

## THE IMPORTANCE OF SANITATION SLUDGE VALORIZATION FOR HEALTH AND ENVIRONMENTAL PROTECTION: CASE STUDY OF KORHOGO CITY, CÔTE D'IVOIRE

### LA IMPORTANCIA DE LA VALORIZACIÓN DE LOS LODOS DE SANEAMIENTO PARA LA SALUD Y LA PROTECCIÓN DEL MEDIO AMBIENTE: ESTUDIO DE CASO DE LA CIUDAD DE KORHOGO, COSTA DE MARFIL

**FRANCK OLIVIER KONAN**

UNIVERSIDAD IBEROAMERICANA, MÉXICO ([OLIVIERKONAN2030@GMAIL.COM](mailto:OLIVIERKONAN2030@GMAIL.COM)) ([HTTPS://ORCID.ORG/0009-0009-6683-3586](https://orcid.org/0009-0009-6683-3586))

---

#### Información del manuscrito:

**Recibido/Received:** 31/01/26

**Revisado/Reviewed:** 02/03/26

**Aceptado/Accepted:** 20/09/26

---

#### ABSTRACT

##### **Keywords:**

Sanitation sludge, sustainable valorization, public health, urban environment, Korhogo

Sanitation sludge management is a major challenge in African cities, where rapid urbanization and informal systems increase health and environmental risks, particularly in secondary cities such as Korhogo, Côte d'Ivoire. To address this problem, the study conducts a qualitative and analytical review of recent literature (2020–2025) — including field studies, international guidelines, and African valorization initiatives — without relying on new quantitative data or technical analyses, examining the potential impacts of sludge valorization on public health, environmental protection, and local economic development. The findings indicate that valorization can reduce pollution, improve sanitation, provide soil amendments for agriculture, and contribute to renewable energy production. Based on these findings, the paper concludes by emphasizing the need for locally adapted strategies, awareness-raising among stakeholders, and public policies to maximize the benefits of sludge valorization while minimizing health and environmental risks.

---

#### RESUMEN

##### **Keywords:**

Lodos de saneamiento, valorización sostenible, salud pública, medio ambiente urbano, Korhogo.

La gestión de lodos de saneamiento es un desafío importante en las ciudades africanas, donde la rápida urbanización y los sistemas informales aumentan los riesgos para la salud y el medio ambiente, particularmente en ciudades secundarias como Korhogo, Côte d'Ivoire. Para abordar este problema, el estudio realiza una revisión cualitativa y analítica de la literatura reciente (2020–2025) —que incluye estudios de campo, guías internacionales e iniciativas africanas de valorización—, sin depender de nuevos datos cuantitativos ni análisis técnicos, examinando los impactos potenciales de la valorización de lodos en la salud pública, la protección ambiental y el desarrollo económico local. Los hallazgos indican que la valorización puede reducir la contaminación, mejorar el saneamiento, proporcionar enmiendas del suelo para la agricultura y contribuir a la producción de energía renovable. A partir de estos hallazgos, el artículo concluye enfatizando la necesidad de estrategias adaptadas localmente, la sensibilización de las partes interesadas y políticas públicas para maximizar los beneficios de la valorización de lodos, minimizando al mismo tiempo los riesgos para la salud y el medio ambiente.

## Introduction

Sanitation sludge management constitutes one of the most pressing challenges facing urban areas in Sub-Saharan Africa, particularly in rapidly growing secondary cities where sanitation infrastructure has not kept pace with population growth and urban expansion. Accelerated urbanization, informal settlements, and limited investment in sanitation services have led to the widespread accumulation of untreated fecal sludge, often discharged directly into the environment (WHO, 2018). This situation poses serious threats to public health, environmental quality, and the sustainable development of urban systems.

