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VALORIZING ORGANIC WASTE FOR BIOREMEDIATION OF POLLUTED WATER BODIES: A SUSTAINABLE APPROACH TO WASTE MANAGEMENT AND ENVIRONMENTAL PROTECTION IN NIGERIA

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ABSTRACT

Nigeria faces a dual environmental challenge of increasing organic-waste generation and persistent pollution of surface and groundwater systems. Poor waste collection, open dumping, weak wastewater treatment, and diffuse agricultural and urban runoff have intensified contamination of rivers, streams, wetlands, and shallow aquifers, while large volumes of biodegradable residues from cassava processing, rice milling, food markets, sawmilling, and oil-palm activities remain underutilized. This review examines the potential of valorizing organic waste into functional materials for the bioremediation of polluted water bodies in Nigeria. The paper synthesizes current evidence on major Nigerian waste streams, conversion pathways, waste-derived remediation materials, pollutant-removal mechanisms, and implementation opportunities within a circular-economy framework. Particular attention is given to biosorbents, biochar, activated carbon-like materials, and biologically active media derived from cassava peels, rice husks, sawdust, market waste, and other biodegradable feedstocks. The review shows that these materials can remove heavy metals, dyes, nutrients, suspended solids, pathogens, and selected organic pollutants through adsorption, ion exchange, surface complexation, filtration, precipitation, and microbially assisted degradation. The paper also highlights Nigeria-specific opportunities for decentralized deployment in agro-processing zones, market clusters, and pollution hotspots where feedstock availability and water-quality pressures overlap. However, major barriers remain, including poor source segregation, inconsistent feedstock quality, limited field-scale

validation, weak standardization, uncertain regeneration pathways, and fragmented institutional coordination. The study concludes that organic-waste valorization offers a practical and sustainable pathway for simultaneously reducing waste burdens and improving water quality in Nigeria, but successful scale-up will require pilot-based implementation, stronger policy integration, and closer alignment between research, local enterprise, and environmental regulation.

KEYWORDS: Organic waste valorization; bioremediation; polluted water bodies; biochar; biosorbents; wastewater treatment; circular economy; Nigeria.

1. INTRODUCTION

Nigeria is increasingly confronted with a dual environmental challenge: the rapid accumulation of organic waste and the persistent deterioration of surface and groundwater quality. Poorly managed biodegradable waste from households, markets, farms, agro-processing facilities, and municipal systems often enters the environment through open dumping, uncontrolled decomposition, and runoff, while rivers, streams, wetlands, and shallow aquifers are simultaneously exposed to untreated domestic wastewater, industrial effluents, and agricultural discharges. Recent reviews describe Nigeria's waste crisis as a product of structural weaknesses in governance, infrastructure, and behavior, with consequences that extend to ecosystem degradation and public health (Nzeadibe et al., 2025). The scale of the problem is substantial. A recent national solid-waste assessment reported that Nigeria generates more than 32 million tonnes of municipal solid waste annually, yet only about 20–30% is collected. The same body of evidence indicates that organic materials account for a large share of the waste stream, making biodegradable waste both a major environmental burden and a potentially valuable resource if properly recovered and processed (National Environmental Standards and Regulations Enforcement Agency [NESREA], 2025). Nigeria's water-security context further strengthens the case for integrated intervention. The World Bank reported that approximately 60 million Nigerians lacked access to basic drinking water in 2019, while about 80 million lacked improved sanitation facilities; in parallel, recent national and international WASH reporting continues to emphasize the need for stronger, safer, and more resilient water and sanitation services (World Bank, 2021; UNICEF Nigeria, n.d.). These deficits increase the vulnerability of households and communities to the impacts of contaminated water bodies, especially where waste disposal and wastewater treatment systems are inadequate. At the same time, Nigeria possesses a large and underutilized biomass base that could support low-cost remediation technologies. FAO reports that the country has about 70.8 million hectares of agricultural land and identifies cassava, maize, millet, yam, and rice among its major crops. This matters because large-scale crop production generates substantial residues such as cassava peels, rice husks, maize cobs, sawdust, food waste, and oil-palm by-products, many of which have favorable lignocellulosic or carbon-rich properties for conversion into biochar, biosorbents, and biologically active treatment media (Food and Agriculture Organization [FAO], n.d.).

The scientific basis for this approach is increasingly well established. Recent studies and reviews show that waste-derived materials can remove metals, dyes, nutrients, hydrocarbons, suspended solids, and selected organic contaminants through adsorption, ion exchange, filtration, precipitation, and microbially assisted degradation. In resource-constrained settings, these materials are especially attractive because they can reduce dependence on expensive conventional adsorbents while supporting decentralized treatment options for polluted water bodies. In Nigeria, this creates an opportunity to connect circular waste management with environmental restoration by transforming organic residues from a disposal problem into a remediation resource (Alfonsín et al., 2023; Li et al., 2024). Despite this promise, the Nigerian literature still lacks sufficient synthesis that explicitly connects waste generation, feedstock availability, polluted water bodies, remediation mechanisms, and implementation pathways within one coherent framework. Much of the available work remains either broad and policy-oriented or highly technical and laboratory-based. A review that brings these strands together is therefore needed to clarify the scale of available waste resources, the types of value-added remediation materials that can be produced, the pollutants they can target, and the institutional conditions required for field-scale application. Against this background, the present paper examines the valorization of organic waste for the bioremediation of polluted water bodies in Nigeria and argues that it offers a practical pathway toward sustainable waste management, improved water quality, and broader environmental protection.

Figure 1: Conceptual framework for the valorization of organic waste into bioremediation material for the treatment of pollution in Nigeria.

2. Review Methodology

This study was conducted as a narrative review with structured evidence synthesis. This approach was adopted because the topic spans multiple fields, including waste management, water pollution, environmental engineering, agricultural residue utilization, and environmental policy in Nigeria. Given this methodological diversity, a strict meta-analysis was not considered appropriate. Instead, the review was organized around transparent search, screening, and synthesis principles consistent with established review guidance (Page et al., 2021; Woodruff & Sutton, 2014). Relevant literature was identified from multidisciplinary academic databases and institutional sources. The core academic sources used were Scopus, Web of Science, and ScienceDirect, which are widely recognized platforms for indexing peer-reviewed environmental and engineering research (Elsevier, n.d.; Clarivate, n.d.). In addition, official and quasi-official sources were consulted for Nigeria-specific background data, especially where national statistics on waste generation, agricultural production, and water access were required (FAO, n.d.; NESREA, 2025; World Bank, 2021). The search strategy combined topic-specific and location-specific keywords. Search terms included combinations of organic waste valorization, bioremediation, biochar, biosorbents, wastewater treatment, polluted water bodies, agricultural residues, and Nigeria. Additional targeted searches were conducted using feedstock-specific terms such as cassava peels, rice husk, sawdust, oil-palm residues, and food waste in order to capture material-specific treatment studies. This keyword-based approach follows standard literature review practice in environmental research, where broad thematic coverage is necessary to capture studies across different technical and policy domains (Page et al., 2021).

