International Journal of Science and Research Archive
eISSN: 2582-8185
Cross Ref DOI: 10.30574/ijsra
Journal homepage: https://ijsra.net/

(REVIEW ARTICLE)

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A review of advanced wastewater treatment technologies: USA vs. Africa

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International Journal of Science and Research Archive, 2024, 11(01), 333–340

Publication history: Received on 06 December 2023; revised on 13 January 2024; accepted on 16 January 2024

Article DOI: https://doi.org/10.30574/ijsra.2024.11.1.0071

Abstract

This research paper conducts a comprehensive comparative analysis of advanced wastewater treatment technologies in the USA and Africa, emphasizing infrastructure, regulatory frameworks, and socio-economic factors. The USA exhibits robust infrastructure, supportive regulations, and technological awareness, fostering the adoption of advanced solutions. In contrast, Africa faces limited resources and diverse regulatory landscapes. Affordability, accessibility, public awareness, and education are critical socio-economic factors influencing technology adoption. Prospects include innovations like AI integration and circular economy principles. Policy recommendations stress adaptive frameworks and international collaborations. The conclusion underscores the importance of inclusive strategies for global sustainable wastewater management, recognizing each region's unique socio-economic diversity. This research contributes valuable insights for policymakers, researchers, and practitioners working towards resilient and equitable wastewater treatment systems.

Keywords: Wastewater Treatment; Advanced Technologies; Socio-economic Factors; Sustainable Management

1. Introduction

Wastewater treatment stands at the nexus of environmental sustainability and public health, which is pivotal in ensuring the responsible management of water resources. As the global population continues to burgeon and urbanization accelerates, the demand for effective wastewater treatment technologies becomes increasingly imperative (Kjellén, 2018; Obaideen et al., 2022; Silva, 2023). In this context, exploring and evaluating advanced wastewater treatment technologies take center stage, heralding a new era in the quest for comprehensive and sustainable solutions.

This research paper critically examines advanced wastewater treatment technologies, comparing the landscape in the United States of America (USA) with that of various nations across the African continent. The choice of this comparative analysis is motivated by the contrasting socio-economic, infrastructural, and regulatory contexts between these two regions. By juxtaposing the advancements and challenges encountered in the USA against those in Africa, we aim to derive insights that can inform policy, investment, and technological strategies for the sustainable management of wastewater on a global scale.

Wastewater treatment has evolved significantly from traditional methods to embrace a spectrum of advanced technologies (Rizzo et al., 2019). While the USA has been at the forefront of adopting and implementing these

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innovations, African nations face unique challenges in deploying such technologies due to varying levels of infrastructure, financial constraints, and regulatory frameworks. The ensuing exploration seeks to unravel the intricate interplay of factors influencing the adoption and efficacy of advanced wastewater treatment technologies in these divergent contexts (Lwoga, 2012; Tan & Taeihagh, 2020; Wilderer et al., 2002). This research endeavors to contribute to the existing knowledge of wastewater treatment by offering a comparative analysis that goes beyond technological considerations. By delving into the infrastructural, regulatory, and socio-economic dimensions, we aim to comprehensively understand the challenges and opportunities different regions face in advancing their wastewater treatment capabilities.

2. Literature Review

Wastewater treatment has historically relied on conventional methods to mitigate the environmental impact of effluents. Primary treatment involves the physical removal of solids through processes like sedimentation, followed by secondary treatment, where microorganisms break down organic matter. Tertiary treatment, the final step, targets the remaining contaminants. Despite their effectiveness, conventional methods may fail to address emerging pollutants and increase water scarcity.

The imperative to improve treatment efficacy has driven the evolution of advanced wastewater treatment technologies. Advances encompass diverse techniques, from physical processes to biological and chemical methods. These innovations enhance pollutant removal, minimize energy consumption, and optimize resource recovery. The continuous refinement of these technologies represents a pivotal shift towards sustainable wastewater management.

2.1. Advanced Wastewater Treatment Technologies

2.1.1. Membrane Bioreactors (MBRs)

MBRs integrate membrane filtration with biological treatment, enhancing solids removal and producing high-quality effluents. The technology has gained prominence globally due to its compact design, reduced footprint, and superior treatment efficiency. However, challenges such as membrane fouling and high operational costs persist, necessitating ongoing research and development .

