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The circular economy for water: International experiences

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Abstract---The circular water economy aims to reuse water, reduce its wastage, and recycle it while minimizing leaks. This approach relies on advanced technologies and integrated water resource management to achieve sustainability and reduce the negative environmental impact. It also enhances water security, especially in regions suffering from water scarcity, ensuring greater continuity of this vital resource for future generations.

Keywords---Circular water economy, environmental security, water.
JEL Classifications---Q53, Q25, Q56.

1. Introduction

In light of the growing environmental and climate challenges, the circular water economy is considered one of the modern concepts that aim to improve the sustainable and efficient management of water resources. It seeks to establish an integrated system that continuously reuses and recycles water instead of following traditional methods that rely on one-time use. With increasing water scarcity, interest in the circular water economy has grown due to rising pressures on water resources, including population growth, urban expansion, and climate change. These challenges are driving communities and governments to search for innovative solutions to address water shortages and deteriorating water quality. By adopting circular economy practices, significant economic and environmental benefits can be achieved, such as reducing waste, enhancing resource use efficiency, finding alternatives for water usage in certain sectors, and improving quality of life for communities. The circular water economy presents a future vision that allows us to live more sustainably while preserving precious water resources for future generations.

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Research Problem: Based on the aforementioned discussion, the study problem can be formulated as follows: **What is the reality of the circular economy for water in countries around the world?**

The following sub-questions can be posed:

-What do we mean by the circular economy?
-What is the circular water economy?
-What is the current state of the circular water economy in different countries around the world?

Research Hypotheses:

To answer the research problem, the following hypotheses are proposed:
-The circular economy consists of technologies that allow for the reuse of both solid and liquid waste of all kinds.
-The circular water economy involves recycling and reusing previously used water, such as gray water, to benefit other sectors like agriculture.
-Global Experiences in the Circular Water Economy: Global experiences in the circular water economy provide insight into how to utilize reused water and reduce future water scarcity.

Importance of the Study:
The significance of this study lies in highlighting the concept of the circular economy in general and, more specifically, in the water sector

Study Objectives:
This study aims to achieve the following:
-Understanding the concept of the circular economy;
-Highlighting the importance of the circular economy;
-Understanding the circular water economy;
-Highlighting the current state of the circular water economy in countries around the world.

Research Methodology:
In this study, we adopted the descriptive method by addressing several concepts related to the study's elements.

2. The Circular Economy.

2.1 Concept of the Circular Economy:

It is "an industrial system that is restorative or regenerative by design, creating a system that replaces the concept of end-of-life by focusing on the recovery and shift towards renewable energy. It eliminates the use of toxic chemical resources that hinder reuse, with the aim of eliminating waste and transforming it from a financial burden into a new economic resource." (Mustafa & Hanaq, 2013, p. 164)

It is also defined as "a sustainable economy that relies on using fewer resources in manufacturing processes, producing very minimal waste, and causing no negative impact on the environment. It is based on recycling previous products that are repairable and renewable, maintaining high quality." (Fatma, 2022, p. 9)

It has also been defined as "an economic system that relies on processing and recycling waste in order to use it in the production process and optimize the use of natural resources, while considering the environmental aspect." (Al-Sadiq, 2021, p. 28)

2.2 The Importance of the Circular Economy:

The circular economy holds great importance due to the role it plays in improving the functioning of the global economy within a healthy environment. Among its key roles, we can mention (Nabil, 2022, pp. 39-40):

- Recycling waste and transforming it into valuable products.
- Reducing the exploitation of natural resources to produce new products, substituting them with products resulting from the recycling process.
- Decreasing the costs of full-scale new production by partially producing through the recycling of previous products.
- Reducing pollution and limiting climate change by eliminating waste through its utilization, preventing it from polluting the environment.
- Encouraging startups that provide solutions for removing environmentally harmful materials.

2.3 Requirements for the Transition to a Circular Economy:

The shift from traditional methods of water use to more advanced methods of reusing water requires several key requirements, including (Nashed, 2023, pp. 216-217):

- Digital transformation contributes to providing accurate information about the availability, location, and condition of resources and products.
- Continuous research and innovation across all fields: economic, social, technological, and commercial.
  Raising environmental awareness and culture and modifying individuals' behaviors in waste management to facilitate its utilization.
- Promoting economic efficiency in production and consumption by using waste and recycling it into new products at minimal costs.