Studies were included if they met at least one of the following criteria: (a) they investigated the conversion of organic or agricultural waste into remediation materials; (b) they reported the application of waste-derived materials for water or wastewater treatment; (c) they examined pollutant-removal mechanisms such as adsorption, ion exchange, filtration, precipitation, or microbial degradation; or (d) they provided Nigeria-specific evidence on waste generation, water pollution, or environmental implementation conditions. Studies were excluded when they focused exclusively on unrelated waste streams, non-aqueous remediation, or end uses not connected to environmental treatment, unless they contained background information necessary for interpreting the Nigerian context. Explicit eligibility criteria of this kind are recommended in review reporting frameworks to improve transparency and reproducibility (Page et al., 2021). To strengthen national relevance, the review combined journal literature with institutional datasets and policy reports. Crop production data were drawn from FAO and FAOSTAT-linked sources because these provide more consistent national statistics for cassava, rice, maize, and oil-palm than direct residue-generation inventories (FAO, n.d.). Water, sanitation, and hygiene indicators were drawn from development-sector reporting, including the World Bank, because these sources provide widely cited baseline estimates for Nigeria's drinking water and sanitation access (World Bank, 2021). Waste-generation and collection estimates were taken from recent Nigerian waste-management assessments, especially where peer-reviewed national inventories were limited (NESREA, 2025). Where direct national residue-generation data were unavailable, residue potential was estimated using transparent derivation from agricultural production volumes and residue factors reported in the literature. These estimates were treated as indicative residue-generation potential rather than direct measured waste totals. This was especially important for waste streams such as cassava peels, rice husks, and oil-palm residues, where national crop-production data are stronger than national residue-inventory data. Such estimation is acceptable in evidence synthesis when direct inventory data are incomplete, provided the assumptions are made explicit and cautiously interpreted (Woodruff & Sutton, 2014).

The extracted literature was synthesized under five major themes: (1) organic waste generation and availability in Nigeria, (2) water pollution and contaminated water bodies, (3) valorization pathways for converting waste into remediation materials, (4) pollutant-removal performance and treatment mechanisms, and (5) implementation opportunities and constraints within the Nigerian context. Quantitative findings were organized into tables showing residue potential, pollutant classes, adsorption capacities, removal efficiencies, and national environmental indicators. This thematic synthesis approach is appropriate for multidisciplinary environmental reviews because it allows comparison across study types, scales, and data sources while preserving contextual interpretation (Page et al., 2021). Because the reviewed studies differ substantially in design, wastewater type, adsorbent preparation, and operating conditions, the quantitative values reported in this paper are interpreted as study-specific findings, not as universally comparable performance benchmarks. As a result, the purpose of the review is not to calculate pooled effect sizes, but to identify defensible trends in feedstock suitability, treatment performance, and implementation potential for Nigeria. This makes the review especially useful for policy framing and future pilot design, even where the underlying studies are technically diverse (Page et al., 2021; Woodruff & Sutton, 2014).

3. Organic Waste Generation and Water Pollution Challenges in Nigeria

3.1 Nigeria's Solid-Waste Management Context

Nigeria's environmental management challenge is strongly shaped by the convergence of two pressures: the rapid accumulation of organic waste and the continued degradation of water resources. Recent evidence shows that Nigeria's solid-waste crisis reflects structural deficiencies in governance, infrastructure, and behavior, with cascading effects on ecosystems and public health (Nzeadibe et al., 2025). At the same time, a major review of Nigeria's water sector examined 305 studies and concluded that the country is marked by the paradox of "abundant water" but "polluted reality," driven by weak treatment systems, poor infrastructure, and ineffective resource management (Akinyemi et al., 2024).

3.2 Scale and Composition of Organic Waste in Nigeria

The waste side of the problem is substantial. A recent Nigerian solid-waste assessment reported that the country generates more than 32 million tonnes of municipal solid waste annually, yet only about 20–30% is collected (National Environmental Standards and Regulations Enforcement Agency [NESREA], 2025). Because collection and treatment remain limited, large volumes of biodegradable waste are left in open dumps, informal disposal sites, and drainage channels, where they contribute to leachate formation, blocked runoff systems, and contamination of nearby water bodies (NESREA, 2025; Nzeadibe et al., 2025). A large proportion of this waste stream is organic, which makes the problem particularly relevant to waste valorization. Nigerian waste-management literature and circular-economy reports indicate that the country's high biodegradable fraction represents both an environmental liability and an economic opportunity, especially for composting, biochar production, and other recovery pathways (United Nations Industrial Development Organization [UNIDO], 2022; Nzeadibe et al., 2025). In practical terms, this means that the same waste currently contributing to pollution could be transformed into materials for environmental remediation if segregation and processing systems are improved.

3.3 Agricultural and Agro-Industrial Residue Availability

Agricultural production further expands the scale of available organic residues. FAO reports that Nigeria has about 70.8 million hectares of agricultural land and identifies cassava, maize, millet, yam, and rice among the country's major crops (Food and Agriculture Organization [FAO], n.d.). The FAO country profile also reports that Nigeria's rice production increased from 3.7 million metric tonnes in 2017 to 4.0 million metric tonnes in 2018, confirming the continued significance of rice-related residue streams such as husk and bran (FAO, n.d.). These crop systems generate substantial biomass residues, including cassava peels, rice husks, maize cobs, stalks, and agro-processing by-products, many of which are lignocellulosic and therefore suitable for conversion into biosorbents and biochar. This residue availability is central to the Nigerian case. Cassava-processing activities generate large quantities of peel waste, rice milling produces husks, sawmilling yields sawdust, and municipal food systems produce market and household organics. Although direct national inventories for each residue are not always consistently reported, the scale of crop production strongly suggests that Nigeria possesses one of the largest biomass bases in sub-Saharan Africa for potential waste-to-remediation applications. This aligns with broader circular-economy discussions in Nigeria, which highlight the large volume of waste generated in the country as a source of opportunities for microenterprises, composting systems, and material recovery activities (UNIDO, 2022).

3.4 Sources and Pathways of Water Pollution

The water-pollution challenge is equally pressing. The 2024 review by Akinyemi et al. found that Nigerian water bodies are affected by multiple pressures, including untreated domestic sewage, industrial discharge, agricultural runoff, and poor waste disposal practices. These sources introduce a broad pollutant mixture into rivers, streams, wetlands, and groundwater systems, including nutrients, suspended solids, pathogens, heavy metals, and organic contaminants (Akinyemi et al., 2024). Because waste disposal and wastewater management are often poorly coordinated, organic waste contributes not only to solid-waste burdens but also to degraded water quality through runoff, direct dumping, seepage, and drainage blockage.

3.5 Water-Service Deficits and Public-Health Implications

Nigeria's freshwater vulnerability is also linked to broader service deficits. The World Bank reported that approximately 60 million Nigerians lacked access to basic drinking water in 2019, while about 80 million lacked improved sanitation facilities (World Bank, 2021). These service gaps intensify the consequences of polluted water bodies because many communities have limited alternatives when local rivers, wells, streams, or shallow aquifers become unsafe. Thus, water pollution in Nigeria is not only an ecological issue but also a direct public-health and livelihood challenge.