2.1.2. Advanced Oxidation Processes (AOPs):

AOPs involve the generation of highly reactive hydroxyl radicals to break down persistent pollutants. This technology addresses recalcitrant compounds not effectively treated by conventional methods. While AOPs exhibit promise, their widespread adoption is hindered by energy-intensive processes and the need for careful optimization to prevent the formation of harmful by-products (Deng & Zhao, 2015; Khan et al., 2023).

2.1.3. Constructed Wetlands

Constructed wetlands emulate natural ecosystems to treat wastewater. They promote biological, physical, and chemical processes, enhancing pollutant removal. Cost-effectiveness and adaptability make constructed wetlands appealing, particularly in decentralized settings. However, their performance can be influenced by climate, vegetation, and hydraulic conditions (Donoso Pantoja, 2018; Qasaimeh, AlSharie, & Masoud, 2015).

2.1.4. Other Emerging Technologies

Many emerging technologies, such as electrochemical treatment, algae-based systems, and nanotechnology applications, are being explored for wastewater treatment. These innovations address specific challenges, offering potential breakthroughs in efficiency, resource recovery, and environmental sustainability. However, their scalability and long-term performance require further investigation (Agarwal, Gupta, & Agarwal, 2019; Gondi et al., 2022).

The USA has witnessed a notable uptick in adopting advanced wastewater treatment technologies. Municipalities and industries increasingly deploy membrane technologies, AOPs, and innovative nutrient removal systems. The shift towards water reuse and resource recovery reflects a growing emphasis on sustainability and resilience in changing environmental dynamics. Several factors shape the adoption of advanced technologies in the USA, including regulatory frameworks, funding mechanisms, technological awareness, and the willingness of stakeholders to embrace innovative solutions. Government initiatives and incentives are pivotal in fostering a conducive environment for integrating advanced wastewater treatment technologies (Compagnucci & Spigarelli, 2018; Reymond, Wahaab, Moussa, & Lüthi, 2018).

The wastewater treatment landscape in Africa exhibits significant diversity, ranging from rudimentary systems to more advanced facilities in urban centers (Gandy, 2014). Challenges such as limited infrastructure, insufficient funding, and inadequate institutional frameworks pose hurdles to the widespread adoption of advanced technologies. The coexistence of traditional and modern treatment methods reflects the complex socio-economic and environmental context.

Africa faces a unique set of challenges in upgrading its wastewater treatment infrastructure (Adewumi, Ilemobade, & Van Zyl, 2010). Limited financial resources, technical capacity, and fragmented regulatory frameworks impede progress. However, opportunities lie in decentralized, nature-based solutions that align with the continent's ecological diversity. Strategic investments, capacity-building initiatives, and international collaborations present avenues for overcoming challenges and advancing sustainable wastewater management practices (Abaza et al.; Franco & Tracey, 2019).

3. Comparative Analysis

3.1. Infrastructure and Investment

The United States boasts a well-established wastewater infrastructure, with centralized treatment plants prevalent across urban and industrial areas. Investment in advanced technologies, such as membrane bioreactors and advanced oxidation processes, is driven by federal and state-level funding, private-sector initiatives, and research institutions. The robust infrastructure allows for the integration of cutting-edge solutions, and a culture of innovation fosters continuous improvement.

In contrast, many African nations grapple with inadequate wastewater infrastructure, particularly in rural and peri-urban areas. Limited financial resources hinder large-scale investments in advanced technologies. However, opportunities emerge in decentralized approaches and nature-based solutions tailored to local conditions. International partnerships, capacity-building programs, and targeted investments present avenues for overcoming infrastructure challenges and unlocking the potential for sustainable wastewater treatment (Sharma et al., 2023).

3.2. Regulatory Framework

The USA benefits from a comprehensive regulatory framework that encourages the adoption of advanced wastewater treatment technologies. Federal laws like the Clean Water Act set water quality standards, while state-level regulations provide additional guidance. Incentives for innovation and stringent discharge standards drive the integration of advanced technologies. Collaboration between regulatory bodies and industry stakeholders ensures a balanced approach to environmental protection (Harrison, 2017; Marquis, Zhang, & Zhou, 2011).