Inadequate management of sanitation sludge is closely associated with the transmission of waterborne and vector-borne diseases, including diarrhea, cholera, typhoid fever, and parasitic infections. Untreated sludge contains high concentrations of pathogenic bacteria, viruses, and helminths, which can contaminate surface waters, infiltrate groundwater, and expose populations through direct contact during informal emptying, transport, and disposal practices (Tra et al., 2024). Numerous studies conducted in African cities have demonstrated that communities located near sludge dumping sites experience higher morbidity rates, particularly among children, the elderly, and other vulnerable groups (Tra et al., 2024).

Beyond public health concerns, poor sludge management significantly degrades urban and peri-urban environments. The uncontrolled discharge of sludge contributes to soil contamination, eutrophication of rivers and lakes, deterioration of water quality, and loss of local biodiversity. Excessive nutrient loads—particularly nitrogen and phosphorus—alter aquatic ecosystems and reduce the availability of safe water resources for domestic, agricultural, and recreational uses (Odirile et al., 2024). These environmental impacts further exacerbate social and economic vulnerabilities, especially in cities where livelihoods depend on urban agriculture and natural resource use.

Despite these risks, sanitation sludge is increasingly recognized not only as a waste product but also as a potentially valuable resource. When adequately treated and managed, sludge can be valorized through a range of processes, including composting, anaerobic digestion, and co-treatment with organic waste. Such valorization pathways enable the recovery of nutrients for agriculture, the production of renewable energy in the form of biogas, and the reduction of waste volumes requiring disposal (UNEP, 2020). In this context, sludge valorization aligns with the principles of the circular economy, transforming environmental liabilities into productive assets while contributing to climate mitigation and resource efficiency.

Several studies across West Africa have highlighted the socio-economic benefits associated with sludge valorization initiatives. The production of organic fertilizers supports urban and peri-urban agriculture, reduces dependence on chemical inputs, and improves soil fertility, while energy recovery creates opportunities for decentralized and affordable energy supply (UNEP, 2020). Moreover, the development of local value chains around sludge collection, treatment, and reuse has the potential to generate employment, strengthen micro-enterprises, and enhance community resilience. However, the success of such initiatives

depends on social acceptance, institutional capacity, regulatory frameworks, and effective stakeholder engagement.

In Côte d'Ivoire, sanitation sludge management remains largely underdeveloped, particularly in secondary cities such as Korhogo. Sludge from domestic septic tanks and small-scale treatment facilities is frequently discharged into open spaces, agricultural lands, or nearby water bodies without prior treatment, increasing health and environmental risks (Tra et al., 2024). At the same time, Korhogo presents significant opportunities for sludge valorization due to its growing population, demand for agricultural inputs, and need for sustainable energy solutions. Yet, scientific literature addressing sludge valorization in this specific urban context remains limited, and most existing studies focus on large metropolitan areas.

Against this backdrop, the present study aims to raise awareness and highlight the importance of sustainable sanitation sludge valorization in the urban context of Korhogo. Through a qualitative and analytical review of recent scientific literature, international guidelines, and African case studies published between 2020 and 2025, this paper examines the potential contributions of sludge valorization to public health protection, environmental sustainability, and local socio-economic development. Rather than providing quantitative assessments, the study adopts a conceptual and critical approach, intended to synthesize existing knowledge, identify key challenges, and draw lessons applicable to secondary cities.

By situating Korhogo within broader regional experiences and best practices, this article seeks to contribute to the ongoing debate on sustainable urban sanitation in Africa. It provides a conceptual foundation for future research and supports policymakers, municipal authorities, and local stakeholders in designing integrated strategies that promote safe sludge management, community participation, and environmentally sound valorization pathways, ultimately contributing to healthier and more resilient urban environments.

**The primary objectives of this study are as follows:**

Identify health, environmental, and socio-economic challenges associated with inadequate sludge management.