3.6 Integrated Implications for Waste Valorization and Water Remediation

Taken together, these conditions create a strong rationale for integrated solutions. Nigeria has a large and poorly managed biodegradable waste stream, a substantial agricultural residue base, and a documented water-pollution crisis. Rather than treating waste and water problems as separate sectors, an integrated framework can view organic waste as a feedstock for remediation materials that help address contaminated water bodies. This systems perspective is especially important in Nigeria, where the same structural weaknesses that affect waste collection and disposal also shape water treatment, environmental enforcement, and infrastructure provision (Akinyemi et al., 2024; NESREA, 2025; Nzeadibe et al., 2025).

Table 1. Major organic waste streams in Nigeria and estimated residue potential for water-remediation applications.

Waste stream	National production basis	Residue factor used	Estimated residue potential	Likely valorized product	Main water-treatment targets
Cassava peels	62.62 million t cassava roots/year	10–20%	6.26–12.52 million t/year	Biochar, activated carbon, biosorbent	Pb, Cu, dyes, organics
Rice husk	8.342 million t rice/year	22%	1.84 million t/year	Rice-husk biochar, silica-rich adsorbent	Metals, dyes, nutrients
Oil-palm empty fruit bunches	12.609 million t oil-palm fruit/year	20%	2.52 million t/year	Biochar, filter media, activated carbon precursor	Hydrocarbons, dyes, metals
OFMSW	>32 million t MSW/year	60–80% organic fraction	19.2–25.6 million t/year	Compost biomedia, biofilter media, char after preprocessing	Nutrients, COD/BOD, suspended solids
Food/market waste	Part of MSW organic fraction	Included above	Substantial share of OFMSW	Compost, wetland substrate, biomedia	Nutrients, biodegradable organics
Maize residues/cobs	11.164 million t maize/year	Not robustly quantified in source set	Large but not precisely estimated here	Biochar, biosorbent, composite media	Nutrients, dyes, metals

Production values and national context are based on FAO/FAOSTAT-linked materials, JICA agricultural survey materials, and recent Nigerian waste assessments. Residue potentials are estimates derived from production × residue factor. Taken together, these data show that Nigeria's organic-waste problem is not only a disposal burden but also a potential raw-material base for remediation. The logical next step is to examine how these wastes can be transformed into functional treatment materials.

Figure 2: Nigeria-Specific Implementation Framework for Organic Waste Valorization and Water Remediatiuon.

4. Valorization Pathways for Organic Waste

4.1 Concept of Organic-Waste Valorization

Organic-waste valorization refers to the conversion of biodegradable residues into useful products that can deliver environmental, technical, or economic value. In the context of polluted water bodies, the most relevant valorization pathways are those that transform agricultural and municipal organic wastes into biosorbents, biochar, activated carbon-like materials, compost-based media, and hybrid substrates for filtration or biologically assisted treatment. Recent reviews note that this approach is attractive because it addresses two challenges simultaneously: the burden of unmanaged waste and the need for lower-cost wastewater treatment technologies (Alfonsín et al., 2023; Li et al., 2024). In Nigeria, these pathways are particularly relevant because of the country's broad feedstock base. Cassava peels, rice husks, sawdust, oil-palm residues, and food waste are produced in large quantities and are often poorly managed, yet they contain lignocellulosic and carbon-rich components that can be converted into functional remediation materials.

4.2 Biosorbent Production from Raw or Minimally Modified Biomass

One major valorization route is the production of biosorbents from raw or minimally modified biomass. In this pathway, residues are typically washed, dried, milled, and sieved before direct use or mild chemical treatment. Agricultural-waste sorbents have been widely studied because they contain cellulose, hemicellulose, lignin, silica, and oxygen-containing functional groups that can bind dissolved contaminants. A recent review of green sorbents from agricultural wastes concluded that such materials are especially promising for the removal of heavy metals, metalloids, and dyes, while also offering a sustainable use for low-cost regional feedstocks (Alfonsín et al., 2023).

For Nigeria, this biosorbent pathway is especially practical for cassava peels, rice husk, and sawdust. These materials are already generated in dispersed agro-processing or timber clusters, meaning they can potentially be converted locally without highly centralized infrastructure. Rice husk is a particularly important example because recent reviews describe it as a versatile biosorbent and advanced adsorbent precursor for the removal of heavy metals from wastewater, whether used in raw, carbonized, or modified form (Gargiulo et al., 2024; Materials review, 2023). This pathway is attractive in low-resource contexts because it demands relatively limited capital and technical sophistication.

4.3 Biochar Production through Thermochemical Conversion

A second major pathway is the thermochemical conversion of biomass into biochar. Biochar is produced under oxygen-limited heating conditions and is valued for its porous structure, reactive surface chemistry, and relative durability. Recent reviews emphasize that biochar can function as both a waste-valorization product and a wastewater-treatment material, with particularly strong relevance for heavy metals, nutrients, and emerging contaminants. The larger surface area and functionalized surfaces of engineered biochars are reported to improve contaminant removal and reuse potential in real-world treatment systems (Li et al., 2024; Molecules review, 2025).

This route is highly relevant to cassava waste. Recent literature on cassava waste conversion highlights that cassava-processing residues are organic and acidic in nature, making their unmanaged disposal environmentally problematic, but also showing that thermochemical conversion can turn them into value-added products linked to pollution control and sustainable development (Nizzy & Kannan, 2022). Other recent work specifically describes biochar production from cassava waste as a techno-economic opportunity because large quantities of feedstock are readily available within the cassava value chain (Biochar production from cassava waste biomass, 2024).

4.4 Activated Carbon-Like and Engineered Adsorbents

A third pathway involves the production of modified or engineered adsorbents. In this case, raw biomass or biochar is chemically, mineralogically, or physically modified to increase pore development, surface functional groups, or selectivity for target pollutants. Reviews on biochar and rice-husk-derived adsorbents show that activation, impregnation, and composite formation can substantially improve performance, especially where multi-contaminant wastewaters are involved (Li et al., 2024; Gargiulo et al., 2024). This is scientifically attractive, although it also introduces higher processing cost and technical complexity, which may limit immediate uptake outside pilot or industrial settings in Nigeria. Even so, engineered materials may become important in contexts where higher treatment efficiency is required, such as industrial wastewater polishing, hospital effluent treatment, or university–industry demonstration projects.

4.5 Compost-Based and Biologically Active Media

A fourth pathway is the conversion of organic residues into compost-based media and biologically active substrates for hybrid treatment systems. While this route is discussed less often in sorption-focused papers than biochar or activated biomass, it is important for food waste and the organic fraction of municipal solid waste, especially where wastewater polishing, nutrient reduction, or low-strength effluent treatment is required. In such systems, the value of the material lies not only in direct adsorption but also in its ability to support microbial activity, filtration, and organic-matter stabilization. This pathway may be especially relevant in peri-urban Nigerian settings where low-energy decentralized systems are more realistic than high-specification treatment plants (Li et al., 2024). Compost-based or hybrid biomedia may therefore support ecological treatment approaches such as biofilters, wetlands, or retention units designed for low-cost community or institutional use.

