The Role of Biochar in Sustainable Wastewater Management in Kenya: Current Practices, Challenges, and Future Prospects

James Kamau Mbugua[1], Mary Nyambura Mbugua[2], Lucy Mumbua Mbugua[2], Gabriel Waswa Andati[3]

[1]Limuru Municipality, Kiambu County P.O. BOX 2344-00900, Kiambu, Kenya

[2]Department Water and Wastewater Engineering, Kenya Water Institute, P.O Box 60013-00200, Nairobi, Kenya

[3]Department of Physical Science, South Eastern Kenya University, P.O. Box 170-90200 Kitui, Kenya

Abstract

Kenya faces growing challenges in managing wastewater due to rapid urbanization, population growth, and limited investment in treatment infrastructure. Conventional wastewater treatment systems are often costly, centralized, and inadequately enforced, leaving many communities-particularly in rural and peri-urban areas-without safe and sustainable sanitation solutions. Biochar, a porous, carbon-rich byproduct of biomass pyrolysis, has gained attention globally for its capacity to enhance wastewater treatment through mechanisms such as heavy metal adsorption, nutrient capture, and organic pollutant removal. This paper critically reviews the role of biochar in sustainable wastewater management in Kenya, beginning with a discussion of biochar's physicochemical properties and production methods, particularly from locally available agricultural feedstocks like maize cobs and sugarcane bagasse. The paper outlines the current landscape of wastewater management in Kenya, highlighting gaps in regulatory enforcement, insufficient treatment capacity, and the pressing need for decentralized, low-cost alternatives. Existing research and pilot projects in Kenya demonstrate the potential of biochar when integrated into systems like constructed wetlands and biofiltration units, with promising treatment efficiencies. However, broader adoption is hindered by several challenges, including variability in biochar quality, limited local production infrastructure, high production costs, lack of supportive policies, and low public and institutional awareness. Looking forward, the paper identifies opportunities to scale up biochar-based treatment through increased research, community-based innovations, policy integration, and multi-stakeholder partnerships. It emphasizes the alignment of biochar solutions with circular economy principles and their contribution to climate resilience and Sustainable Development Goal 6: Clean Water and Sanitation.The review concludes that biochar represents a practical and scalable approach to enhancing wastewater treatment in Kenya. With targeted investment, supportive policy frameworks, and enhanced awareness, biochar can play a significant role in transforming the country's sanitation landscape.

Keywords

Adsorption, Biochar, Filtration, Sustainability, Wastewater

1. Introduction

1.1 Background on Wastewater Challenges Globally and in Kenya

Globally, wastewater management remains a pressing environmental and public health concern. An estimated 80% of all wastewater is discharged into the environment without adequate treatment, leading to significant ecological degradation and health risks [1]. In developing countries, this figure is even more alarming, with only about 4.2% of wastewater receiving proper treatment [1].

In Kenya, the situation mirrors global trends, with rapid urbanization and population growth outpacing the development of wastewater infrastructure. Only about 19% of the population is connected to sewer systems, and of the wastewater collected, a mere 60% reaches treatment facilities according to Water Services Regulatory Board [WASREB], 2022. The majority of treatment plants operate below capacity, and untreated or partially treated effluents are often discharged into natural water bodies, posing severe environmental and health hazards [2].

1.2 Importance of Sustainable Wastewater Treatment Methods

The inadequacy of conventional wastewater treatment methods, coupled with the high costs and energy demands associated with them, underscores the need for sustainable and cost-effective alternatives. Sustainable wastewater treatment approaches not only aim to mitigate environmental pollution but also strive to recover resources, such as water, energy, and nutrients, thereby contributing to the circular economy [3].

1.3 Introduction to Biochar: Origin, Production, and Basic Properties

Biochar, a carbon-rich material produced through the pyrolysis of organic biomass under limited oxygen conditions, has garnered attention for its multifaceted applications, including soil amendment, carbon sequestration, and wastewater treatment [4]. Its porous structure, high surface area, and functional groups enable it to adsorb a wide range of contaminants, including heavy metals, nutrients, and organic compounds, making it a promising material for wastewater remediation [4].

