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Optimizing Raw Water Sustainability through Innovative Supply Chain Management

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Abstract The global water crisis threatens not only the availability of potable water, but also the supply of fresh water for industrial and agricultural use. In order to satisfy the rising demand for water, it is essential that the basic water supply chain be managed sustainably. This study seeks to investigate current practises in the administration of the raw water supply chain and to identify areas where innovation can be implemented to enhance sustainability. The research will consist of a comprehensive literature evaluation followed by qualitative interviews with subject-matter experts. The literature review will investigate the current state of raw water supply chain management, as well as the obstacles and constraints confronted by stakeholders. The interviews will provide valuable insight into the implementation of sustainable raw water supply chain management, including the application of technology and best practises. The findings of this study will be useful for water resource administrators, policymakers, and industries dependent on a constant supply of natural water. The results will also inform the development of innovative solutions to enhance the sustainability of the administration of the natural water supply chain. This study's ultimate objective is to contribute to the global effort to assure a sustainable fresh water supply for future generations.

Keywords: sustainability, raw water, supply chain management

1. Introduction

1.1. Background on water sustainability challenges

More than 40 percent of the world's population is affected by water scarcity, and the demand for freshwater resources is rising due to population growth, urbanisation, and climate change (United Nations, 2020). It is essential to investigate innovative strategies for optimising the sustainability of fresh water, ensuring that this vital resource remains accessible for agriculture, industry, and residential use, among others.

1.2. Importance of raw water supply chain management

The natural water supply chain, which includes water sources, extraction, treatment, distribution, and final use, is crucial to water sustainability (Gude, 2015). (Mukheibir et al., 2018) Effective administration of raw water supply channels can help minimise losses, reduce wastage, and ensure equitable distribution of water resources. In order to optimise the administration of the basic water supply chain and ensure the long-term sustainability of water, it is essential to investigate novel approaches.

1.3. Aim and scope of the review paper

This document seeks to provide a comprehensive overview of the innovations, challenges, and opportunities associated with optimising the sustainability of raw water supply chain innovations. Focusing on urban, agricultural, and industrial water supply chain management, this paper discusses technological advancements, process optimisation, and policy and regulatory innovations. The paper also provides recommendations for future research, policy, and implementation, taking into account the opportunities and challenges associated with scaling up these innovations.

2. Raw Water Supply Chain: An Overview

2.1. Key components of raw water supply chain

Raw water supply chain components include water sources (e.g., rivers, lakes, aquifers), extraction (e.g., wells, intakes, desalination plants), treatment (e.g., filtration, disinfection, softening), distribution (e.g., pipelines, reservoirs, pumping stations), and end-use (e.g., residential, agricultural, industrial) (Gude, 2015). Through inventive supply chain management, each component presents unique challenges and opportunities for optimising the sustainability of natural water.

2.2. Stakeholders involved in raw water management

Government agencies, water utilities, private corporations, research institutions, non-governmental organisations, and end-users are involved in raw water management (Mukheibir et al., 2018). Collaboration among these stakeholders is essential for the development and implementation of innovative solutions to optimise the sustainability of natural water.

2.3. Current challenges and limitations

The natural water supply chain faces numerous obstacles, such as ageing infrastructure, rising demand, the effects of climate change, and competing water uses

(United Nations, 2020). Inadequate investments, lack of technical expertise, and fragmented governance structures also impede the efficient administration of raw water supply chains (Mukheibir et al., 2018). To surmount these obstacles, it is essential to investigate innovative methods for optimising the sustainability of natural water through supply chain management.

3. Innovations in Raw Water Supply Chain Management

3.1. Technological innovations

3.1.1. Remote sensing and surveillance

Bhaduri et al. (2019) report that remote sensing technologies, such as satellite imagery, aerial photography, and ground-based sensors, can provide valuable data on water resources, thereby facilitating the monitoring of water quality, quantity, and availability. These technologies enable timely detection of changes in water resources, facilitating proactive management and decision-making in the management of the raw water supply chain (Khan et al., 2018).

3.1.2. Analytics of big data and artificial intelligence

Big data analytics and artificial intelligence (AI) can improve raw water supply chain management by providing insights into water demand patterns, identifying potential inefficiencies, and predicting the future availability of water resources (Hashmi et al., 2021). In order to optimise water allocation, distribution, and utilisation, machine learning algorithms can process large datasets from various sources, such as remote sensing, water metering, and social media (Khan et al., 2018).

3.1.3. Blockchain innovation

Blockchain technology can enhance raw water supply chain management's transparency, provenance, and accountability by securely recording transactions and information exchanges between stakeholders (Ghosh et al., 2020). Al-Aqaf and Seidler (2017) state that blockchain-based platforms can facilitate efficient water trading, systematise invoicing and payments, and enable real-time monitoring of water resources, thereby contributing to enhanced raw water sustainability.