In Africa, regulatory frameworks vary widely, and enforcing existing regulations is often challenging. Limited capacity and resources contribute to a lack of consistency in wastewater management practices. Strengthening regulatory institutions, harmonizing standards, and promoting cross-border cooperation are essential steps to create an environment that enables the adoption of advanced technologies in wastewater treatment across the continent (Fritzon, Ljungkvist, Boin, & Rhinard, 2007; Kanakoudis et al., 2017; Stern & Holder, 1999).

3.3. Environmental Impact

Advanced wastewater treatment technologies in the USA substantially reduce pollutant discharge and improve water quality. Effluent reuse and resource recovery further underscore the environmental benefits. Life cycle assessments and environmental impact studies ensure that adopting advanced technologies aligns with sustainability goals and minimizes adverse ecological effects (Ziegler et al., 2016).

In Africa, the environmental impact of wastewater treatment technologies is nuanced by the continent's ecological diversity. Nature-based solutions, such as constructed wetlands, offer potential benefits with minimal environmental disruption. However, carefully considering local ecosystems and climate variability and preventing unintended consequences is paramount. Balancing the need for effective treatment with environmental conservation is a crucial challenge in the African context (Hellweg, Benetto, Huijbregts, Verones, & Wood, 2023; Ziegler et al., 2016).

4. Socio-Economic Factors

4.1. Affordability and Accessibility

In the United States, the cost implications for municipalities and industries influence the adoption of advanced wastewater treatment technologies. While these technologies may involve higher initial capital investments, they often offer long-term economic benefits. The reduction in environmental impact, potential for resource recovery, and improved overall efficiency contribute to the economic viability of advanced systems. However, ensuring affordability remains a consideration, especially for smaller municipalities and economically disadvantaged areas (Ekins et al., 2016; Liang et al., 2022).

Affordability is a significant challenge in many African nations, where limited financial resources and competing socio-economic priorities often impede the adoption of advanced wastewater treatment technologies. The high upfront costs and ongoing operational and maintenance expenses pose barriers to implementation. Accessibility is another critical aspect, particularly in rural and underserved areas where basic sanitation infrastructure is often lacking. Developing inclusive and context-specific financing models and strategies is essential to address affordability and accessibility issues (Amaefule et al., 2023; Onu, Ayeleru, Oboirien, & Olubambi, 2023).

4.2. Public Awareness and Education

Public awareness and education play a crucial role in shaping attitudes towards wastewater treatment in the USA. Educational programs, outreach initiatives, and media campaigns contribute to an informed and engaged public. Environmental education in schools, community workshops, and online platforms foster a culture of responsible water use and wastewater management. The active involvement of the public influences policy decisions and supports sustainable practices (Robinson, Robinson, Raup, & Markum, 2012; White, 2013).

In contrast, many African regions face disparities in education and awareness levels regarding wastewater management. Tailored strategies are required to enhance awareness, considering diverse cultural and linguistic contexts. Community engagement through local leaders, traditional communication channels, and collaboration with non-governmental organizations (NGOs) can be instrumental. International partnerships can facilitate knowledge transfer and capacity-building initiatives, empowering communities to participate actively in sustainable wastewater management practices (Islam, 2014; Wang, Cao, Yuan, & Zhang, 2020).

4.3. Challenges and Opportunities

Both the USA and Africa encounter challenges related to socio-economic factors in the adoption of advanced wastewater treatment technologies. Limited financial resources, competing priorities, and the need for infrastructure development are common hurdles. Addressing socio-economic disparities, ensuring equitable access, and overcoming resistance to change are shared challenges.

Innovation in socio-economic aspects presents opportunities for advancing wastewater management. In the USA, opportunities lie in developing financing models that encourage private-sector involvement, create incentives for sustainable practices, and address affordability concerns for marginalized communities. In Africa, embracing decentralized and nature-based solutions aligned with local socio-economic conditions can unlock opportunities for sustainable and inclusive wastewater management practices (Sayers & Smith, 2018; Thorn et al., 2021).