1.4 Rationale for Reviewing Biochar Use in Kenya's Wastewater Treatment

Given Kenya's pressing wastewater management challenges and the need for sustainable treatment solutions, exploring the application of biochar presents a viable avenue. Utilizing locally available biomass residues to produce biochar could offer a low-cost and effective method for wastewater treatment, particularly in decentralized systems. Therefore, this review aims to assess the current practices, challenges, and future prospects of biochar application in Kenya's wastewater management landscape [5-8].

1.5 Scope and Structure of the Paper

This paper provides a comprehensive review of biochar's role in sustainable wastewater management in Kenya. It begins with an overview of the country's wastewater management landscape, followed by an examination of biochar's properties and mechanisms relevant to wastewater treatment. Subsequent sections delve into current practices in Kenya, the challenges faced in adopting biochar-based treatments, and the future prospects for integrating biochar into the country's wastewater management strategies.

2. Overview of Wastewater Management in Kenya

Kenya, like many rapidly urbanizing countries, faces significant challenges in managing wastewater effectively. The growing population, expansion of informal settlements, and industrial development have all contributed to increasing volumes of wastewater, much of which remains untreated or poorly managed. Understanding the structure, limitations, and dynamics of wastewater management in Kenya is critical for assessing the potential role of sustainable innovations such as biochar [3,9].

2.1 Sources of Wastewater

Wastewater in Kenya originates from diverse sources including domestic households, industrial operations, agricultural runoff, and commercial facilities. Domestic sources-primarily from urban areas-are the largest contributors and include sewage, greywater from kitchens and showers, and blackwater from toilets. Industrial wastewater varies depending on the sector but often includes effluents from agro-processing industries, textile manufacturing, and chemical production. Agricultural sources, although diffuse, contribute significantly to non-point pollution through nutrient-laden runoff, pesticides, and animal waste [10].

2.2 Current Treatment Infrastructure and Capacity

Kenya's wastewater treatment infrastructure is generally limited in coverage and capacity. Most of the country relies on centralized sewerage systems that serve only major urban centers such as Nairobi, Kisumu, and Mombasa. Even within these cities, connection rates to sewer systems remain low-estimated at less than 30% of the urban population [11]. Many municipalities operate outdated treatment plants, often functioning below capacity or entirely dysfunctional due to poor maintenance, lack of funding, and limited technical expertise [3].

In rural and peri-urban areas, the situation is more dire. There is heavy reliance on on-site sanitation systems like pit latrines and septic tanks, which often discharge into the environment without adequate treatment. Informal settlements, which house a significant proportion of Kenya's urban population, typically lack access to any formal wastewater services, leading to direct discharge into rivers and open drains [12].

2.3 Regulatory Frameworks

Kenya's institutional and legal framework for water and wastewater management is anchored by several key laws and agencies. The Water Act of 2016 provides a comprehensive structure for water resource management and service delivery, including sanitation services. The National Environment Management Authority (NEMA) is tasked with enforcing environmental regulations, including effluent discharge standards under the Environmental Management and Coordination Act (EMCA).

Additionally, the Water Services Regulatory Board (WASREB) oversees service providers and ensures compliance with quality and efficiency standards. Despite these frameworks, enforcement remains weak. Many industries and municipalities either fail to meet the prescribed standards or operate without discharge permits, often due to a lack of monitoring capacity and corruption in enforcement chains [13].

2.4 Gaps and Challenges in Conventional Wastewater Treatment

A major challenge in Kenya's wastewater management landscape is the persistent gap between policy and implementation. While regulations exist, practical enforcement is limited. Budget constraints at both the national and county levels hamper infrastructure upgrades and the construction of new treatment facilities. There is also a lack of investment in wastewater reuse, with treated water often discharged into water bodies rather than being recycled for irrigation or industrial use [3].

Another significant limitation is the energy and operational costs associated with conventional treatment plants. These systems often rely on mechanical processes and imported technologies that are ill-suited to Kenya's economic and environmental context. Furthermore, there is limited public awareness and engagement in wastewater issues, reducing demand for improved sanitation services and accountability among service providers [14].