4.6 Comparative Suitability of Valorization Pathways for Nigeria

From a systems perspective, these valorization routes are not mutually exclusive. A single waste stream may be directed into different products depending on treatment needs, local infrastructure, and desired cost–performance balance. For example, cassava peels may be used as a raw biosorbent, upgraded into activated carbon-like materials, or pyrolyzed into biochar, while rice husks may serve as silica-rich sorbent precursors or as carbonized media for more advanced wastewater applications. This flexibility is one of the main strengths of organic-waste valorization because it allows technology selection to be adapted to the Nigerian context rather than imposed as a single standardized solution (Alfonsín et al., 2023; Nizzy & Kannan, 2022).

At the same time, pathway selection should be guided by practical considerations. Raw biosorbents are more accessible where capital and energy inputs are limited, but they may be less durable or selective. Biochar and engineered materials can provide higher performance and greater stability, but they require more controlled processing. Compost-based media are attractive for decentralized ecological treatment, though they are generally better suited to nutrient-rich or low-strength wastewaters than to high-strength industrial discharges. These trade-offs are repeatedly emphasized in recent reviews, which argue that the future of waste-derived remediation depends not only on material performance but also on standardization, regeneration, and real-world integration into treatment systems (Li et al., 2024; Biochar-based filtration systems review, 2025). The available evidence indicates that Nigeria has multiple feasible pathways for transforming organic waste into remediation materials. The strongest near-term opportunities likely lie in feedstocks that are abundant, geographically concentrated, and already linked to environmental problems, particularly cassava peels, rice husks, sawdust, and market organics. The next section therefore examines the actual waste-derived materials produced through these pathways and the quantitative evidence for their pollutant-removal performance.

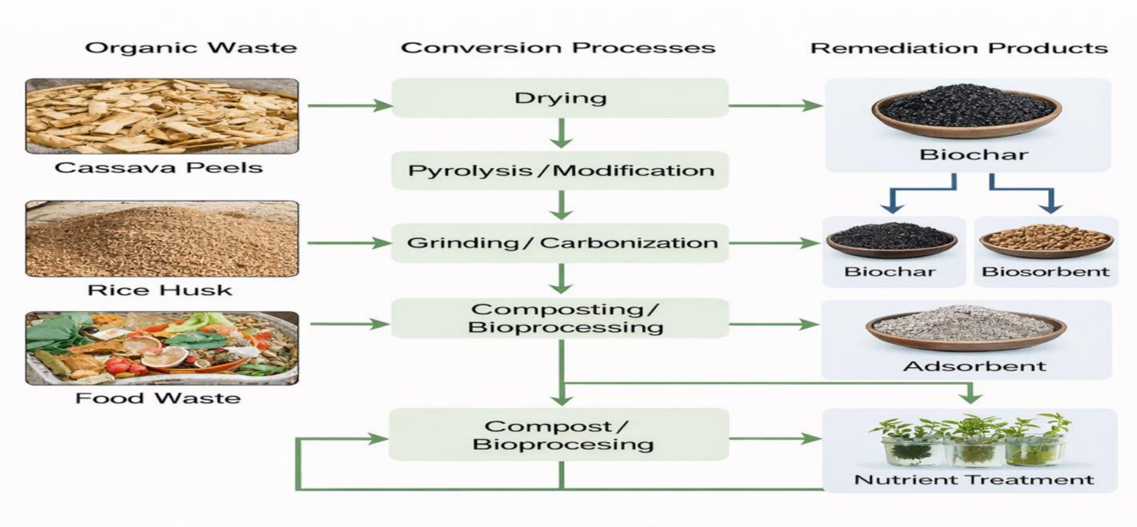

Figure 2: Major conversion pathways for transforming organic waste streams into remediation products.

5. Waste-Derived Materials for Water Bioremediation

5.1 Biosorbents

The practical relevance of organic-waste valorization lies in the properties of the materials produced for pollutant removal. One of the most accessible categories is the biosorbent, which is typically produced from raw or minimally processed biomass such as cassava peels, rice husk, sawdust, shells, or other crop residues. Recent reviews emphasize that these materials are attractive because they combine low-cost feedstocks with useful surface chemistry and pollutant-binding potential, particularly for heavy metals, dyes, and selected organic contaminants (Alfonsín et al., 2023; Asim et al., 2023).

The appeal of biosorbents comes largely from their natural composition. Agricultural residues contain cellulose, hemicellulose, lignin, silica, and oxygen-containing functional groups that can interact with dissolved pollutants. As a result, they offer a practical pathway for low-cost adsorption-based treatment in settings where conventional adsorbents may be too expensive or difficult to obtain. For Nigeria, this is especially important because many promising feedstocks are already available in large quantities and are often concentrated around agro-processing and market clusters.

5.2 Cassava Peel-Derived Materials

For the Nigerian context, cassava peel-derived materials are especially important because cassava processing generates large residue volumes and cassava waste is already recognized as a potential feedstock for value-added environmental applications. A review on cassava-waste management reported laboratory-scale success in the use of cassava peels as adsorbents for various grades of industrial wastewater and highlighted their role in the production of activated carbon and other value-added products (Adebayo et al., 2021).

Experimental evidence also supports this potential. In a study using activated carbon from cassava peels to treat hospital wastewater, the maximum adsorption capacities were reported as 5.80 mg/g for Pb(II) and 8.00 mg/g for Cu(II). Under the same study conditions, sorption efficiency increased from 12% to 73% for Pb(II) and from 26% to 79% for Cu(II) as adsorbent dose increased from 2 to 12 g, with optimum pH reported as 8 and rapid binding occurring within 20–120 min (Owamah, 2013). These findings indicate that cassava peels can serve not only as a simple waste-derived sorbent but also as a precursor for higher-value activated materials.

5.3 Biochar

A second major category is biochar, which has become one of the most widely studied waste-derived materials for wastewater treatment. Biochar is valued because pyrolysis can convert low-value biomass into a porous carbon-rich product that supports adsorption, ion exchange, and, in some systems, microbial attachment. A recent review in the *Journal of Water Process Engineering* emphasized that biochar serves not only as a wastewater-treatment material but also as a waste-valorization tool, and highlighted the importance of improving performance and durability in real-world applications (Li et al., 2024). A broader recent review similarly concluded that biochar can adsorb minerals, heavy metals, and organic pollutants, and that its effectiveness depends strongly on feedstock, conversion pathway, and surface characteristics (Khalid et al., 2024). This is important for Nigeria because it suggests that local biomass resources can be converted into treatment materials, but that preparation conditions will strongly influence final performance.

5.4 Rice Husk-Derived Biochar and Advanced Adsorbents

Within the broad biochar category, rice-husk-derived materials are particularly significant. Rice husk has been identified in recent review literature as a versatile precursor for advanced materials aimed at heavy-metal removal from wastewater, with the advantage of being silica-rich and relatively easy to process into adsorbents or carbonaceous composites (Gargiulo et al., 2024). This makes rice husk especially relevant for Nigeria, where rice production and milling generate relatively predictable residue streams.

Newer studies also suggest that functionalization can sharply improve performance. For example, a recent article on functionalized rice husk biochar reported maximum adsorption capacities of 179.77 mg/g for Pb^{2+} and 173.01 mg/g for methylene blue, demonstrating the capacity of modified rice-husk-derived materials to target both metal and dye contaminants in industrial wastewater contexts (Singh et al., 2025). These findings suggest that rice husk can support both low-cost and more advanced remediation pathways depending on the level of processing applied.

