economic studies of water recycling systems are not common, particularly when it comes to cost- benefit analysis for low-income households and small businesses. Also, there is still a dearth of research on low-energy methods for treating industrial wastewater, which puts smaller businesses at a disadvantage when it comes to implementing CE standards. The lack of comprehensive legislative framework demotivates businesses and households to engage in waste water management and then, water recycling becomes another concern. Furthermore, studies do not indicate a lot about the social aspects that would affect the adoption of CE in water usage, thus emphasising the need for observing community participation and awareness campaigns.

KEYWORDS: *Circular economy, contamination, conservation, sustainable, detoxification.*

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I. INTRODUCTION

"The earth, the air, the land, and the water are not an inheritance from our forefathers but on loan from our children. So, we have to hand over to them at least as it was handed over to us".
– Mahatma Gandhi

So there arises the need to use the resources sustainably, and here comes the role of the circular economy. Sustainability has become a global concern in the past few decades. This is due to the increasing cost of water and inefficient waste management of water resources. This issue has been worsened due to traditional consumption methods, which involve direct utilization of a resource and then recklessly disposing of it, leading to severe water shortage and contamination. The practice of dumping waste, which prevails to this day, remains a temporary solution. These sites often lead to soil and groundwater contamination due to seepage, exacerbating water scarcity and compromising local ecosystems. Moreover, this activity increases greenhouse gas emissions and the environmental effects of garbage.

According to the Water Resources Institute (WRI), in 2023, more than half of the world's population lived under highly water-stressed conditions for at least one month of the year.

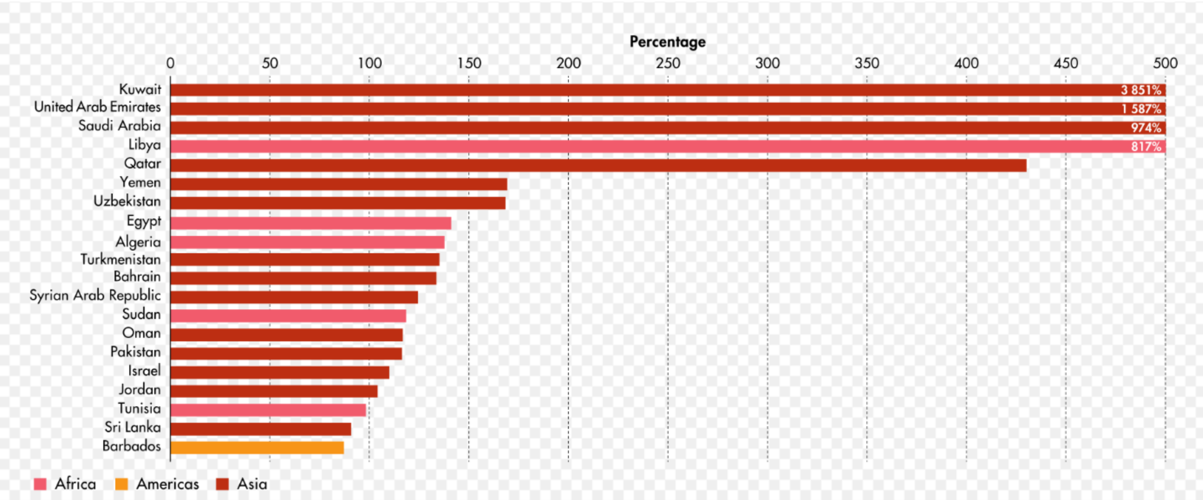

Figure 1: Most water-stressed countries in 2020
Source: FAO (2023), https://doi.org/10.4060/cc8166en

Earth's total water volume is estimated at 1.386 billion km³, with 97.5% consisting of salt water and only 2.5% classified as freshwater. Of this freshwater, merely 0.3% exists as liquid on the surface. Agriculture is the largest consumer of freshwater, utilizing 70%, followed by industry at just under 20%, and domestic (municipal) use at approximately 12%. Groundwater contributes around 25% of the water used for irrigation and supplies half of the freshwater withdrawn for domestic use. [9]

In this context, circular economy (CE) principles offer an alternative that shifts focus from disposal to resource regeneration. CE enables sustainable management of water and waste by treating waste as a resource and implementing closed-loop systems. This review explores CE applications at both household and industrial levels, with a focus on water conservation, resource efficiency, and minimizing waste output. This review examines the application of CE at the household as well as industrial level, focusing on reducing waste, water conservation, and efficient use of resources.