2.5 Relevance of Low-Cost and Decentralized Treatment Options

Given these constraints, there is growing recognition of the need for alternative approaches that are low-cost, decentralized, and environmentally sustainable. Decentralized wastewater treatment systems (DEWATS), ecological sanitation models, and constructed wetlands have been piloted in parts of the country, especially in community and NGO-led initiatives. These systems, often using locally available materials and requiring minimal energy inputs, align well with the socioeconomic realities of many Kenyan communities [4].

It is within this context that biochar presents a promising solution. Its ability to improve contaminant removal, particularly when incorporated into filters or wetlands, makes it highly relevant for rural and low-income settings. Moreover, the potential to produce biochar from agricultural waste strengthens the circular economy model and reduces dependence on external inputs.

3. Biochar: Properties and Mechanisms for Wastewater Treatment

Biochar is a carbon-rich product derived from the thermal decomposition of organic biomass under oxygen-limited conditions. It is typically produced through processes such as pyrolysis and gasification, with variations in temperature, heating rate, and feedstock influencing its properties [4]. The growing interest in biochar for environmental remediation stems from its unique physicochemical characteristics that support contaminant removal in wastewater.

Among its most critical features, biochar possesses a highly porous structure with significant surface area-often exceeding 100 m^2/g-which provides numerous active sites for adsorption [4]. These physical characteristics, in combination with its chemical composition, give biochar a high cation exchange capacity (CEC), enabling it to attract and retain nutrients and heavy metal ions effectively.

The mechanisms by which biochar facilitates wastewater treatment are diverse. One primary mechanism is adsorption, where contaminants adhere to the surface or within the pores of the biochar. Heavy metals such as lead (Pb^{2+}), cadmium (Cd^{2+}), and arsenic (As^{3+}) are immobilized through electrostatic attraction and complexation with functional groups on the biochar surface. In parallel, nutrient retention is facilitated through ion exchange and surface interactions. Nutrients such as ammonium (NH_4^+) and phosphate (PO_4^{3-}), which contribute to eutrophication if discharged into natural water bodies, are efficiently captured by biochar [4].

In addition to inorganic contaminants, biochar can remove a wide range of organic pollutants including pesticides, dyes, and pharmaceutical residues. This capability is attributed to its hydrophobic surface and the presence of aromatic structures that allow π–π interactions and van der Waals forces to operate [4]. These mechanisms enable biochar to serve as a multi-functional treatment agent suitable for complex wastewater matrices.

In the Kenyan context, the selection of feedstocks is closely aligned with the country's agricultural profile. Residues such as sugarcane bagasse, maize cobs, and rice husks are widely available and have been successfully transformed into biochar with promising treatment capacities. A recent study highlights that biochar from sugarcane bagasse, maize cobs, and rice husks exhibited effective removal of heavy metals and nutrients when applied in soil and water systems [3]. These feedstocks are not only cost-effective but also support circular economy practices by converting agricultural waste into environmental solutions.

Given its versatility and affordability, biochar presents a promising material for addressing wastewater challenges in low- and middle-income countries such as Kenya. Its ability to treat a broad range of contaminants and integrate into existing infrastructure makes it a viable candidate for scaling up in both rural and urban wastewater systems.

4. Current Practices in Kenya

The application of biochar in wastewater treatment within Kenya remains in early developmental stages but is steadily gaining attention through academic research, pilot projects, and community-led initiatives. Several studies have focused on evaluating biochar's potential in improving water quality, particularly using locally available feedstocks.

For example, a recent study by Lema [3] conducted in Bungoma County evaluated the treatment efficiency of biochar derived from sugarcane bagasse, maize cobs, and rice husks. The results demonstrated high adsorption capacities for nitrogen, phosphorus, and select heavy metals, indicating biochar's potential for enhancing both domestic and agricultural wastewater treatment. These findings have been supported by parallel efforts from research institutions such as the University of Nairobi, which has been experimenting with biochar-integrated treatment systems, particularly constructed wetlands and sand filtration units.

Universities and NGOs have played an essential role in piloting these technologies. Projects led by organizations like EcoAct and community-based initiatives have implemented biochar filters in small-scale sanitation projects. These filters often serve informal settlements or schools that lack access to centralized treatment systems. In such contexts, biochar serves not only as an adsorbent but also as a component that enhances the microbiological stability of treatment units.