3.2. Process improvement

3.2.1. Forecasting and allocating demand

Accurate demand forecasting is essential for the efficient administration of the raw water supply chain, allowing for a more equitable distribution of water resources across sectors and regions (Mukheibir et al., 2018). Incorporating variables such as population growth, climate change, and land-use change, advanced forecasting models can help predict future water demand and inform infrastructure planning and investment decisions (Xue et al., 2019).

3.2.2. Infrastructure optimisation

Optimising the infrastructure of the raw water supply chain can reduce losses, decrease energy consumption, and improve system dependability (Gude, 2015). Upgrades to pipelines and pumping stations, adoption of energy-efficient technologies, and implementation of real-time monitoring and control systems are examples of infrastructure optimisation (Mukheibir et al., 2018). In addition, decentralised water supply systems, such as rainwater harvesting and on-site purification, can contribute to enhanced raw water sustainability by decreasing reliance on centralised infrastructure (Keremane et al., 2017).

3.2.3. Recycling and resource conservation

Reducing waste and recovering resources are essential components for optimising the sustainability of natural water. Reuse, recycling, and reclamation of water can aid in reducing freshwater withdrawals and relieving pressure on water resources (Gude, 2015). In addition, extracting valuable resources from effluent, such as nutrients and energy, can generate new revenue streams and improve the overall efficiency of raw water supply chain management (Xue et al., 2019).

3.3. Innovations in policy and regulatory frameworks

3.3.1. Financial instruments

In raw water supply chain management, market-based instruments, such as water pricing, water trading, and pollution permits, can provide incentives for efficient water use and pollution control (Mukheibir et al., 2018). By internalising the environmental and social costs of water use, these instruments can aid in the equitable and sustainable allocation of water resources.

3.3.2. Government-private partnerships

Public-private partnerships (PPPs) can leverage the expertise, innovation, and investment of the private sector to enhance the administration of the natural water supply chain (Mukheibir et al., 2018). PPPs can facilitate technology transfer, capacity development, and risk sharing, thereby enhancing the sustainability of unprocessed water (Marin, 2009).

4. Case Studies: Success Stories and Lessons Learned

4.1. Urban water supply chain administration

The Singaporean water management model exemplifies effective urban water supply chain management by employing a diverse portfolio of water sources, sophisticated treatment technologies, and strong governance structures. Key innovations like NEWater, desalination, and integrated water resource management contribute to long-term water security and sustainability.

4.2. Management of the agricultural water supply chain

Israel's agricultural water management exemplifies novel approaches to maximising the sustainability of fresh water. The nation has pioneered drip irrigation, precision agriculture, and water reuse in agriculture, thereby reducing water consumption substantially while maintaining high agricultural productivity . The National Water Carrier and water pricing policies in Israel have also promoted the efficient allocation and use of water in the agricultural sector.

4.3. Management of the industrial water supply chain
Zero Liquid Discharge (ZLD) is an example of effective industrial water supply chain management in India's textile industry. (Ghosh et al., 2019) ZLD involves recycling and repurposing wastewater, minimising liquid discharge, and reclaiming valuable byproducts. To conform with stringent environmental regulations and reduce freshwater consumption, the Indian textile industry has adopted ZLD technologies such as reverse osmosis and evaporators.

5. Measuring the Impact of Innovative Supply Chain Management on Raw Water Sustainability

5.1. Key performance measures
Key performance indicators (KPIs) can assist in measuring the effect of innovative supply chain management on the sustainability of natural water. Water use efficiency, non-revenue water, water quality, and environmental performance are examples of KPIs (Gude, 2015). These key performance indicators can provide valuable insights into the efficacy of various innovations and inform decision-making and resource allocation in the management of the raw water supply chain.

5.2. Quantitative and qualitative evaluation techniques
Methods of quantitative assessment, such as cost-benefit analysis, water footprint analysis, and life cycle assessment, can be used to evaluate the economic, environmental, and social impacts of innovative supply chain management on the sustainability of unprocessed water (Hoekstra et al., 2011; ISO, 2014). Qualitative assessment methods, such as stakeholder interviews, case studies, and participatory approaches, can shed light on the challenges, opportunities, and lessons learned from implementing innovations in various contexts (Mukheibir et al., 2018).

5.3. Long-term evaluation and monitoring
In order to assess the sustainability and scalability of innovative raw water supply chain management solutions, long-term monitoring and evaluation are required. Continuous monitoring enables adaptive management and learning by identifying emerging trends, potential risks, and unintended consequences (Mukheibir et al., 2018). (United Nations, 2015) Evaluation frameworks, such as the Sustainable Development Goals (SDGs), can provide an exhaustive set of indicators for assessing the progress of innovations towards attaining the sustainability of natural water.