5.5 Modified and Engineered Biochar

The literature also points to the value of engineered or modified biochar, especially when wastewater is chemically complex. Modification methods may include mineral impregnation, magnetic functionalization, acid or alkali activation, and composite formation. Recent reviews emphasize that these treatments can improve pore structure, introduce more reactive functional groups, and enhance selectivity for target contaminants, although they also increase process complexity and cost (Li et al., 2024; Khalid et al., 2024).

For this reason, engineered materials may be better suited to pilot systems, industrial applications, or university–industry collaborations than to immediate low-tech rural deployment. In Nigeria, such materials may be most useful where treatment targets are more demanding, such as industrial effluent polishing, mixed-contaminant streams, or demonstration projects requiring higher and more consistent removal performance.

5.6 Activated Carbon-Like Materials

Another important category is activated carbon-like materials produced from agricultural residues. These generally involve a higher level of processing than raw biosorbents and are valued for their improved pore development, greater surface area, and stronger adsorption performance. Cassava peels, rice husks, and other biomass residues can all serve as precursors for this kind of material, making activated carbon-like production one of the more promising value-added routes for waste utilization. In the Nigerian context, this category is especially attractive because it bridges waste reduction with high-performance treatment potential. Although production is more technically demanding than direct biosorbent use, it remains more locally adaptable than importing conventional activated carbons. This makes it relevant for small enterprises, technical institutes, or community-scale processing hubs where moderate technological upgrading is possible.

5.7 Biochar-Based Filter Media and Hybrid Treatment Media

Another important category is biochar-based fixed filter media or hybrid treatment media. These materials are used not only as loose adsorbents in batch systems, but also in columns, filters, and constructed-wetland-like systems where they provide adsorption sites, filtration surfaces, and microbial habitats. A recent comprehensive review of biochar-based fixed filter columns reported average removal efficiencies of about 80% for COD, 71% for ammonium-N, and 57% for phosphate-P, alongside an average pathogen reduction of 2.4 log10. The same review notes that pyrolysis temperatures of roughly 300–800 °C and durations of 1–4 h influence specific surface area and column performance, underscoring the role of processing conditions in practical application (Mohan et al., 2024).

This category is especially relevant for Nigeria because decentralized filter units may be more realistic than fully centralized treatment systems in many communities. Biochar-based columns and hybrid biomedia can therefore offer a pathway for modular and low-energy treatment designs that match local infrastructure constraints.

5.8 Sawdust and Other Lignocellulosic Sorbents

Although much of the literature focuses on carbonized materials, raw or modified sawdust-based sorbents also remain relevant, especially where simplicity and low cost are priorities. Agricultural-waste adsorbent reviews continue to identify wood-derived residues and sawdust as promising materials for metal uptake because of their lignocellulosic structure and modifiable surface groups (Alfonsín et al., 2023; Asim et al., 2023).

In Nigeria, this has practical importance for sawmill towns and timber-processing clusters where waste wood residues are abundant and could be incorporated into decentralized filtration units or pre-treatment systems. Their lower processing demand may make them attractive as early-stage or transitional materials in resource-constrained settings.

5.9 Material Diversity and Relevance for Nigeria

The literature suggests that Nigeria does not need a single universal remediation material. Instead, it can draw on a portfolio of waste-derived materials matched to local feedstocks and pollution problems. Cassava peels appear especially promising for activated carbon-like biosorbents, rice husk is highly relevant for biochar and advanced adsorbents, and mixed organics or market waste are better suited to compost-based or biologically active media in low-energy treatment systems.

The significance of this diversity is that it allows treatment design to be adapted to Nigerian conditions rather than imported as a one-size-fits-all technology. Different residues can support different levels of technological sophistication, from simple locally prepared sorbents to engineered materials for specialized applications. The next section therefore examines the mechanisms of pollutant removal that explain why these waste-derived materials can perform effectively in water-remediation systems.

Table 2. Quantitative performance of selected waste-derived remediation materials relevant to the paper.

Material	Pollutant / endpoint	Quantitative performance	Key conditions	Main mechanism(s)
Activated carbon from cassava peels	Pb(II)	q_{max} = 5.80 mg/g; removal 12–73%	pH 8; 20–120 min	Adsorption, diffusion
Activated carbon from cassava peels	Cu(II)	q_{max} = 8.00 mg/g; removal 26–79%	pH 8; 20–120 min	Adsorption, diffusion
Fe_3O_4-modified rice-husk biochar	Pb(II)	95.0% removal; 73.68 mg/g; >41.2% efficiency after 6 cycles	Optimized aqueous tests	Complexation, ion exchange
Activated rice-husk carbon	Methylene blue	q_{max} = 476.2 mg/g	Langmuir/pseudo-second-order fit	Adsorption, pore filling
Modified sawdust biosorbent	Pb(II)	304 mg/g	pH 5; 25 °C	Surface complexation
Biochar filter	COD	80%	Wastewater filter	Filtration +

columns (review average)			systems	adsorption
Biochar filter columns (review average)	NH4-N	71%	Wastewater filter systems	Ion exchange + biology
Biochar filter columns (review average)	PO4-P	57%	Wastewater filter systems	Adsorption + precipitation
Biochar filter columns (review average)	Pathogens	2.4 log10 reduction	Wastewater filter systems	Filtration + biofilm effects

Values summarize cited experimental and review findings and should be presented as reported study results rather than universal performance benchmarks.

6. Mechanisms of Pollutant Removal

6.1 Adsorption

The effectiveness of waste-derived remediation materials depends not only on feedstock type, but also on the mechanisms through which pollutants are removed from water. One of the most important of these mechanisms is adsorption, in which contaminants accumulate on the external surface or within the internal pores of the material. This is especially significant for dyes, heavy metals, and dissolved organic pollutants. Reviews on agricultural-waste biosorbents note that lignocellulosic residues contain abundant hydroxyl, carboxyl, and phenolic groups that promote pollutant binding, while carbonized materials such as biochar contribute higher porosity and greater internal surface area (Alfonsín et al., 2023; Asim et al., 2023). In practice, adsorption performance is strongly influenced by pore-size distribution, surface area, feedstock composition, and preparation method.

6.2 Pore Filling and Physical Sorption

A closely related mechanism is pore filling and physical sorption. During carbonization or activation, biomass develops micro- and mesopores that can trap dissolved contaminants, especially smaller organic molecules and dyes. Recent reviews on biochar wastewater treatment emphasize that physical adsorption and pore filling become more prominent as pyrolysis conditions increase porosity and specific surface area, thereby enhancing mass transfer and retention within the material matrix (Santos et al., 2024; Wang et al., 2024). This means that the structural evolution of the material during processing has a direct bearing on its treatment performance.

6.3 Ion Exchange

For inorganic pollutants, particularly dissolved metals, ion exchange is often central. In this process, ions associated with the sorbent surface are exchanged with pollutant ions in solution. Biochar and biomass-derived sorbents often contain exchangeable cations and oxygen-containing surface groups that interact with Pb^{2+}, Cu^{2+}, Cd^{2+}, and related species. Recent reviews identify ion exchange as one of the dominant pathways for heavy-metal removal by waste-derived materials, especially where the sorbent retains mineral ash content or has been chemically modified (Wang et al., 2024; Khalid et al., 2025). This mechanism is particularly important for wastewaters containing elevated concentrations of dissolved metals.