II. DISCUSSION

The primary objective of this review is to examine CE practices in household-level water recycling and treating industrial water before it is discharged, while also identifying the major obstacles that are present in the process. The purpose of this study is to highlight the importance of sustainable development, the implementation of regulatory frameworks and conservation of resources.

Principles of Circular Economy

The circular economy is a framework aimed at reducing waste by extending the lifecycle of products and maximizing resource utilization. CE develops systems where resources and materials are continually recycled, unlike linear consumption models where the resources are consumed and discharged without considering recycling or undergoing treatment methods. CE techniques aim to lower waste output, water consumption, and pollution, in the context of water and waste management. According to research, implementing CE techniques can alleviate significant issues such as pollution from traditional waste management, resource depletion, and groundwater contamination.

Current Practices in Water and Waste Management

Conventional techniques such as disposing waste in landfills/ dumping, are harmful to the environment and unsustainable. Even though these are temporary waste disposal methods, the harmful toxins generated from such sites seep into the soil and contaminate groundwater and ultimately raise pollution levels. Water is usually utilized once before being disposed of, both in household as well as in industrial areas. This generates wastewater on an even larger scale and strains water resources.

CE Approaches for Water Conservation

Implementing CE in water management focuses on recycling and reusing water, which lowers the demand for natural resources. In addition, households can reuse greywater for irrigation and non-drinking purposes, while industries utilize advanced filtration and detoxification techniques to treat wastewater. Studies indicate that integrating CE principles into water use systems can lower resource consumption and environmental impact, although cost and technological complexities often limit its widespread adoption. Reclaimed domestic wastewater is increasingly recognized as a valuable alternative water source capable of supporting various end-uses, including process water, drinking water, and irrigation. [10]

Environmental Impact of Poor Waste Management

The ecosystem suffers greatly from inadequate waste management, especially when it comes to contaminated soil and water. Pollutants from poorly managed trash can seep into groundwater sources, affecting ecosystems, human health, and the quality of drinkable water. Excessive groundwater extraction and pollution from industrial waste damage aquifers and worsen water scarcity. Garbage accumulation at temporary dumping sites also contributes to pollution, soil degradation, and climate change by raising greenhouse gas emissions.

The significant initial investment required to implement circular economy principles is a major obstacle, particularly in industrial environments. The high expense of advanced water treatment technologies, such as chemical detoxification systems and multi-stage filtration, makes it difficult for small and medium-sized businesses (SMEs) to implement them. Even though home remedies such as rainwater collection and greywater recycling are often less expensive, they still require some initial infrastructure investment. Adoption of such techniques may be discouraged by this initial expense, especially in low-income households and smaller businesses without outside financial assistance or incentives.

Current advances in water treatment and recycling are often limited in scalability due to high energy requirements, complex operations, and associated costs. These energy-intensive technologies are difficult to implement effectively in places with poor energy availability. Furthermore, industrial water purification systems frequently need constant energy input, which raises operating costs and harms the environment. CE's accessibility is limited by the absence of affordable, low-energy alternatives, particularly in rural or economically underdeveloped areas where readily available and flexible technology is crucial.

Effective CE adoption relies heavily on regulatory frameworks, which vary widely throughout regions, leading to inadequate implementation. Policymakers and lawmakers play a crucial role in shaping water reuse initiatives. In Japan, the advancement of innovative decentralized water reuse systems is a direct result of supportive laws and regulations. [2] While some areas have policies that encourage CE practices through incentives, subsidies, tax breaks, etc., others lack such support, making it difficult to establish standardized CE practices in water and waste management. Given that only a small fraction of wastewater is currently regenerated, it is important to emphasize that the growth in wastewater reuse has yet to reach its full potential. China and the United States lead in expanding reuse capacity. However, many ongoing projects aligned with the circular economy (CE) model face challenges due to insufficient regulations and a lack of consumer acceptance. [3] The inconsistency in regulatory support creates challenges for industries and households to adopt CE practices broadly, as incentives and enforcement mechanisms are unevenly applied.

Supportive infrastructure is the key to CE implementation, which is often lacking, particularly in densely populated urban areas. For example, many urban areas lack decentralized systems for greywater recycling, while rural regions may struggle with inadequate facilities for wastewater treatment. Developing countries, in particular, face these challenges as limited budgets and other priorities do not permit establishing the necessary infrastructure for efficient CE practices. A change in societal attitude and public understanding is necessary for the effective adoption of CE practices, especially with regard to waste management and water recycling. But in many places, people are still unaware of these advantages, and there are still unfavourable opinions about utilizing recycled water, especially for non-drinking uses. Social buy-in is still low in the absence of focused educational initiatives and campaigns, which decreases family and community involvement in CE practices.