6. Challenges and Opportunities in Scaling up Innovations

6.1. Financial and economic considerations
Significant financial and economic investments are required to scale up innovative raw water supply chain management solutions, including infrastructure, technology, capacity building, and research and development (Mukheibir et al., 2018). Innovative financial instruments, such as green bonds, have an
Investing and integrated finance can help mobilise capital from the private sector and leverage public funds for the sustainability of unprocessed water (OECD, 2017). In addition, cost recovery through water pricing and resource recovery can improve the financial viability of these innovations.

6.2. Social and cultural factors
The adoption and success of innovative raw water supply chain management solutions can be affected by social and cultural factors such as public acceptance, trust, and awareness (Mukheibir et al., 2018). Jenkins et al. (2017) state that engaging communities, promoting education and awareness, and resolving equity and affordability concerns are crucial for fostering social acceptance and assuring the long-term success of these innovations.

6.3. Political and institutional stumbling blocks
Political and institutional obstacles, including fragmented governance, regulatory uncertainty, and lack of political will, can impede the implementation and scaling up of innovative raw water supply chain management solutions (Mukheibir et al., 2018). Bhaduri et al. (2019) state that strengthening governance structures, harmonising regulations, and nurturing political commitment are crucial for overcoming these obstacles and promoting the sustainability of unfiltered water.

6.4. There are technological and infrastructure limitations.
Innovative raw water supply chain management solutions may be limited in their effectiveness and scalability by technological and infrastructural constraints, such as the availability of suitable technologies, access to dependable data, and compatibility with existing infrastructure (Gude, 2015). To address these limitations, ongoing research and development, technology transfer, and investments in infrastructure modernization and upkeep are required (Mukheibir et al., 2018).

7. Future Recommendations for Research and Policy

7.1. Vacancies in research and emerging technologies
Future research should concentrate on addressing knowledge deficits and investigating emerging technologies for the administration of the fresh water supply chain. Integrated modelling and decision support systems, sensor networks and the Internet of Things, and nature-based water resource management solutions are key areas of interest (Bhaduri et al., 2019). Moreover, interdisciplinary research that bridges the divide between water management, energy, and agricultural systems can contribute to a more comprehensive comprehension of the sustainability of natural water (Bizikova et al., 2013).

7.2. Best practises for successful implementation
The identification and dissemination of best practises for the successful implementation of innovative raw water supply chain management solutions can facilitate learning and replication across diverse contexts (Mukhebir et al., 2018). Case studies and lessons learned from different sectors and regions can provide valuable insights into the factors that contribute to the success of these innovations, such as enabling policies, stakeholder

engagement, capacity development, and adaptive management (Gude, 2015).

7.3. Recommendations for innovation promotion

Among the policy recommendations for promoting innovation in the administration of the natural water supply chain are:

- (Bhaduri et al., 2019) Establishing a policy and regulatory environment that encourages innovation, risk-taking, and collaboration.
- Providing targeted financial incentives and funding mechanisms to support innovative solution research, development, and deployment (OECD, 2017).
- Strengthening institutional capacity and fostering partnerships among public, private, and non-governmental actors in order to facilitate technology transfer, knowledge exchange, and capacity building (Mukheibir et al., 2018).
- (Bizikova et al., 2013) Integrating raw water supply chain management considerations into broader water, energy, and food policies to promote cross-sectoral collaboration and synergies.

8. Conclusion

8.1. Summary of significant results

This exhaustive review has examined the innovations, challenges, and opportunities for optimising the sustainability of raw water supply chain innovation. The discussion focused on technological advancements, process optimisation, and policy and regulatory innovations, emphasising pertinent case studies from urban, suburban, and rural environments.

Management of agricultural and industrial water supply chains. In addition, the paper identified key performance indicators, assessment methodologies, and long-term monitoring and evaluation strategies for measuring the impact of these innovations on the sustainability of unprocessed water.

8.2. Consequences for practise and policy

The findings of this review have several implications for raw water supply chain management practise and policy. To increase efficiency, reduce waste, and ensure equitable distribution of water resources, practitioners should consider employing innovative technologies and process optimisation strategies. Policymakers should cultivate an environment that encourages raw water sustainability innovation, collaboration, and investment. This can be accomplished through supportive policies, targeted financial incentives, and partnerships between public, private, and non-governmental entities.

8.3. Future themes in scholarship

Future research should concentrate on filling in knowledge voids, investigating emerging technologies, and identifying best practises for the successful implementation of innovative raw water supply chain management solutions. Research that bridges the divide between water management, energy, and agricultural systems can contribute to a more comprehensive understanding of the sustainability of natural water. In addition, long-term monitoring and evaluation of these innovations are necessary for determining their sustainability and scalability, which informs adaptive management and learning.

In conclusion, optimising raw water sustainability through innovative supply chain management is essential for addressing the global water crisis and ensuring that this vital resource remains accessible to multiple sectors, including agriculture, industry, and households. It is possible to surmount current challenges and pave the way for a more sustainable and resilient future by embracing technological advancements, process optimisation, and policy and regulatory innovations.

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