While conventional treatment infrastructure in Kenya often struggles with capacity and maintenance challenges, biochar offers a low-cost, decentralized alternative. It is particularly suitable for rural areas and peri-urban zones where centralized sewer systems are unavailable or unreliable. Moreover, the use of biochar can be combined with other treatment technologies such as wetlands, aerobic digesters, and slow sand filters, improving their performance without requiring major capital investments.

Pilot projects in western and central Kenya have shown that biochar integration can reduce nitrogen and phosphorus concentrations by over 70%, and significantly lower heavy metal levels in domestic greywater [3]. Additionally, the low operational costs and ease of production make biochar a practical option for communities seeking affordable and sustainable wastewater solutions.

Despite its promise, mainstream adoption of biochar-based treatment in Kenya is limited by several factors, including a lack of regulatory support, minimal technical awareness, and insufficient funding for pilot-to-scale transitions. However, increasing academic interest and donor-funded research offer pathways for expanding the knowledge base and developing locally optimized biochar solutions.

The integration of biochar into existing wastewater management frameworks in Kenya represents a promising opportunity for addressing treatment inefficiencies and enhancing environmental sustainability. With further investment, training, and policy support, biochar can play a significant role in closing the wastewater treatment gap in both urban and rural contexts.

5. Challenges in Adopting Biochar-Based Wastewater Treatment in Kenya

The integration of biochar into wastewater treatment systems in Kenya presents a promising avenue for sustainable environmental management. However, several challenges impede its widespread adoption. These challenges span technical, economic, institutional, and social domains, each influencing the feasibility and scalability of biochar-based solutions.

5.1 Technical Challenges

A significant technical hurdle is the variability in biochar quality, which stems from differences in feedstock types and production methods. Biochar's physicochemical properties, such as surface area, porosity, and functional groups, are highly dependent on the source material and pyrolysis conditions. This inconsistency affects its adsorption capacity and overall effectiveness in contaminant removal, leading to unpredictable treatment outcomes [4].

Moreover, Kenya lacks a standardized framework for biochar production, resulting in disparate quality across different producers. The absence of quality control measures and certification processes further exacerbates this issue, making it challenging for stakeholders to assess and trust the efficacy of biochar products.

Limited local production infrastructure also poses a challenge. While biochar can be produced using simple technologies, scaling up production to meet the demands of wastewater treatment facilities requires more sophisticated equipment and processes. Currently, such infrastructure is scarce in Kenya, hindering the ability to produce biochar at the necessary scale and consistency [3].

5.2 Economic Factors

The economic viability of biochar-based wastewater treatment is influenced by several factors, including production costs and the absence of financial incentives. Producing high-quality biochar entails expenses related to feedstock collection, processing, and equipment maintenance. These costs can be prohibitive, especially for small-scale producers and community-based initiatives.

In comparison to conventional wastewater treatment methods, biochar systems may require higher initial investments. Without subsidies or financial support, the adoption of biochar technologies becomes less attractive to stakeholders. Furthermore, the lack of a well-established market for biochar products in Kenya limits opportunities for cost recovery and revenue generation, making it challenging to sustain operations in the long term [4].

5.3 Institutional and Policy Limitations

Institutional and policy frameworks in Kenya have yet to fully incorporate biochar-based solutions into national water and sanitation strategies. While the Water Act (2016) and the National Water Resources Strategy (2020–2025) provide guidelines for water resource management, they do not explicitly address the role of biochar in wastewater treatment [14].

This omission reflects a broader lack of recognition and support for innovative treatment technologies within policy documents. Consequently, there are no specific regulations or standards governing the production, application, and monitoring of biochar in wastewater systems. This regulatory gap creates uncertainty for potential adopters and limits the integration of biochar into formal treatment frameworks.

Additionally, enforcement of existing environmental regulations remains weak. Agencies such as the National Environment Management Authority (NEMA) face challenges in monitoring compliance and ensuring adherence to environmental standards. This lack of enforcement undermines efforts to promote sustainable practices and hinders the adoption of alternative treatment technologies like biochar [3].

5.4 Awareness and Training Gaps

Awareness and knowledge about biochar's potential in wastewater treatment are limited among key stakeholders, including policymakers, practitioners, and the general public. This lack of awareness impedes the dissemination of information and best practices related to biochar applications.