Poor sludge management in urban settings can lead to numerous health risks, including the spread of waterborne diseases, soil contamination, and adverse effects on community well-being. Environmentally, untreated or improperly handled sludge can contaminate rivers, groundwater, and urban soils, disrupt ecosystems, and contribute to greenhouse gas emissions. Socio-economically, inadequate management affects vulnerable populations, increases municipal costs, and limits the potential for resource recovery. This study examines these multifaceted challenges in a holistic manner, providing a comprehensive understanding of the consequences of mismanagement in African cities.

Highlight the potential benefits of sustainable sludge valorization. Beyond risk mitigation, sludge represents a valuable resource that can be leveraged for agricultural improvement, energy production, and local economic development. Sustainable valorization, including composting, anaerobic digestion, or incorporation into construction materials, has shown positive outcomes in numerous African contexts. By evaluating these opportunities, this study underscores the potential of turning a waste product into a driver of environmental and socio-economic benefits.

Serve as a conceptual foundation for future, more technical, and quantitative studies.

While this research is qualitative in nature, the insights generated can guide subsequent field studies, laboratory analyses, and policy-oriented research. By identifying critical knowledge gaps and conceptual models, the study provides a roadmap for technical investigations that measure nutrient content, pathogen reduction, energy yield, and cost-benefit ratios in sludge valorization projects.

## **Method**

### **Study design**

This research adopts a qualitative and analytical design, primarily centered on a comprehensive review of recent scientific literature and the critical analysis of sanitation sludge management and valorization practices. Given the nature of sanitation sludge as both a public health concern and a resource for sustainable development, a qualitative and analytical approach is particularly appropriate. Unlike purely quantitative studies that focus on measurable parameters such as pathogen counts, chemical composition, or energy potential, this study seeks to synthesize diverse sources of knowledge, identify conceptual frameworks, and critically evaluate practical and policy experiences in different African urban contexts.

This approach is particularly aligned with the objectives of awareness-raising and policy-oriented articles, which aim to inform stakeholders, guide decision-making, and influence sustainable practice adoption. Moreover, the methodology is consistent with the standards of the Journal of Environmental Sciences and Practices for review articles, which emphasize systematic literature evaluation, critical synthesis, and relevance to contemporary environmental and urban challenges.

### **Selection of documentary sources**

#### **Temporal Scope**

The literature selected for this study covers the period 2020–2025. This temporal restriction ensures that the data, findings, and recommendations reflect the most current practices, technological developments, and policy frameworks in the field of sanitation sludge management. Given the rapid evolution of urban sanitation systems, particularly in West Africa, focusing on recent literature provides insights into emerging trends, innovative valorization techniques, and contemporary challenges that older studies may not capture.

#### **Source Types**

The study draws upon a diverse range of documentary sources, including:

Peer-reviewed scientific articles: To ensure the credibility and reliability of findings, only articles published in recognized journals with rigorous peer review processes were considered. These articles provide detailed case studies, empirical results, and methodological rigor essential for critical evaluation.

**International reports and guidelines:** Publications from authoritative organizations such as the World Health Organization (WHO), the Food and Agriculture Organization (FAO), and the United Nations Environment Programme (UNEP) offer globally recognized standards and recommendations for sanitation management and sludge valorization. These reports provide policy context and comparative benchmarks for local practices.

**Theses and dissertations:** Graduate research provides in-depth analyses of specific contexts, including urban centers like Korhogo, often combining field observations with theoretical frameworks.

**West African case studies:** Given the focus on African urban sanitation, studies from cities in Côte d'Ivoire, Ghana, Nigeria, and Senegal were prioritized. These cases provide relevant lessons, technical innovations, and socio-economic considerations that are directly applicable to the study area.

## **Databases Consulted**

A systematic search was conducted in major scientific databases, including:

**ScienceDirect:** For peer-reviewed journals in environmental science, urban planning, and public health.

**SpringerLink:** For technical publications, conference proceedings, and books addressing sanitation and waste management.