5. Future Prospects and Recommendations

5.1. Innovations and Emerging Technologies

A dynamic landscape of innovations and emerging technologies marks the future of wastewater treatment. Advanced wastewater treatment methods will likely see further integration with digital technologies, including artificial intelligence and machine learning, enhancing process efficiency and real-time monitoring. Decentralized treatment systems, smart sensor networks, and using renewable energy sources are expected to become more prevalent, aligning with global sustainability goals (Mondejar et al., 2021; Onyinyechukwu, 2023).

Future prospects in the USA and Africa include exploring innovations that address specific challenges. Modular and scalable treatment systems could provide flexible solutions for diverse urban and rural contexts. Additionally, the integration of circular economy principles may unlock opportunities for resource recovery, transforming wastewater

into valuable products such as energy, nutrients, and clean water (Naidoo et al., 2021; Van Fan, Lee, Lim, Klemeš, & Le, 2019).

5.2. Policy Recommendations

In the USA, policy changes should focus on strengthening incentives for collaboration between government bodies, private sectors, and research institutions. Continuous support for research and development initiatives, including pilot projects and technology demonstrations, is crucial for successfully integrating emerging technologies. Policy frameworks should also be adaptive, accommodating advancements and addressing potential challenges associated with new treatment methods (Sahoo & Goswami, 2023).

For Africa, recommendations include developing and enforcing robust regulatory frameworks that encourage the adoption of advanced wastewater treatment technologies. International collaborations and partnerships with developed nations can facilitate technology transfer, providing access to expertise and funding. Governments should explore innovative financing models, such as public-private partnerships, to overcome financial constraints and promote sustainable wastewater management practices (Koppenjan & Enserink, 2009; Onukogu et al., 2023).

5.3. Environmental Sustainability

Future prospects hinge on the integration of environmentally sustainable practices in wastewater treatment. Both regions should prioritize technologies that minimize energy consumption, reduce carbon footprints, and maximize resource recovery. Nature-based solutions, such as constructed wetlands and eco-friendly treatment processes, should be explored to harmonize wastewater treatment with local ecosystems (Biswas et al., 2022).

Considering the increasing impacts of climate change, wastewater treatment strategies need to be resilient and adaptable. Infrastructure planning should incorporate climate-resilient designs to withstand extreme weather events. Policies should address the potential challenges of climate change, ensuring that wastewater treatment systems remain effective and reliable under changing environmental conditions (Hanjra, Blackwell, Carr, Zhang, & Jackson, 2012).

5.4. Inclusive Strategies for Affordability

Future strategies should include the development of financial mechanisms that cater to the economic diversity within communities. Governments, NGOs, and international agencies should collaborate to create innovative financing models, such as micro-financing and community-based funding, to ensure that advanced wastewater treatment technologies are affordable and accessible to all population segments.

Encouraging public-private partnerships can stimulate investment in wastewater treatment infrastructure. In both the USA and Africa, fostering collaborations between governmental bodies and private enterprises can enhance efficiency, bring in additional funding, and promote the adoption of advanced technologies. Governments should provide incentives and regulatory frameworks to encourage private sector participation in wastewater treatment projects (Baumert & Bloodgood, 2004).

5.5. Capacity Building and Knowledge Transfer

Capacity-building initiatives should be prioritized, particularly in regions with limited technical expertise. Governments and international organizations can invest in training programs, workshops, and knowledge transfer initiatives to empower local communities with the skills to operate and maintain advanced wastewater treatment technologies effectively. International collaboration is crucial for knowledge exchange. Establishing partnerships between research institutions, universities, and industry players in the USA and Africa can facilitate the transfer of technology, research findings, and best practices. Collaborative projects should emphasize sustainability, inclusivity, and the mutual benefit of shared knowledge.

6. Conclusion

In conclusion, the comparative analysis of advanced wastewater treatment technologies in the USA and Africa underscores the dynamic interplay of diverse factors influencing the trajectory of sustainable wastewater management. Examining infrastructure, regulatory frameworks, socio-economic factors, and future prospects has provided insights into both regions' challenges, opportunities, and potential pathways.