6.4 Surface Complexation

Another major mechanism is surface complexation, in which metal ions or polar contaminants form coordinated bonds with functional groups on the sorbent surface. Carboxyl, hydroxyl, and carbonyl groups are especially important in this regard. Reviews on biochar potential for pollutant removal indicate that surface complexation often operates alongside ion exchange and physical adsorption, particularly in systems targeting metals and polar contaminants (Santos et al., 2024). Because the density and accessibility of these functional groups depend on feedstock and processing conditions, the same organic waste can perform differently depending on how it is converted into a remediation material.

6.5 Electrostatic Attraction

Electrostatic attraction also plays an important role, particularly where contaminants are ionic and the sorbent surface charge is sensitive to solution chemistry. The literature shows that pH strongly influences this mechanism because it affects both pollutant speciation and the surface charge of waste-derived materials. As a result, cationic and anionic pollutants may respond differently under acidic or alkaline conditions. This is especially important for real wastewater systems, where pH fluctuations and co-occurring ions can alter the removal efficiency observed under controlled laboratory settings (Wang et al., 2024).

6.6 Precipitation and Co-Precipitation

For some systems, especially modified biochars and mineral-rich residues, precipitation and co-precipitation contribute to pollutant removal. Metals or nutrients may react with mineral phases in the sorbent or with precipitating species generated during treatment, forming less soluble compounds that are retained within the matrix. Reviews of biochar wastewater applications report that precipitation can complement adsorption and ion exchange, particularly when ash-rich biochars or engineered composites are used (Santos et al., 2024; Khalid et al., 2025). This mechanism is therefore especially relevant where the treatment material contains substantial inorganic or alkaline components.

6.7 Filtration and Physical Entrapment

In flow-through systems such as columns and filter beds, filtration and physical entrapment become increasingly important. Rather than functioning solely as passive sorbents, waste-derived materials in packed filters can trap suspended solids, slow hydraulic movement, and increase contact time between contaminants and reactive surfaces. A recent review of biochar-based fixed filter columns reported average treatment efficiencies of 80% for COD, 71% for ammonium-N, 57% for phosphate-P, and 2.4 log10 pathogen reduction, indicating that filtration-based systems can provide multi-contaminant control beyond simple batch adsorption (Mohan et al., 2024; Li et al., 2024). This makes filtration-oriented applications especially relevant for practical wastewater polishing and decentralized treatment.

6.8 Microbially Assisted Degradation

A further mechanism, especially in compost-amended or hybrid systems, is microbially assisted degradation. Waste-derived materials can act as support media for microbial colonization, thereby promoting biodegradation of organics and transformation of nutrients. In these systems, the material does not only bind pollutants but also creates a habitat for biofilms that contribute to COD removal, nitrification, denitrification, and pathogen reduction. Recent reviews on biochar and ecological wastewater treatment highlight this combined role of sorption media and microbial habitat as a major reason for the success of filter-column and hybrid treatment systems (Li et al., 2024; Mohan et al., 2024).

6.9 Multi-Mechanism Performance in Mixed Wastewaters

An important point for the Nigerian context is that polluted water bodies rarely contain just one contaminant. Urban drainage channels, agro-processing discharges, and surface waters affected by dumping typically contain mixtures of nutrients, organic matter, metals, pathogens, and suspended solids. For this reason, the value of waste-derived materials lies in their ability to support multiple simultaneous mechanisms. A cassava-peel biochar, for example, may adsorb dissolved metals, trap suspended solids, and support biofilm development within the same treatment unit. This multi-mechanism behavior is one reason why biochar and biosorbent systems are attractive for decentralized and low-cost treatment applications in resource-constrained settings (Alfonsín et al., 2023; Li et al., 2024).

Overall, the mechanisms of pollutant removal confirm that waste-derived remediation materials are scientifically credible options for polluted water treatment. Their value lies not only in low feedstock cost, but also in the diversity of removal pathways they can provide. This makes them especially relevant for Nigeria, where contaminated water bodies often present mixed pollutant loads and where flexible, low-cost, and regionally adaptable treatment approaches are needed. The next section therefore turns to the Nigeria-specific implementation pathway, with emphasis on feedstock zones, treatment deployment, and policy considerations.

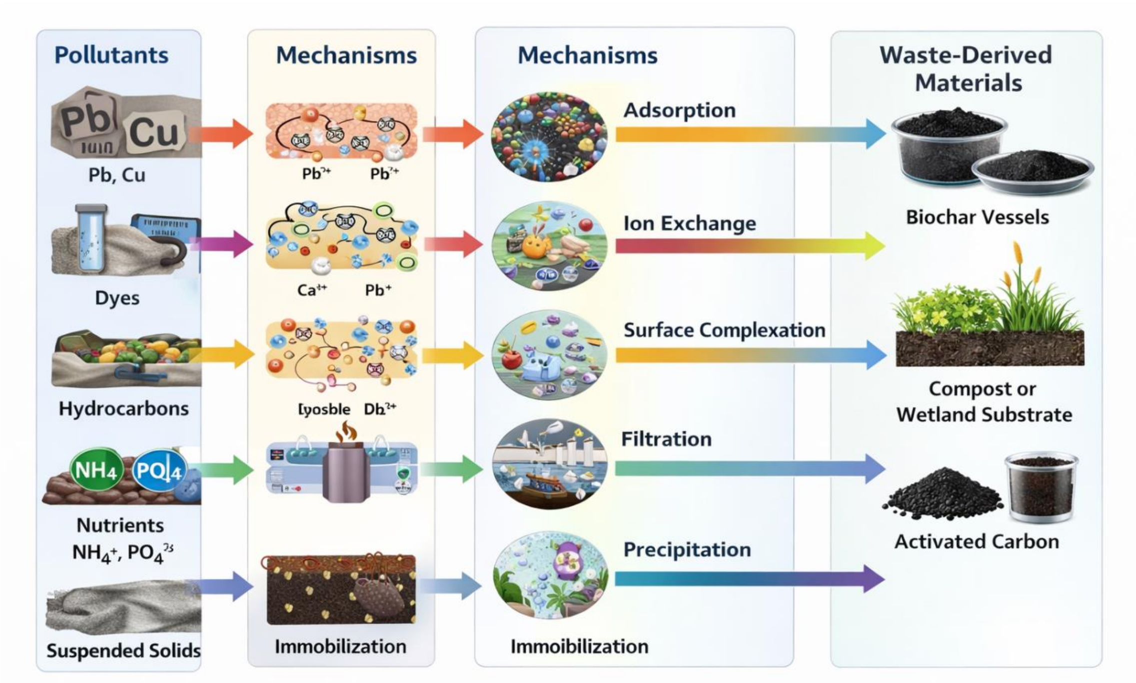

Figure 3: Mechnisms of Pollutant Removal by Waste-Derived Materials.