Training opportunities for individuals involved in wastewater management are also scarce. Without adequate training programs, there is a deficiency in the technical expertise required to produce, apply, and manage biochar effectively. This skills gap hinders the implementation of biochar-based solutions and reduces confidence in their efficacy.

Furthermore, the absence of demonstration projects and pilot studies limits the visibility of biochar's benefits in real-world settings. Such initiatives are crucial for showcasing the practical applications of biochar and building trust among stakeholders. Without tangible examples, it becomes challenging to advocate for the adoption of biochar technologies on a broader scale [3].

While biochar presents a promising avenue for sustainable wastewater treatment in Kenya, several challenges must be addressed to facilitate its adoption. Technical issues related to quality variability and production infrastructure, economic constraints, institutional and policy gaps, and deficiencies in awareness and training collectively hinder the integration of biochar into wastewater management systems. Addressing these challenges requires a concerted effort involving policy reforms, investment in infrastructure, capacity building, and the promotion of research and demonstration projects. By tackling these obstacles, Kenya can harness the full potential of biochar to enhance its wastewater treatment capabilities and promote environmental sustainability.

6. Future Prospects and Opportunities for Biochar-Based Wastewater Management in Kenya

Biochar, a carbon-rich material derived from the pyrolysis of organic biomass, has garnered attention for its potential in sustainable wastewater management. In Kenya, the integration of biochar into wastewater treatment systems presents opportunities to address environmental challenges, promote resource recovery, and align with global sustainability goals.

6.1 Research Needs and Innovation Potential

Advancing biochar applications in wastewater treatment necessitates focused research to optimize production processes, enhance contaminant removal efficiencies, and understand long-term environmental impacts. Studies have highlighted the need for standardized protocols to assess biochar's performance in diverse wastewater contexts, considering factors such as feedstock variability and pyrolysis conditions [4]. Innovations in biochar modification, such as surface functionalization, can improve adsorption capacities for specific pollutants, including heavy metals and organic compounds.

Furthermore, interdisciplinary research integrating biochar technology with other treatment methods, like constructed wetlands and anaerobic digestion, can yield synergistic effects, enhancing overall system efficiency. Collaborative efforts between academic institutions, research centers, and industry stakeholders are essential to drive innovation and translate laboratory findings into practical applications.

6.2 Scaling Up Community-Based and Low-Tech Biochar Systems

Implementing biochar-based wastewater treatment at the community level offers a decentralized approach to sanitation, particularly in rural and peri-urban areas lacking centralized infrastructure. Low-tech biochar systems, such as biochar-amended sand filters and pit latrine additives, have demonstrated effectiveness in pathogen reduction and nutrient retention [3].

Scaling up these systems requires capacity-building initiatives to train local artisans and technicians in biochar production and application techniques. Establishing demonstration projects can showcase the practicality and benefits of biochar technologies, fostering community acceptance and participation. Moreover, integrating biochar initiatives into existing community-based organizations and cooperatives can facilitate resource mobilization and knowledge dissemination.

6.3 Policy Integration and Public-Private Partnerships

The successful adoption of biochar in wastewater management hinges on supportive policy frameworks that recognize and promote its use. Currently, biochar is not explicitly addressed in Kenya's national water and sanitation policies, creating a regulatory gap that hinders its mainstreaming [14]. Incorporating biochar into policy instruments, such as the Water Act and environmental management guidelines, can provide a formal basis for its implementation.

Public-private partnerships (PPPs) offer a mechanism to leverage resources and expertise from various sectors. Engaging private enterprises in biochar production and distribution can stimulate market development, while public institutions can provide regulatory oversight and technical support. PPP models have the potential to enhance scalability, sustainability, and innovation in biochar-based wastewater treatment initiatives.

6.4 Potential for Circular Economy

Biochar production aligns with circular economy principles by converting agricultural and organic waste into valuable products for environmental remediation. In Kenya, abundant biomass residues, such as sugarcane bagasse, maize cobs, and rice husks, can serve as feedstocks for biochar production, reducing waste and promoting resource efficiency [15,16].