3. Circular Water Economy.

3.1 Definition of the Circular Water Economy:

It is an economic framework aimed at reducing and conserving water and using it in the most efficient way by avoiding waste, ensuring effective use, and maintaining quality while protecting the environment. It views water as a valuable resource, product, and service that must be managed sustainably within the natural water cycle. (Morseletto, Caro, & Stefania, 2022, p. 4)

"It is also defined as the recycling and recovery of resources in our aquatic systems, which aims to provide maximum benefits to communities and the environment, help overcome and combat climate change, promote equitable economic opportunities, and ensure dependence. (wef.org, 2024)

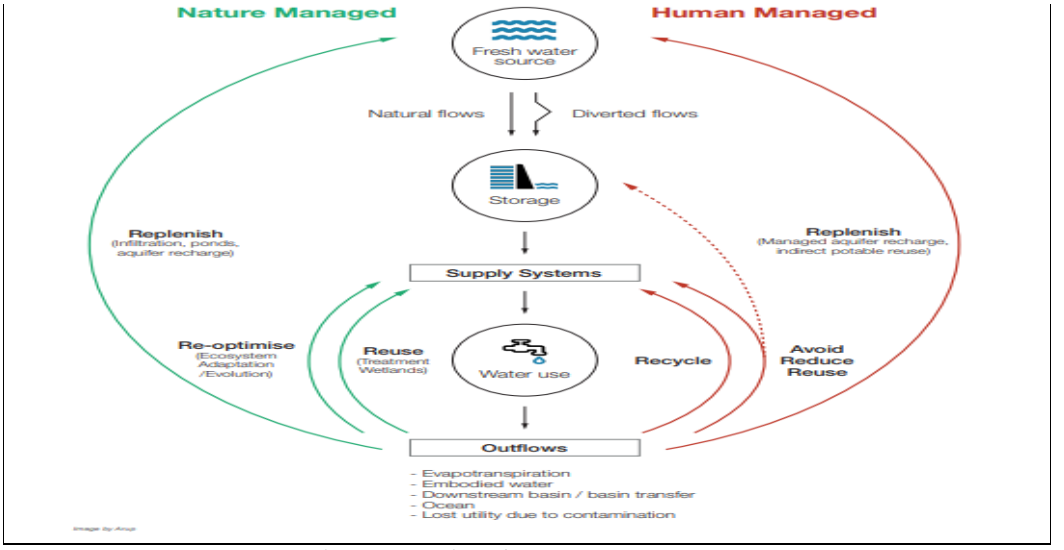

Figure 1: Circular water economy.
Source: (Qtaishat, Jan, & Kemi, 2022, p. 866)

Figure 1 represents the graphical representation of the circular water economy, summarizing the natural management system and the human management system (Siraj Tahir, Martin r, & Tristan , 2019, p. 12):

Natural Management System: The water cycle in nature works to naturally purify, reuse, and renew water. This occurs within defined limits of water to maintain the ecosystem and biodiversity. Plants and animals play a role in this cycle through processes like transpiration and evaporation, which eventually transform into water flows via precipitation.

Human Management System: This involves human intervention and its impact on the natural water cycle through changes that include:

-Extracting freshwater at rates greater than its natural replenishment.
-Polluting water and reducing its usefulness for other users.
-Using irrigation methods that contribute to waste and accelerate water loss.

Opportunities for Circular Water Economy: Due to the negative impact of human water management on the natural system, which incurs severe economic losses, it is essential to find ways to avoid these losses. The circular water economy provides an opportunity for integration between human water cycles and natural water cycles through the following measures:

- Eliminating ineffective water use practices.
- Reducing consumption, which leads to continuous improvement in water efficiency.
- Reusing water by exploiting all opportunities for water reclamation within operations and technologies.
- Recycling water within both internal and external processes.