7. Nigeria-Specific Opportunities and Implementation Pathways

7.1 Strategic Relevance of Organic-Waste Valorization in Nigeria

The case for organic-waste valorization in Nigeria is strongest when viewed through the lens of implementation rather than theory alone. Nigeria combines three conditions that make this approach especially relevant: a large and poorly managed waste stream, widespread water-pollution pressures, and growing interest in circular-economy policy and enterprise development (National Environmental Standards and Regulations Enforcement Agency [NESREA], 2025; Nzeadibe et al., 2025; United Nations Industrial Development Organization [UNIDO], 2022). These conditions create a practical opportunity to connect waste recovery with decentralized water treatment and environmental restoration.

7.2 Feedstock-Rich Zones and Residue Clusters

A first opportunity lies in feedstock-rich zones. Nigeria's cassava, rice, timber, and market systems generate substantial localized organic residues, meaning that feedstock availability is not evenly distributed but clustered around production and processing areas. Cassava-processing centers generate concentrated peel waste; rice mills generate husk in relatively predictable volumes; sawmills produce steady wood residues; and urban markets produce large volumes of mixed organics. This clustering matters because transport is a major constraint in waste recovery systems. Locating sorbent or biochar production close to residue generation points can reduce logistics costs and make small-scale processing more feasible (Adebayo et al., 2021; UNIDO, 2022).

7.3 Pollution Hotspots Suitable for Decentralized Treatment

A second opportunity lies in pollution hotspots where decentralized treatment is more realistic than large conventional infrastructure. Nigeria's water-pollution literature indicates that surface-water degradation is linked to untreated discharges, weak wastewater systems, poor drainage management, and indiscriminate waste disposal (Akinyemi et al., 2024). In such settings, small or modular treatment systems based on waste-derived media may be more deployable than centralized treatment plants, especially for effluent polishing, drain-water improvement, agro-processing wastewater treatment, and low-strength peri-urban wastewater streams. This is important because implementation success in Nigeria often depends on systems that can operate under constrained infrastructure and maintenance conditions rather than under ideal treatment-plant assumptions.

7.4 Source Separation and Feedstock Recovery

A practical Nigerian implementation pathway would begin with source separation and organized collection. Current waste-management evidence shows that one of the central barriers in Nigeria is not only waste volume but weak sorting, mixed disposal, and inadequate collection systems (NESREA, 2025; Nzeadibe et al., 2025). For organic-waste valorization to work, relatively clean biomass streams must be separated at source or recovered from predictable processing locations such as cassava mills, rice mills, timber markets, and food markets. This suggests that the earliest pilot programs should target waste streams with high purity and low collection complexity rather than mixed municipal waste.

7.5 Localized Processing Hubs and Enterprise Development

The next stage would involve localized processing hubs. UNIDO's circular-economy programming in Nigeria explicitly identifies the waste-management value chain as a space for enterprise development, including community material-recovery facilities, composting facilities, and related small- and medium-scale infrastructure (UNIDO, 2022). In the context of this paper, that logic can be extended to biochar kilns, biomass drying and grinding units, adsorbent preparation workshops, and hybrid biomedia production points. These hubs could be linked to universities, technical institutes, local governments, or small enterprises to support quality control and product standardization.

7.6 Modular Deployment Pathways

After processing, deployment would most realistically occur through modular treatment applications rather than broad river-scale intervention at the outset. Waste-derived materials are likely to be most successful in packed-bed filters, polishing columns, biochar-amended channels, retention units, and wetland-supported systems positioned at discharge points or in small drainage corridors. Such applications fit Nigeria's infrastructure reality better than immediate large-scale retrofitting of formal treatment plants, particularly in communities or sectors where wastewater is partially treated or untreated. The objective should therefore be gradual demonstration: using waste-derived materials first in manageable, monitorable treatment nodes before wider scaling. This staged implementation logic is consistent with broader Nigerian water-infrastructure literature, which emphasizes sustainability, maintainability, and local appropriateness in system design (Akinyemi et al., 2024).

7.7 Circular-Economy and Livelihood Opportunities

A further opportunity lies in the circular-economy framing of the technology. Nigerian circular-economy analyses argue that the large volume of waste generated in the country presents business opportunities across the recovery and recycling chain, including micro, small, and medium-scale enterprises (UNIDO, 2022). For organic-waste valorization, this means remediation media can be framed not only as environmental tools but also as marketable products linked to local jobs, private-sector participation, and community-level environmental services. This framing may improve adoption because it shifts the narrative from waste disposal to resource production and local enterprise development.

7.8 Policy, Regulation, and Institutional Coordination

However, implementation depends heavily on regulation and institutional coordination. Nigeria already has environmental regulations and policy instruments relevant to this space, including NESREA's laws and regulations, the National Environmental (Surface and Groundwater Quality Control) Regulations, and broader policy guidance under the National Policy on Environment (NESREA, n.d.-a, n.d.-b). Yet recent analyses emphasize that enforcement remains inconsistent and coordination across institutions is weak (Nzeadibe et al., 2025; Okonkwo, 2025). This means that technical feasibility alone will not be enough; successful deployment will also require clearer standards for waste-derived remediation materials, monitoring protocols for treated effluents, and stronger collaboration between environmental, waste-management, and water-sector institutions.

7.9 Pilot-Scale Demonstration as the Most Realistic Pathway

For this reason, a realistic Nigerian pathway should prioritize pilot-scale demonstration projects in locations where feedstock supply and pollution burden clearly overlap. Cassava-processing corridors, rice-milling communities, urban market districts, and sawmill clusters are particularly good candidates because they combine visible residue generation with nearby wastewater or drainage problems. Pilot projects in such settings would allow direct testing of feedstock availability, material performance, regeneration potential, user acceptance, and regulatory fit before wider rollout. They would also generate the field-scale evidence that is still largely missing from the literature, which remains dominated by laboratory studies and conceptual policy discussions.

Nigeria's implementation pathway for organic-waste valorization should be understood as a staged systems model: feedstock mapping, source separation, localized processing, modular treatment deployment, regulatory support, and iterative scaling through pilots. This pathway is especially suitable for Nigeria because it matches local realities of uneven infrastructure, clustered residue generation, and decentralized pollution pressures. It also aligns with current circular-economy thinking and environmental policy aims, while offering a practical bridge between waste reduction and water-quality improvement. The next section therefore examines the major barriers, limitations, and future directions that will determine whether this pathway can move from promising concept to durable practice.

Table 3. Nigeria-specific quantitative context for scaling waste valorization for water bioremediation.

Indicator	Quantitative value	Relevance	
MSW generated annually	>32 million t/year	Indicates large feedstock base	
MSW collection rate	20–30%	Shows severity of unmanaged waste	
Organic fraction of waste stream	60–80%	Suggests large biodegradable recoverable fraction	
Nigerians without basic drinking water	~60 million	Confirms scale of water-service vulnerability	
Nigerians without improved sanitation	~80 million	Indicates contamination pressure	
Nigerians without basic handwashing facility	~167 million	Underscores public-health risk	
Studies synthesized in recent water-crisis review	305	Shows broad evidence base	
Cassava production	62.62 million t (2024)	Supports peel availability	
Rice production	8.342 million t (2021)	Supports husk availability	
Oil-palm fruit production	12.609 million t (2022)	Supports palm-residue availability	

Table 3 note. These indicators are not treatment-performance data; they are implementation-context data supporting the feasibility and urgency of waste valorization in Nigeria.