The USA, with its robust infrastructure, supportive regulatory environment, and advanced technological awareness, stands at the forefront of adopting innovative wastewater treatment solutions. The integration of advanced

technologies, coupled with a commitment to sustainability, reflects a proactive approach towards addressing environmental concerns. In contrast, Africa faces unique challenges, including limited financial resources, diverse regulatory landscapes, and varying levels of technological awareness. However, amidst these challenges lie opportunities for nature-based solutions, decentralized approaches, and collaborative international initiatives that can harness the continent's ecological diversity.

The socio-economic factors, such as affordability, accessibility, public awareness, and education, emerge as pivotal determinants influencing the successful adoption of advanced technologies. While the USA is more advanced in these aspects, Africa's socio-economic diversity necessitates inclusive strategies and tailored approaches to ensure equitable access to sustainable wastewater treatment. Looking to the future, innovations, policy changes, and sustainable practices hold the key to advancing wastewater treatment globally. The recommendations outlined, spanning inclusive financing models, public-private partnerships, climate-resilient designs, and capacity-building initiatives, provide a roadmap for both regions to navigate the evolving landscape of wastewater management.

As we aspire towards a more sustainable and resilient future characterized by inclusive access to clean water, minimized environmental impact, and resource recovery, collaboration between nations, regions, and stakeholders becomes paramount. The comparative analysis serves as a foundation for ongoing research, policy development, and international cooperation, fostering a shared commitment to sustainable wastewater management on a global scale. Through collective efforts, the vision of a future where wastewater is treated and viewed as a valuable resource can be realized, ensuring a harmonious balance between environmental preservation and human development.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Abaza, H., Bankobeza, S., Bendahou, N., Buyse-Kalneiva, A., Claasen, D., Ingraham, B., . . . Zucca, C. Capacity Building for Sustainable Development: An overview of UNEP environmental capacity development initiatives.

[2] Adewumi, J., Ilemobade, A., & Van Zyl, J. (2010). Treated wastewater reuse in South Africa: Overview, potential and challenges. *Resources, Conservation and Recycling, 55*(2), 221-231.

[3] Agarwal, P., Gupta, R., & Agarwal, N. (2019). Advances in synthesis and applications of microalgal nanoparticles for wastewater treatment. *Journal of Nanotechnology, 2019*.

[4] Amaefule, E. O., Amarachi, A. S., Abuka, C. O., Nwaogazie, F. O., Nwabuko, C. N., & Divine, C. C. (2023). Water and Wastewater Treatment in Nigeria: Advancements, Challenges, Climate Change and Socioeconomic Impacts. *Path of Science, 9*(8), 2010-2031.

[5] Baumert, J., & Bloodgood, L. (2004). *Private sector participation in the water and wastewater services industry*. Retrieved from

[6] Biswas, J. K., Mondal, M., Kumar, V., Bhatnagar, A., Biswas, S., & Vithanage, M. (2022). Nature-inspired ecotechnological approaches toward recycling and recovery of resources from wastewater. In *Integrated Environmental Technologies for Wastewater Treatment and Sustainable Development* (pp. 101-145): Elsevier.

[7] Compagnucci, L., & Spigarelli, F. (2018). Fostering cross-sector collaboration to promote innovation in the water sector. *Sustainability, 10*(11), 4154.

[8] Deng, Y., & Zhao, R. (2015). Advanced oxidation processes (AOPs) in wastewater treatment. *Current Pollution Reports, 1*, 167-176.

[9] Donoso Pantoja, N. C. (2018). *Environmental assessment of constructed wetlands for agricultural wastewater treatment.* Ghent University,

[10] Ekins, P., Hughes, N., Brigenzu, S., Arden Clark, C., Fischer-Kowalski, M., Graedel, T., . . . Havlik, P. (2016). Resource efficiency: Potential and economic implications.

[11] Franco, I. B., & Tracey, J. (2019). Community capacity-building for sustainable development: Effectively striving towards achieving local community sustainability targets. *International Journal of Sustainability in Higher Education, 20*(4), 691-725.

[12] Fritzon, Å., Ljungkvist, K., Boin, A., & Rhinard, M. (2007). Protecting Europe's critical infrastructures: problems and prospects. *Journal of Contingencies and Crisis Management, 15*(1), 30-41.

[13] Gandy, M. (2014). *The fabric of space: Water, modernity, and the urban imagination*: MIT Press.