Many CE technologies, especially sophisticated industrial systems like chemical detoxification or filtration, need to be operated and maintained by qualified workers. The adoption of CE is further limited in distant areas due to a shortage of skilled workers to run such systems. Although workforce development and training initiatives are crucial for improving CE practices, there are still few educational resources available for technical skills, especially in places where access to vocational training is restricted. Few studies examine the economic possibility of CE practices, especially for smaller firms and lower-income individuals, despite the ample evidence of their technological capacity in waste and water management. Comprehensive cost-benefit evaluations that assess long-term savings, economic incentives, and other funding sources are inadequate. Policymakers and believe it is challenging to defend investments in CE practices without this information. Subsidies, financing schemes, and financial incentives that would enable a more thorough implementation of CE standards require more investigation.

Research on low-cost, energy-efficient technology that may be used in both home and industrial settings is insufficient. As they often require considerable energy inputs, current high-efficiency treatment systems are less feasible in environments with limited resources. Research developing low-cost and low-energy solutions is essential to making CE accessible in a range of socioeconomic and geographic circumstances. These include decentralized technology, microbiological treatment methods, and natural filtration systems.

Desalination technologies are considered by many to be the most dependable ways to bridge the gap between water supply and demand; however, when implemented extensively, desalination is viewed as a costly solution with negative environmental effects and does not address wastewater management issues. [3]

The majority of CE research in water and waste management is concerned with technical aspects, and little attention is paid to the behavioural and social factors that affect its adoption. It is essential to understand the thought process and cultural factors of the community about recycling and reuse activities. To encourage the wider adoption of CE, research on public behaviour, and readiness to embrace sustainable behaviours, and successful behaviour-change initiatives is crucial. Research on communication and community involvement techniques can also assist in overcoming opposition and promoting effective practices.

Research on efficient regulatory frameworks that might encourage water and waste management practices within a CE model is lacking, despite the fact that the significance of policy in promoting CE is generally recognized. The impact of current policies is limited because they are frequently disjointed or lack enforcement mechanisms. Successful policy approaches, such as the impact of tax breaks, subsidies, and environmental laws on the adoption of CE, might be found via more investigation. Furthermore, research could examine how partnerships between communities, businesses, and governments could contribute to the development of standardized procedures that provide a sustainable approach to water and waste management.

The potential decentralized and localized systems that are suitable for rural or economically disadvantaged areas is sometimes overlooked in the research that currently exists, which mostly concentrates on centralized water treatment systems. For areas with limited resources or water, small-scale solutions such as rainwater collection, community-based greywater recycling, or inexpensive wastewater treatment systems offer affordable alternatives. Studying the creation, viability, and use of these decentralized solutions may increase the application of CE techniques and promote sustainable water management in a variety of situations.

Few studies examine the use of digital tools and IoT technologies in CE water and waste management, despite the fact that they could improve CE practices by providing real-time data on resource use, trash levels, and environmental impact. To advance CE practices, it is essential to study how IoT, AI, and data analytics can optimize water consumption, forecast resource demands, and track system efficiency. Creating easy-to-use digital tools to monitor resource conservation initiatives might help people, businesses, and governments manage waste and water resources more efficiently. Few studies evaluate the environmental trade-offs of CE methods, such as the energy costs involved with industrial recycling or the ecological effect of chemical treatment operations, despite the fact that CE encourages waste reduction and resource conservation. Thorough research on the carbon and water footprints of CE practices would guarantee that these solutions are in line with long-term objectives.

Household Water Recycling

Household water use may be significantly decreased by using greywater for non-drinking uses like toilet flushing and irrigation. This procedure helps create a closed-loop system that minimizes the environmental effect of disposing of wastewater while conserving freshwater supplies. Collecting rainwater provides an eco-friendly method for households to supplement their water needs and reduces dependency on public water sources, encouraging sustainability.

Industrial Wastewater Treatment

Complex treatment procedures are required for wastewater produced by industries that contain chemicals and heavy metals. To ensure that treated water fulfils environmental requirements for reuse, biological detoxification, and multi-stage filtration, are essential. Despite their advantages, industrial treatment systems are sometimes too costly and energy-intensive for smaller businesses to utilize. Therefore, reasonably priced solutions are necessary for broader industry use of CE.