8. Challenges, Limitations, and Future Perspectives

8.1 Weaknesses in Nigeria's Waste-Management System

Despite the promise of organic-waste valorization for water remediation, several barriers continue to limit its practical adoption in Nigeria. The first is the weakness of the country's waste-management system itself. Recent Nigerian waste-management reviews describe the sector as being constrained by institutional fragmentation, weak infrastructure, inconsistent collection, and behavioral challenges, all of which reduce the reliability of clean feedstock recovery for downstream reuse (Nzeadibe et al., 2025). The 2025 NESREA assessment similarly identifies major gaps in collection, transfer, and broader system organization, reinforcing the point that waste valorization cannot scale effectively where the underlying waste system is still underperforming (National Environmental Standards and Regulations Enforcement Agency [NESREA], 2025).

8.2 Feedstock Quality and Consistency Constraints

A second major challenge is feedstock quality and consistency. Many of the materials discussed in this paper perform well only when the source biomass is relatively clean, homogeneous, and processed under controlled conditions. In practice, however, Nigerian organic waste is often mixed with plastics, metals, and other contaminants, especially within municipal streams. This affects not only the safety of the resulting remediation materials but also their reproducibility and pollutant-removal performance. For this reason, the most realistic early applications are likely to depend on relatively pure, clustered feedstocks such as cassava peels, rice husks, and sawdust rather than mixed municipal organics.

8.3 The Laboratory-to-Field Performance Gap

A third limitation is the persistent gap between laboratory evidence and field performance. Recent reviews on biochar for wastewater treatment emphasize that although many materials show high adsorption capacities under controlled conditions, real-world systems are constrained by physical degradation, competing ions, fouling, variable pollutant mixtures, and reduced reuse potential (Li et al., 2024). Related reviews on biochar preparation, modification, and environmental applications similarly stress that preparation method, feedstock variability, and operational conditions strongly affect performance, making standardization difficult (Khalid et al., 2025). These concerns are particularly important for Nigeria, where polluted water bodies often contain mixed loads of suspended solids, nutrients, pathogens, metals, and organics rather than single-solute laboratory conditions.

8.4 Limited Pilot-Scale and Long-Term Field Evidence

Another challenge is the limited availability of pilot-scale and long-term field studies. Much of the literature on waste-derived biosorbents and biochar remains experimental and bench-scale, while far fewer studies examine durability, regeneration, and performance under actual wastewater flow conditions. Recent work on biochar use in larger-scale wastewater systems notes the need to evaluate long-term stability and performance in real settings before broad deployment can be justified. Without this step, it is difficult to determine whether materials that perform well in batch adsorption studies will remain effective in Nigerian treatment channels, wetland systems, or filter columns over time.

8.5 Regeneration, Reuse, and End-of-Life Management

A further issue concerns regeneration, reuse, and end-of-life management. For any sorbent-based technology, pollutant transfer from water to media is not sufficient on its own; the loaded material must also be safely regenerated, stabilized, or disposed of. Reviews on biochar-based treatment increasingly identify reuse potential and material durability as central issues for real-world viability. This matters greatly in the Nigerian context because weak post-treatment handling could simply shift contaminants from water to land if spent materials are dumped or reused inappropriately. More work is therefore needed on regeneration cycles, secondary contamination risk, and safe disposal routes for pollutant-loaded media.

8.6 Economic and Technical Capacity Constraints

Economic and technical capacity constraints also remain significant. Although waste-derived materials are often described as low cost, that advantage depends on more than feedstock availability. Costs associated with source separation, collection, drying, preprocessing, carbonization, modification, transport, and quality control can become substantial if systems are poorly organized. In addition, more advanced materials such as engineered or functionalized biochars require technical expertise and equipment that may not yet be widely available outside research institutions or specialized industrial settings. This suggests that future adoption in Nigeria will depend on matching material sophistication to local capacity rather than assuming that the highest-performing laboratory material is automatically the best practical option.

8.7 Regulatory and Institutional Coordination Challenges

Institutional and regulatory constraints are equally important. Circular-economy programming in Nigeria has highlighted opportunities for waste-based enterprise development, but recent analyses still show that environmental governance, enforcement, and cross-sector coordination remain weak (UNIDO, 2022; Nzeadibe et al., 2025). Because organic-waste valorization for water remediation cuts across waste management, water regulation, environmental monitoring, and enterprise development, fragmented governance can slow deployment even where technical solutions exist. Stronger coordination is needed among waste agencies, water authorities, environmental regulators, local governments, and research institutions if pilot projects are to move beyond isolated demonstrations.

8.8 Water-Infrastructure and Maintenance Challenges

Nigeria's broader water-infrastructure context adds another layer of difficulty. Studies on water-system sustainability in Nigeria emphasize persistent challenges related to infrastructure functionality, maintenance, and long-term service performance. These concerns are relevant to waste-derived remediation systems because even promising treatment media may fail if they are placed into poorly maintained or weakly governed water infrastructure. In other words, the success of sorbent or biochar systems will depend not only on the material itself but also on the sustainability of the treatment setting in which it is deployed.

8.9 Future Perspectives and Research Priorities

Even with these limitations, the future prospects remain strong if development proceeds incrementally. The most promising pathway is a pilot-first approach focused on locations where three conditions overlap: abundant clean feedstock, identifiable pollution pressure, and manageable treatment scale. Examples include cassava-processing clusters, rice-milling communities, timber-processing zones, and urban market drainage systems. Pilot projects in such areas can generate the missing field evidence on performance, durability, regeneration, user acceptance, and institutional feasibility. They can also help define realistic standards for material preparation and system monitoring before larger rollouts are attempted.

Future research should therefore move in four directions. First, more Nigeria-specific field studies are needed to test waste-derived materials under real wastewater conditions. Second, more attention should be given to standardization and quality control, including feedstock selection, preparation protocols, and regeneration. Third, researchers should increasingly evaluate life-cycle and techno-economic performance, not just pollutant removal in short-term laboratory tests. Fourth, future work should link material science more explicitly with governance and business models, since circular-economy scaling depends on institutions and incentives as much as on adsorption performance.

The barriers identified in this section do not negate the promise of organic-waste valorization; rather, they define the conditions under which it can become practical. If these issues are addressed through staged implementation, stronger institutional support, and field-based validation, organic-waste valorization could evolve from a promising research area into a practical element of environmental protection and decentralized water management in Nigeria.

9. CONCLUSION

Organic-waste valorization offers Nigeria a practical pathway for addressing two interconnected environmental problems: the poor management of biodegradable waste and the pollution of water bodies. The review shows that widely available residues such as cassava peels, rice husks, sawdust, oil-palm residues, and market organics can be converted into biosorbents, biochar, activated carbon-like materials, and biologically active treatment media for removing metals, dyes, nutrients, suspended solids, pathogens, and selected organic pollutants. The paper also demonstrates that this approach is especially relevant to Nigeria because it links waste recovery with decentralized water treatment, circular-economy development, and environmental protection. However, its large-scale success will depend on stronger waste segregation, feedstock quality control, field-scale validation, safe regeneration pathways, and better institutional coordination. Overall, organic-waste valorization has strong potential to move from laboratory promise to practical application in Nigeria if supported by pilot-based implementation, policy integration, and collaboration among researchers, regulators, and local enterprises.

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