3.2 Benefits of the Circular Water Economy:

The water circular economy has several benefits, including (Morseletto, Caro, & Stefania, 2022, p. 4):
-Efficient water use.
-This economy plays a major role in sustainable water management, as it allows for reorganizing water use and maximizing its value.
-Preserving water and its quality for long periods while working to reduce wastage.
-It is considered an effective framework for addressing the challenges of global environmental change.
-Providing innovative solutions for reusing water instead of traditional methods.

3.3 Principles of Circular Water Economy:

The principles of the circular water economy are demonstrated through the following (Siraj Tahir, Martin r, & Tristan , 2019, p. 6):
- Reusing wastewater and reducing pollution.
- Improving the consumption of water.
- Using measures or solutions that achieve the same result without using water.
- Enhancing the extraction of energy or resources from the water system and maximizing their reuse.
- Maximizing environmental flows by reducing both consumptive and non-consumptive uses of water.
- Preserving and enhancing natural capital (such as river restoration and pollution prevention).
- Ensuring minimal disruption to natural water systems from human interactions and excessive use.

3.4 Challenges of the Circular Water Economy:

The circular water economy faces several obstacles and challenges in achieving its goals, including (Qtaishat, Jan, & Kemi, 2022, p. 877):
- Design and technology limitations, such as the lack of necessary technologies for this process.
- The initial costs of water management are very high.
- Difficulty in obtaining licenses within the framework of this process.
- The absence of financial and legislative tools supporting water recycling.

3.5 Strategies of the Circular Water Economy:

The strategies of the circular water economy are as follows (Elżbieta Wołoszyńska-Wiśniewska, February 2024, p. 5):

Reduction Strategy: This refers to reducing water use through avoidance (i.e., preventing unnecessary use of resources), reduction (i.e., lowering water use compared to typical business scenarios), and substitution (replacing water with another material).
Improvement Strategy: This refers to improving water use through reuse and recycling (both related to the secondary use of water, with or without treatment), and cascading (sequential use of water extracted from one process as an input to another).

Retention Strategy: This refers to storage (retaining used water in reservoirs) and recovery (purifying water while recovering biochemical compounds and retaining or generating energy).

3.6 Solutions Provided by the Circular Water Economy:

The opportunities offered by the circular water economy include (Elżbieta Wołoszyńska-Wiśniewska, February 2024, p. 8):
- Reusing wastewater and recovering nutrients can contribute to addressing global water scarcity.
- Recharging groundwater, producing biogas, and supporting the creation of green job opportunities.
- Treated wastewater reuse can provide a reliable source of water for industry, agriculture, and sometimes drinking water, with lower investment costs and energy consumption compared to other sources (such as desalination or water transfer between basins).

4. International Experiences in the Circular Water Economy:

Below, we will examine some global experiences in the circular economy in the water sector:

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4.1Saudi Arabia's Experience:

-Solar-Powered Water Desalination: Saudi Arabia is making significant efforts to desalinate water using various methods, including solar energy. An example of this is the Khafji plant, which desalinate water using photovoltaic solar-powered reverse osmosis technology. This plant produces approximately 60,000 cubic meters of clean water daily. This method reduces costs, allowing for additional energy to be used in other areas. The development of this plant is part of the "Vision 2030" plan. (Metcalfe, May 2023, p. 32)

-Smart Irrigation System Project: This project was undertaken by Lumo, a company specialized in developing water management technologies to address the global challenge of water scarcity. The project aims to address the shortcomings of traditional irrigation methods by developing a smart valve and integrating it with water flow sensor units and devices. This system helps to provide the necessary amount of water without excess or shortage, contributing to a 90% reduction in labor costs and a 20% savings in water consumption, while also promoting environmental sustainability. (Ministry of Environment, Water, and Agriculture, March 2024, p. 18)

4.2--India's Experience:

Chennai was the first city in India to mandate rainwater harvesting. It also has two large desalination plants under the management of the Metropolitan Water Supply and Sewerage Board (CMWSSB). CMWSSB has carried out several projects related to wastewater treatment and reuse for various purposes. They sell treated water to industries and also sell biosolids generated from wastewater treatment plants as fertilizers for agricultural use. The revenues generated cover all operation and maintenance costs, as illustrated in the following figure. (Delgado, Diego , Carlo A, & Midori, 2021, p. 23):