Economic and Environmental Benefits

There are economic and environmental advantages to using CE in waste and water management. Greywater reuse is an example of a household water saving technique that can reduce water costs and alleviate the burden on public water infrastructure. Recycling treated water in business encourages resource efficiency and reduces pollution. In general, CE methods lower pollutants and enhance groundwater quality.

Barriers to CE Adoption

The high price of complex treatment technology and the scarcity of reasonably priced substitutes impose serious problems. Low-energy, scalable technologies that can be employed in areas with limited resources are desperately needed. The widespread adoption of CE practices in homes and businesses is hindered by a lack of regulatory backing and public awareness.

Relevance of Findings

The findings demonstrate how CE practices can assist in achieving the Sustainable Development Goals (SDGs) by promoting clean water, responsible consumption, and climate action. By using water recycling techniques, households can conserve the environment by reducing their water consumption.

Practical Implications for Households

Practical Implications for Households Greywater reuse and other easy-to-implement CE techniques provide a reasonable cost for advancing sustainability at the local level. Initiatives to collect rainwater provide a neighbourhood-based strategy for group water saving.

Consequences for Industry

CE techniques may increase resource efficiency and lower pollution in companies. To promote greater use, however, financial incentives and support regulations are essential due to the high cost of sophisticated treatment systems.

Regulations and Policies

A regulatory framework that promotes and demands sustainable activities is necessary to implement CE practices. In order to close the gap between current practices and sustainable water and waste management goals, supportive policies are essential.

Society

In order to make CE practices successful, social aspects are essential. Long-term behavioural changes towards waste reduction and water conservation can be facilitated by education and awareness programs that promote sustainable behaviour and community participation. Future research should focus on developing scalable and affordable water treatment systems that are affordable for low-income homes and SMEs. The economic feasibility of recycling systems must also be examined to support the successful adoption of CE practices in low-resource areas. Furthermore, authorities must prioritize creating incentives that encourage the adoption of CE, particularly in areas with little regulatory approval. At the local and regional levels, further research on behavioural obstacles to CE can promote sustainable behaviours and encourage community involvement.

III. CONCLUSION

This study highlights the importance of community awareness, technological innovation, and legislative support in advancing water reuse. Despite economic, political, and environmental challenges. [3] However, the lack of research from water-stressed regions highlights the need for further studies on low-cost, energy-efficient water treatment solutions.