[14] Gondi, R., Kavitha, S., Kannah, R. Y., Karthikeyan, O. P., Kumar, G., Tyagi, V. K., & Banu, J. R. (2022). Algal-based system for removal of emerging pollutants from wastewater: A review. *Bioresource technology, 344*, 126245.

[15] Hanjra, M. A., Blackwell, J., Carr, G., Zhang, F., & Jackson, T. M. (2012). Wastewater irrigation and environmental health: Implications for water governance and public policy. *International journal of hygiene and environmental health, 215*(3), 255-269.

[16] Harrison, K. (2017). Talking with the donkey: Cooperative approaches to environmental protection. In *International Environmental Governance* (pp. 317-338): Routledge.

[17] Hellweg, S., Benetto, E., Huijbregts, M. A., Verones, F., & Wood, R. (2023). Life-cycle assessment to guide solutions for the triple planetary crisis. *Nature Reviews Earth & Environment, 4*(7), 471-486.

[18] Islam, M. R. (2014). Non-governmental organizations' role for social capital and community empowerment in community development: experience from Bangladesh. *Asian Social Work and Policy Review, 8*(3), 261-274.

[19] Kanakoudis, V., Papadopoulou, A., Tsitsifli, S., Curk, B. C., Karleusa, B., Matic, B., . . . Banovec, P. (2017). Policy recommendation for drinking water supply cross-border networking in the Adriatic region. *Journal of Water Supply: Research and Technology—AQUA, 66*(7), 489-508.

[20] Khan, Z. U. H., Gul, N. S., Sabahat, S., Sun, J., Tahir, K., Shah, N. S., . . . Iqbal, J. (2023). Removal of organic pollutants through hydroxyl radical-based advanced oxidation processes. *Ecotoxicology and Environmental Safety, 267*, 115564.

[21] Kjellén, M. (2018). Wastewater Governance and the Local, Regional and Global Environments. *Water Alternatives, 11*(2).

[22] Koppenjan, J. F., & Enserink, B. (2009). Public–private partnerships in urban infrastructures: Reconciling private sector participation and sustainability. *Public Administration Review, 69*(2), 284-296.

[23] Liang, X., Kurniawan, T. A., Goh, H. H., Zhang, D., Dai, W., Liu, H., . . . Othman, M. H. D. (2022). Conversion of landfilled waste-to-electricity (WTE) for energy efficiency improvement in Shenzhen (China): A strategy to contribute to resource recovery of unused methane for generating renewable energy on-site. *Journal of Cleaner Production, 369*, 133078.

[24] Lwoga, E. (2012). Making learning and Web 2.0 technologies work for higher learning institutions in Africa. *Campus-Wide Information Systems, 29*(2), 90-107.

[25] Marquis, C., Zhang, J., & Zhou, Y. (2011). Regulatory uncertainty and corporate responses to environmental protection in China. *California Management Review, 54*(1), 39-63.

[26] Mondejar, M. E., Avtar, R., Diaz, H. L. B., Dubey, R. K., Esteban, J., Gómez-Morales, A., . . . Prasad, K. A. (2021). Digitalization to achieve sustainable development goals: Steps towards a Smart Green Planet. *Science of the Total Environment, 794*, 148539.

[27] Naidoo, D., Nhamo, L., Lottering, S., Mpandeli, S., Liphadzi, S., Modi, A. T., . . . Mabhaudhi, T. (2021). Transitional pathways towards achieving a circular economy in the water, energy, and food sectors. *Sustainability, 13*(17), 9978.

[28] Obaideen, K., Shehata, N., Sayed, E. T., Abdelkareem, M. A., Mahmoud, M. S., & Olabi, A. (2022). The role of wastewater treatment in achieving sustainable development goals (SDGs) and sustainability guideline. *Energy Nexus, 7*, 100112.

[29] Onu, M. A., Ayeleru, O. O., Oboirien, B., & Olubambi, P. A. (2023). Challenges of wastewater generation and management in sub-Saharan Africa: A Review. *Environmental Challenges*, 100686.