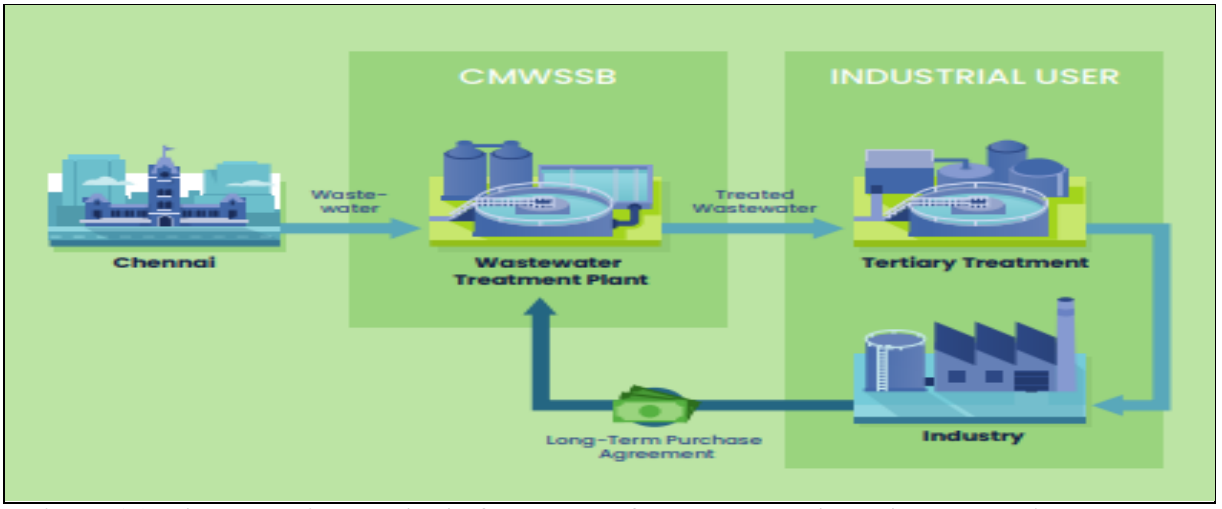

Figure (2): The operating method of CMWSSB for water supply and sewerage in Chennai Metropolitan.
Source: (Delgado, Diego, Carlo A, & Midori, 2021, p. 23).

4.3-United States Experience:

-**Direct Drinking Water Reuse Project in Wichita Falls:** The Direct Drinking Water Reuse project was launched in Wichita Falls in 2014. It involves a seven-step process for water treatment. After treating the water at the wastewater treatment plant, the treated water is disinfected and sent to the River Road Resource Recovery Facility, and then to the Cypress Water Treatment Plant. The water is then processed through microfiltration and reverse osmosis at the purification plant. After that, the reused water undergoes reverse osmosis and is released into a holding pond. The reused water is mixed with raw water from the city's lakes at a 50-50 ratio, with the mixed water coming from sources such as Lake Arrowhead and Lake Kickapoo. This results in clean, safe drinking water, ready for distribution. (AQUINO & D ROBERT C, June 2021, p. 7)

-**Wahaso Dual System for Rainwater and Greywater Collection Project:** This project was carried out by Mercy Housing Lakefront, a non-profit organization that is redefining affordable housing through sustainable living solutions. One of their circular water economy projects is the development of the Wahaso dual system for rainwater and greywater collection to significantly reduce freshwater use. The system filters water from sinks and bathtubs, sterilizes, and stores it, allowing it to be reused for flushing toilets, which meets 100% of the water needs of the Margot and Harold Schiff Residence. Additionally, rainwater is collected from the roof and stored for reuse in irrigation. (AQUINO & D ROBERT C, June 2021, p. 5)

4.4-Denmark's Experience:

The Aarhus Vand water utility in Denmark implemented energy-saving technologies at the Marselisborg wastewater treatment plant, including the SCADA advanced control system, a new turbo compressor, and an enhanced fine-bubble aeration system. These innovations reduced electricity consumption by