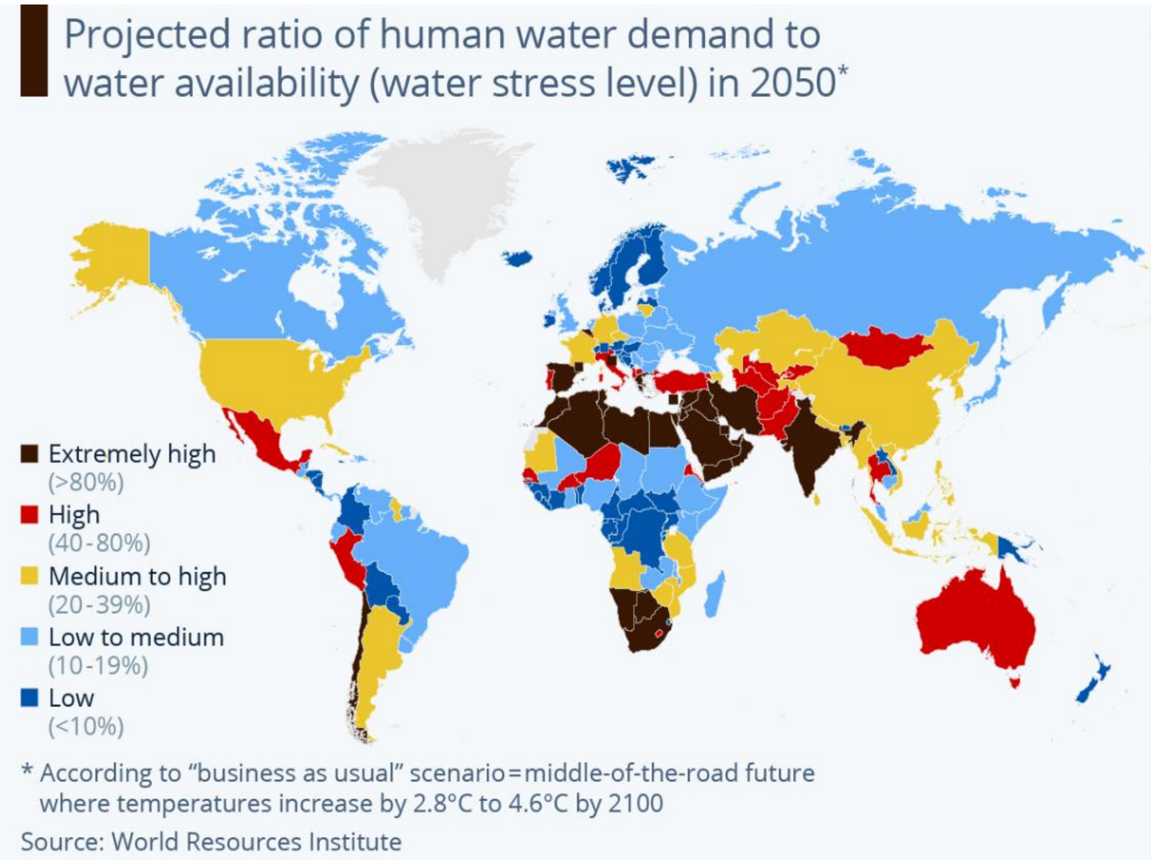

Figure 2: Estimated water stress level in 2050
Source: https://www.statista.com

Moreover, the successful adoption of CE practices depends not only on technology and policies but also on behavioral change at both household and industrial levels. Governments must introduce financial incentives, regulatory frameworks, and educational programs to encourage CE adoption. Businesses, communities, and individuals all play a role in reshaping water management practices. A multi-stakeholder approach is crucial to overcoming the barriers to CE adoption and ensuring a sustainable and resilient water future.

The application of circular economy principles in water and waste management is not just an environmental necessity but a critical strategy for addressing water scarcity, reducing pollution, and securing water resources for future generations.

REFERENCES

[1]. Armstrong, M. (2024). *Where water stress will be highest by 2050*. Retrieved from https://www.statista.com

[2]. Dai, T., Watanabe, K., & Maruyama, Y. (2011). A study on the factors promoting the development of water reuse systems in Japan. *Water Science and Technology: Water Supply*, 11(1), 99–106. https://doi.org/10.2166/ws.2011.008

[3]. Fernandes, E., & Marques, R. C. (2023). Review of water reuse from a circular economy perspective. *Water*, 15(5), 848. https://doi.org/10.3390/w15050848

[4]. Food and Agriculture Organization of the United Nations. (2023). *World food and agriculture – Statistical yearbook 2023*. Rome. https://doi.org/10.4060/cc8166en (Figure 64)

[5]. Kummu, M., Guillaume, J. H. A., de Moel, H., Eisner, S., Flörke, M., Porkka, M., Siebert, S., Veldkamp, T. I. E., & Ward, P. J. (2016). The world's road to water scarcity: Shortage and stress in the 20th century and pathways towards sustainability. *Scientific Reports*, 6(1), 38495. https://doi.org/10.1038/srep38495

[6]. Kuzma, S., Saccoccia, L., & Chertock, M. (2023). *25 countries, housing one-quarter of the population, face extremely high water stress*. World Resources Institute. Retrieved from https://www.wri.org

[7]. Lall, U., Josset, L., & Russo, T. (2020). A snapshot of the world's groundwater challenges. *Annual Review of Environment and Resources*, 45(1), 171–194. https://doi.org/10.1146/annurev-environ-102017-025800

[8]. Mainardis, M., Cecconet, D., Moretti, A., Callegari, A., Goi, D., Freguia, S., & Capodaglio, A. G. (2022). Wastewater fertigation in agriculture: Issues and opportunities for improved water management and circular economy. *Environmental Pollution*, 296, 118755. https://doi.org/10.1016/j.envpol.2021.118755

[9]. *The United Nations World Water Development Report 2017: Wastewater: The untapped resource.* United Nations Educational, Scientific and Cultural Organization. https://unesdoc.unesco.org/ark:/48223/pf0000247153

[10]. Vinayagam, V., Sikarwar, D., Das, S., & Pugazhendhi, A. (2024). Envisioning the innovative approaches to achieve circular economy in the water and wastewater sector. *Environmental Research*, 241, 117663. https://doi.org/10.1016/j.envres.2023.117663

[11]. UNESCO. (2024). *United Nations World Water Development Report 2024*. Retrieved from https://www.unesco.org/reports/wwdr/en/2024/s#:~:text=SDG%206%20indicators-,Water%20demand%20and%20use,freshwater%20withdrawn%20for%20domestic%20purposes

[12]. UN-IGRAC. (n.d.). *What is groundwater?* Retrieved from https://www.un-igrac.org/what-groundwater