The application of biochar in wastewater treatment facilitates the recovery of nutrients, which can be reused in agriculture, closing the nutrient loop. Additionally, the treated water can be repurposed for irrigation and other non-potable uses, conserving freshwater resources. By integrating biochar into wastewater management, Kenya can advance towards a more sustainable and resilient water sector [17,18].

6.5 Role of Academia, Government, and NGOs

Academic institutions play a critical role in advancing biochar research, developing context-specific technologies, and training the next generation of environmental professionals. Government agencies are responsible for creating enabling environments through policy formulation, funding, and infrastructure development. Non-governmental organizations (NGOs) contribute by implementing pilot projects, raising awareness, and facilitating community engagement.

Collaborative networks among these stakeholders can foster knowledge exchange, resource sharing, and coordinated action. For instance, partnerships between universities and NGOs can lead to the co-creation of biochar solutions tailored to local needs, while government support can ensure scalability and integration into national programs.

6.6 Climate Resilience and SDG Alignment

Biochar's role in wastewater treatment contributes to climate resilience by mitigating greenhouse gas emissions, enhancing soil carbon sequestration, and improving water quality. These benefits align with several Sustainable Development Goals (SDGs), notably:

- SDG 6: Ensuring availability and sustainable management of water and sanitation for all.
- SDG 12: Promoting sustainable consumption and production patterns through waste valorization.
- SDG 13: Taking urgent action to combat climate change and its impacts by reducing emissions and enhancing adaptive capacity.

By integrating biochar into wastewater management strategies, Kenya can make significant strides towards achieving these global objectives, enhancing environmental sustainability and public health outcomes [11].

Certainly, the future of biochar-based wastewater management in Kenya is promising, offering multifaceted benefits that address environmental, economic, and social challenges. Realizing this potential requires concerted efforts in research, policy development, community engagement, and cross-sector collaboration. By embracing biochar technologies, Kenya can advance towards a more sustainable and resilient water sector, contributing to national development goals and global sustainability agendas.

7. Conclusion

This paper explored the role of biochar in sustainable wastewater management in Kenya by analyzing current practices, challenges, and future opportunities. It began with a global and national overview of wastewater challenges and highlighted the urgent need for cost-effective, decentralized, and environmentally friendly treatment methods. Biochar, a carbon-rich material produced through the thermal decomposition of organic biomass, has demonstrated considerable promise in this regard due to its porous structure, high surface area, and ability to adsorb a wide range of contaminants including heavy metals, nutrients, and organic pollutants.

Kenya’s wastewater infrastructure remains underdeveloped, especially in rural and peri-urban areas, where conventional centralized systems are economically and logistically unfeasible. Existing biochar research and pilot projects in Kenya-often spearheaded by universities and NGOs-have shown encouraging results, particularly when using locally available agricultural residues such as maize cobs and sugarcane bagasse as feedstocks. These initiatives have proven biochar’s adaptability and relevance in local contexts, particularly when integrated into systems like constructed wetlands and biochar-amended filtration units.

Despite these advancements, several challenges impede the wide-scale adoption of biochar in Kenya. Technical issues such as variability in biochar quality, inadequate production infrastructure, and a lack of standardized application protocols persist. Economically, the initial costs of biochar production remain a concern when compared to conventional methods, and there is a notable absence of policy support, subsidies, or inclusion in national water strategies. Moreover, institutional gaps, weak regulatory frameworks, and low public awareness further hinder implementation.

Looking ahead, there is substantial potential to scale up biochar-based wastewater treatment in Kenya through collaborative efforts involving academia, government, NGOs, and the private sector. Policy reforms that formally integrate biochar into wastewater treatment frameworks, along with investment in low-tech and community-scale systems, could accelerate adoption. Additionally, utilizing agricultural waste for biochar aligns with circular economy principles and contributes to climate resilience and Sustainable Development Goal 6: Clean Water and Sanitation.

In summary, biochar offers a practical, scalable, and sustainable solution for addressing Kenya's wastewater management challenges. With appropriate investment, policy backing, and continued research, biochar could become a cornerstone in the transition towards more resilient and sustainable water systems in the country.