25%, equivalent to about 1 gigawatt/year. At the same time, energy production was improved by installing new, energy-efficient biogas engines (combined heat and power), which increased electricity production by another 1 gigawatt/year. A new heat exchanger was also installed to sell surplus heat to the distribution network, contributing an additional 2 gigawatts/year. (Delgado, Diego , Carlo A, & Midori, 2021, p. 33)

4.5-China's Experience:

The city of Lingyuan, China, has taken the opportunity to address water scarcity, eliminate pollution, and promote circular economy principles by collecting, treating, and reusing wastewater. The city upgraded its wastewater treatment plant and established separate systems for stormwater and sewage. It also sells treated water to industrial users, and the project's revenues are used to rejuvenate an urban lake, restoring biodiversity and preserving the groundwater surrounding the lake. This helps recharge the groundwater, as industries no longer use this water, as shown in the following figure (Delgado, Diego , Carlo A, & Midori, 2021, p. 32):

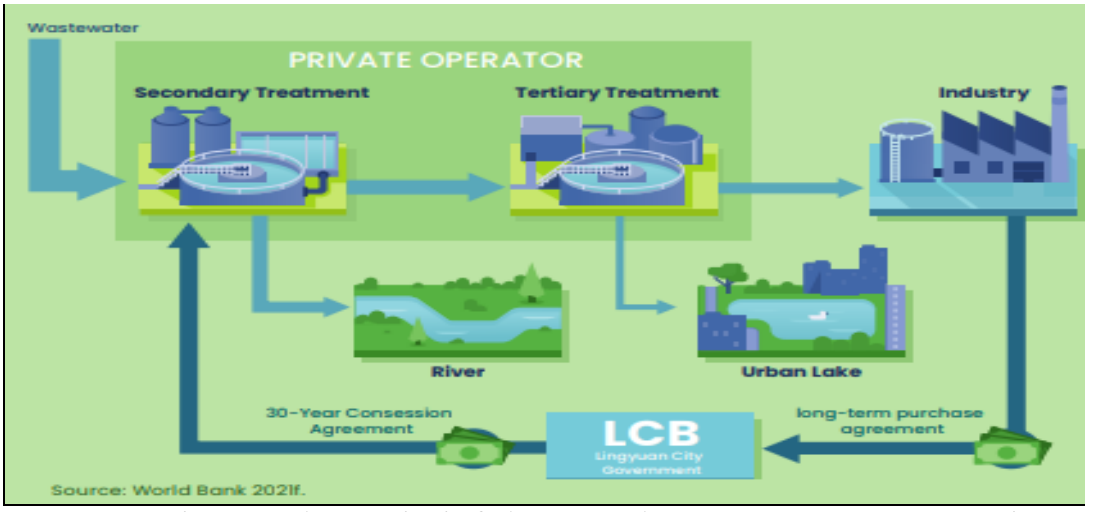

Figure (3): The operation method of Lingyuan City's wastewater treatment plant. Source: (Delgado, Diego , Carlo A, & Midori, 2021, p. 32)

4.6-Arequipa, Peru Experience:

Under a public-private partnership (PPP) agreement, the mining company "Cerro Verde" and the municipal water utility "SEDAPAR" decided that the mining company would be responsible for designing, financing, building, and operating a wastewater treatment plant to treat about 95% of the city's wastewater. In return, "Cerro Verde" could use part of the treated water for its mining operations, with the remaining water being discharged into the river for downstream use by farmers. These integrated solutions allowed the mines to expand their operations, while the municipality saved money (as the cost of building and operating the wastewater treatment plant would have exceeded 335 million USD for the city). At

the same time, the Chili River was significantly restored, benefiting the city and its residents. (Delgado, Diego , Carlo A, & Midori, 2021, p. 38)

4.7-Turkey's Experience:

The Narkoy Ecological Hotel in Turkey uses an on-site biological wastewater treatment system, Biopipe, to treat and recycle 100% of its wastewater for irrigating its organic farm. This system has allowed for future water savings. (AQUINO & D ROBERT C, June 2021, p. 6)

4.8-Brazil's Experience:

After decades of investing in traditional infrastructure (grey infrastructure) to provide drinking water to its residents, the Greater Metropolitan Area of Espírito Santo State in Brazil faced issues of erosion and sediment pollution, which degraded water reservoirs. In collaboration with the World Bank, the state identified natural solutions to these problems through the Watershed Management and Forest Cover Restoration Project. This project provided payments to landowners in upland areas to reforest, conserve, and manage forests in ways that reduce erosion and prevent sediment buildup in water reservoirs. The project also included a $7.4 million pilot initiative to reduce sediment accumulation that hinders water treatment plant operations. This is an example of a holistic approach combining reforestation and better land management. The estimated economic benefits of these interventions ranged from $13 million to $18 million, with an internal rate of return between 12.7% and 16.8%. It is estimated that the water utility CESAN will save a total of 15.5 million Brazilian Reais over 30 years in the costs of purchasing and maintaining new filtration equipment. Landowners also benefit from the PES system, regulatory compliance, and increased income from productive practices. (Delgado, Diego , Carlo A, & Midori, 2021, p. 38)

4.9-Taiwan's Experience:

The traditional textile dyeing process uses a large amount of water and generates polluted wastewater that must undergo extensive treatment before it can be reused. In response, a new dyeing technology was adopted by DyeOx in Taiwan, using carbon dioxide (CO2) instead of water in the dyeing process, without the need for chemicals. This innovation has helped reduce environmental pollution, as well as lower energy and water consumption compared to the traditional method. (Siraj Tahir, Martin r, & Tristan , 2019, p. 22)

Figure (4): Waterless Dyeing Technology Units.
Source : (Siraj Tahir, Martin r, & Tristan , 2019, p. 22)

4.10-South Africa's Experience:

Due to the large water consumption by Eskom to generate electricity, which provides power to about 95% of users in South Africa, and the scarcity of water, an innovative direct dry cooling technology was implemented to reduce water consumption.

The Matimba Power Station located in the Limpopo province of South Africa is the largest direct dry cooling power station in the world, with an installed capacity of over 4,000 megawatts. The use of closed-loop cooling technology allows for a significant reduction in water consumption. (Siraj Tahir, Martin r, & Tristan , 2019, p. 23) .

4.11-Palestine's Experience:

Gaza is one of the most water-scarce places in the world, relying primarily on groundwater for its water supply. As the population grew, pressures on Gaza and its wastewater treatment plants worsened, especially after around 1.5 million cubic meters of wastewater overflowed from an existing treatment plant into the surrounding sand dunes, eventually forming a 30-hectare lake. The wastewater seeped into the groundwater, exposing residents to waterborne diseases and the risk of sewage floods.

In 2004, the North Gaza Emergency Sewage Treatment Project, supported by the World Bank, addressed these issues by building a plant that increased wastewater treatment capacity. The project then recovered the treated water and reused it to recharge groundwater and irrigate agricultural land, leading to the removal of groundwater pollution and improvements in sanitation services and public health.

However, the operating costs of this solution were extremely high, and the expected financial return was not achieved, partly due to the high cost of

electricity. This ultimately led to the development of a complementary solution, which is now being implemented, using solar panels and biogas to cover the project's electricity needs. (Delgado, Diego , Carlo A, & Midori, 2021, p. 39)

5. Conclusion

The circular water economy represents a fundamental shift in how water resources are managed. It aims to achieve sustainable and efficient water use through recycling and reducing waste, and seeks to leverage modern technologies to maximize the benefits of every drop of water. This type of circular economy helps achieve significant benefits, including the preservation of natural water resources, improvement of water quality, and reduction of costs associated with water treatment and disposal. However, the success of this approach requires effective and practical strategies, the integration of efforts, and raising awareness among various stakeholders, including governments, businesses, and civil society, in order for this economy to overcome various obstacles and challenges. Based on the above, we can arrive at the following recommendations:

- Work on raising cultural awareness regarding the circular water economy.
- Establish a legal framework to encourage and promote the mission of the circular water economy by enacting laws and regulations from various countries around the world.
- Strive to prevent the waste of water resources and use them according to necessity.
- Preserve natural resources, particularly water, for future generations.
- Increase investments in water recycling and support them with government incentives.

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