**ResearchGate:** To access emerging studies, preprints, and collaborative research projects in West African contexts.

**Scopus:** To ensure broad coverage of indexed journals and citation tracking, facilitating the identification of influential studies in sludge valorization.

## **Selection Criteria**

Inclusion criteria for selecting sources were as follows:

Focus on sanitation sludge valorization or management practices.

Address health, environmental, or socio-economic impacts.

Include urban case studies in African contexts, with particular attention to West Africa.

Provide evidence-based findings, methodologies, or conceptual analyses applicable to municipal decision-making and policy formulation.

## **Exclusion criteria were:**

Non-scientific sources, such as newspaper articles or non-peer-reviewed reports lacking methodological rigor.

Outdated studies prior to 2020 that may not reflect current practices, technologies, or policy frameworks.

Publications not directly relevant to sludge valorization or its socio-environmental implications.

This rigorous selection ensures the reliability, relevance, and applicability of the literature reviewed, providing a robust foundation for analysis and synthesis.

## **Analysis procedure**

The analysis was structured into a multi-step process to ensure systematic evaluation and meaningful synthesis.

### **Identification of Key Themes**

The review process began with the identification of recurring themes and critical issues within the literature, categorized into three main areas:

**Public Health:** Studies were examined to identify key pathogens present in untreated sludge, incidences of waterborne and vector-borne diseases linked to improper sludge management, and patterns of exposure among urban populations, particularly vulnerable groups such as children and informal settlement dwellers.

**Environmental Impacts:** This theme encompasses soil and water contamination, impacts on biodiversity, greenhouse gas emissions, and other ecological consequences associated with sludge mismanagement.

**Sustainable Development and Valorization:** This includes approaches to sludge reuse, such as composting, anaerobic digestion for biogas production, nutrient recovery for agriculture, and incorporation into construction materials, aligning with circular economy principles.

### **Synthesis of Information**

Information was systematically synthesized by grouping data and examples according to the key themes. For each theme, the study highlights:

Quantitative and qualitative findings from the literature.

Specific examples from West African urban contexts, illustrating successes and failures.

Comparative insights from international experiences that could inform local practices.

This synthesis allows for a holistic understanding of both risks and opportunities associated with sludge valorization.

### **Critical Analysis**

Critical analysis involved comparing local practices in Korhogo with international standards and African best practices. Key aspects included:

Identification of gaps between current municipal practices and WHO/FAO recommendations.

Assessment of the feasibility and sustainability of existing valorization initiatives in the local context.

Evaluation of socio-economic, cultural, and institutional barriers that may affect the adoption of sustainable practices.

The analysis highlights areas for policy intervention, technical improvement, and community engagement to enhance the effectiveness of sludge valorization strategies.

### **Integrated Writing and Recommendations**

Each theme was then discussed in relation to urban, health, and environmental challenges, allowing the formulation of context-specific recommendations. This integrative approach ensures that:

Recommendations are grounded in empirical and theoretical evidence.

Policy and practice suggestions are adapted to the socio-economic realities of Korhogo.

Potential trade-offs between environmental, health, and economic objectives are clearly addressed.

By combining critical review, thematic synthesis, and contextual analysis, this methodology provides a comprehensive framework for understanding and promoting sustainable sludge management and valorization in African urban settings.

## Results

### Public Health Challenges of Sanitation Sludge

Poor sanitation sludge management represents a critical public health issue, particularly in rapidly urbanizing cities of Africa where infrastructure development often lags behind population growth. Untreated sludge contains a diverse array of microbial pathogens, including *Escherichia coli*, *Salmonella* spp., *Shigella*, as well as intestinal viruses and helminths, which are responsible for waterborne and soil-transmitted diseases (Tra et al., 2024; WHO, 2018). These pathogens can spread via several routes: direct contact during informal emptying, contamination of surface water bodies, infiltration into groundwater, and airborne transmission in some cases.