[30] Onukogu, O. A., Onyebuchi, C. N., Scott, T. O., Babawarun, T., Neye-Akogo, C., Olagunju, O. A., & Uzougbo, C. G. (2023). Impacts of Industrial Wastewater Effluent on Ekerekana Creek and Policy Recommendations for Mitigation. *The Journal of Engineering and Exact Sciences, 9*(4), 15890-15801e.

[31] Onyinyechukwu, C. (2023). *Design, analysis and remote monitoring of a solar powered orphan oil well pumping system in Nigeria.* Memorial University of Newfoundland,

[32] Qasaimeh, A., AlSharie, H., & Masoud, T. (2015). A review on constructed wetlands components and heavy metal removal from wastewater. *Journal of Environmental Protection, 6*(07), 710.

[33] Reymond, P., Wahaab, R. A., Moussa, M. S., & Lüthi, C. (2018). Scaling up small scale wastewater treatment systems in low-and middle-income countries: An analysis of challenges and ways forward through the case of Egypt. *Utilities Policy, 52*, 13-21.

[34] Rizzo, L., Malato, S., Antakyali, D., Beretsou, V. G., Đolić, M. B., Gernjak, W., . . . Ribeiro, A. R. L. (2019). Consolidated vs new advanced treatment methods for the removal of contaminants of emerging concern from urban wastewater. *Science of the Total Environment, 655*, 986-1008.

[35] Robinson, K. G., Robinson, C. H., Raup, L. A., & Markum, T. R. (2012). Public attitudes and risk perception toward land application of biosolids within the south-eastern United States. *Journal of environmental management, 98*, 29-36.

[36] Sahoo, S. K., & Goswami, S. S. (2023). A comprehensive review of multiple criteria decision-making (MCDM) Methods: advancements, applications, and future directions. *Decision Making Advances, 1*(1), 25-48.

[37] Sayers, P., & Smith, A. (2018). Can Africa take the lead on Sustainable Water Infrastructure?

[38] Sharma, B. M., Scheringer, M., Chakraborty, P., Bharat, G. K., Steindal, E. H., Trasande, L., & Nizzetto, L. (2023). Unlocking India's potential in managing endocrine-disrupting chemicals (EDCs): importance, challenges, and opportunities. *Exposure and Health, 15*(4), 841-855.

[39] Silva, J. A. (2023). Wastewater treatment and reuse for sustainable water resources management: a systematic literature review. *Sustainability, 15*(14), 10940.

[40] Stern, J., & Holder, S. (1999). Regulatory governance: criteria for assessing the performance of regulatory systems: An application to infrastructure industries in the developing countries of Asia. *Utilities Policy, 8*(1), 33-50.

[41] Tan, S. Y., & Taeihagh, A. (2020). Smart city governance in developing countries: A systematic literature review. *Sustainability, 12*(3), 899.

[42] Thorn, J. P., Aleu, R. B., Wijesinghe, A., Mdongwe, M., Marchant, R., & Shackleton, S. (2021). Mainstreaming nature-based solutions for climate resilient infrastructure in peri-urban sub-Saharan Africa. *Landscape and urban planning, 216*, 104235.

[43] Van Fan, Y., Lee, C. T., Lim, J. S., Klemeš, J. J., & Le, P. T. K. (2019). Cross-disciplinary approaches towards smart, resilient and sustainable circular economy. *Journal of Cleaner Production, 232*, 1482-1491.

[44] Wang, Y., Cao, H., Yuan, Y., & Zhang, R. (2020). Empowerment through emotional connection and capacity building: Public participation through environmental non-governmental organizations. *Environmental Impact Assessment Review, 80*, 106319.

[45] White, G. F. (2013). Formation and role of public attitudes. In *Environmental quality in a growing economy* (pp. 105-127): RFF Press.

[46] Wilderer, P. A., Bungartz, H.-J., Lemmer, H., Wagner, M., Keller, J., & Wuertz, S. (2002). Modern scientific methods and their potential in wastewater science and technology. *Water Research, 36*(2), 370-393.

[47] Ziegler, F., Hornborg, S., Green, B. S., Eigaard, O. R., Farmery, A. K., Hammar, L., . . . Skontorp Hognes, E. (2016). Expanding the concept of sustainable seafood using Life Cycle Assessment. *Fish and Fisheries, 17*(4), 1073-1093