References

[1] UNESCO. (2021). International Year of Creative Economy for Sustainable Development. https://www.unesco.org/en/articles/international-year-creative-economy-sustainable-development
[2] WASREB.(2022).Impact 14 2022 Report In Nairobi. Retrieved from https://wasreb.go.ke/impact-reports-issue-no-14/
[3] Lema, M. W. (2025). Wastewater crisis in East African cities: Challenges and emerging opportunities. Discover Environment, 3(18). https://doi.org/10.1007/s44274-02500206-w
[4] Wang, Z., Muchiri, P., & Karani, G. (2020). Evaluating low-cost wastewater treatment technologies for use in rural Kenya. Journal of Water, Sanitation and Hygiene for Development, 10(4), 713–725. https://doi.org/10.2166/washdev.2020.016
[5] Gupta, M., Savla, N., Pandit, C., Pandit, S., Gupta, P. K., Pant, M., Khilari, S., Kumar, Y., Agarwal, D., Nair, R. R., Thomas, D., & Thakur, V. K. (2022). Use of biomass-derived biochar in wastewater treatment and power production: A promising solution for a sustainable environment. The Science of the total environment, 825, 153892. https://doi.org/10.1016/j.scitotenv.2022.153892
[6] Omohovwo E.J.(2024). Wastewater management in Africa: Challenges and recommendations. Environ. Health Insights, 18 11786302241289680. https://doi.org/10.1177/11786302241289681
[7] Silva, J. A. (2023). Wastewater Treatment and Reuse for Sustainable Water Resources Management: A Systematic Literature Review. Sustainability, 15(14), 10940. https://doi.org/10.3390/su151410940
[8] Obaideen, K., Shehata, N., Sayed, E. T., Abdelkareem, M. A., Mahmoud, M. S., & Olabi, A. G. (2022). The role of wastewater treatment in achieving sustainable development goals (SDGs) and sustainability guideline. Energy Nexus, 7, Article 100112. https://doi.org/10.1016/j.nexus.2022.100112
[9] Mulwa, F., Li, Z. and Fangninou, F.F. (2021) Water Scarcity in Kenya: Current Status, Challenges and Future Solutions. Open Access Library Journal, 8, 1-15. doi: 10.4236/oalib.1107096.
[10] Odhiambo, F., Wanyama, D., & Mwangi, A. (2022). Domestic and industrial wastewater contributions in urban Kenya. Water and Environment Journal, 36(1), 55–67. https://doi.org/10.1111/wej.12709
[11] World Bank. (2021). Kenya urban sanitation review: Challenges and opportunities. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/378911612819498801
[12] UNEP. (2022). Status of wastewater treatment in Kenya: Opportunities for circular economy solutions. United Nations Environment Programme. https://www.unep.org/resources/report/status-wastewater-treatment-Kenya-2022
[13] Muindi, K., Mwalili, S. & Karanja, L. (2020). Evaluating enforcement of effluent discharge standards in Kenya: Challenges and prospects. Environmental Policy and Law, 50(5), 351–359. https://doi.org/10.3233/EPL-200210
[14] FAO. (2020). The national water resources strategy (2020–2025). Food and Agriculture Organization. https://faolex.fao.org/docs/pdf/ken214249.pdf
[15] Roobroeck D. (2024). Potential of Biochar with Crop Residues in Maize Systems from Kenya – Ex-Ante Assessment for Strategic Guidance of Research, Investment and Policy. IITA.
[16] Gitau, A. N., Ndiritu, J. G., & Mavura, M. (2021). Performance of maize stalk-derived biochar in treating faecal sludge in constructed wetlands. Water Practice and Technology, 16(2), 491–502. https://doi.org/10.2166/wpt.2021.033
[17] Kameo, D., Wanyama, J., & Ombaka, D. (2022). Biochar derived from sugarcane bagasse for wastewater treatment in Kenya. Environmental Technology & Innovation, 27, 102404. https://doi.org/10.1016/j.eti.2022.102404
[18] Abhilash, P. C., Dubey, R. K., Tripathi, V., Gupta, V. K., & Singh, H. B. (2021). Biochar in wastewater treatment: A sustainable solution. Environmental Research, 194, 110656. https://doi.org/10.1016/j.envres.2020.110656