Field studies conducted in several West African cities report an association between proximity to sludge dumping sites and increased prevalence of gastrointestinal infections, including diarrhea, cholera outbreaks, and other enteric diseases (Tra et al., 2024). This body of evidence also points to the disproportionate vulnerability of children, elderly populations, and immunocompromised individuals, highlighting the critical need for intervention in densely populated urban neighborhoods.

No dedicated field survey of Korhogo was conducted for this review, and comprehensive local epidemiological data remain unavailable. However, by analogy with practices documented in comparable West African secondary cities, it is plausible that sludge from septic tanks and small treatment facilities is disposed of near residential areas, informal waterways, or agricultural fields. If such practices occur, they would create continuous exposure pathways for local communities, particularly children who play near drainage channels, as well as adults engaged in informal agriculture or sanitation services. Evidence from comparable contexts suggests that communities with repeated exposure experience chronic gastrointestinal and parasitic infections, leading to reduced productivity, increased healthcare costs, and diminished quality of life — a hypothesis that dedicated local data collection could confirm.

The potential solution lies in sustainable sludge valorization, which includes treatment, transformation, and safe reuse. Properly treated sludge can significantly reduce microbial loads, minimizing the risk of waterborne disease transmission. Methods such as composting, anaerobic digestion, and thermal treatment not only neutralize pathogens but also stabilize organic matter, making sludge safe for agricultural use or energy recovery (UNEP, 2020). Beyond technical interventions, public health awareness campaigns and community engagement are essential to ensure that treated sludge is handled safely and that residents adopt hygienic practices during its use.

## **Environmental challenges**

The environmental repercussions of poorly managed sanitation sludge are extensive and multifaceted. Untreated sludge contributes to soil, surface water, and groundwater pollution, decreasing both water and soil quality, disrupting ecosystems, and threatening biodiversity (Odirile et al., 2024). Excess nutrients, particularly nitrogen and phosphorus, lead to eutrophication of rivers and lakes, promoting algal blooms and oxygen depletion, which negatively affects aquatic life. Moreover, organic matter decomposition in sludge generates methane and nitrous oxide, potent greenhouse gases contributing to climate change.

Pilot studies in West African cities have demonstrated that even basic valorization strategies can markedly reduce environmental risks. Composting, for example, not only stabilizes organic matter and reduces pathogen loads but also transforms sludge into a valuable soil amendment capable of restoring degraded lands. Anaerobic digestion enables the production of biogas, providing renewable energy while simultaneously reducing the organic and microbial content of sludge. Nartey et al. (2021) show that fecal-sludge-derived compost fertilizer applied to agricultural soils enhances soil fertility and increases crop yields — by 12% to 30% depending on the crop in field trials conducted in Ghana — while reducing reliance on chemical fertilizers.

In Korhogo, even small-scale initiatives, such as localized composting or anaerobic digestion at community levels, could significantly mitigate environmental contamination, especially in neighborhoods adjacent to informal drainage channels. Integrating sludge valorization into local urban planning has the potential to transform urban waste into a renewable resource, reducing pollution and promoting sustainable resource management.

Furthermore, environmental benefits extend beyond pollution control. Reusing treated sludge in agriculture or urban greening projects contributes to soil carbon sequestration, improves soil water retention, and strengthens resilience to urban flooding. Such interventions align with Sustainable Development Goals (SDGs), particularly SDG 6 (clean water and sanitation), SDG 11 (sustainable cities), and SDG 13 (climate action), emphasizing the intersection between sanitation management and broader urban sustainability objectives.

## **Socio-economic opportunities of sludge valorization**

Beyond public health and environmental benefits, sludge valorization presents substantial socio-economic opportunities, particularly in the context of African cities with growing urban populations and limited municipal resources. Literature shows that valorization can lead to the production of organic fertilizers, energy recovery through biogas generation, and job creation across collection, treatment, and distribution sectors (UNEP, 2020).

In cities such as Lomé (Togo) and Ouagadougou, sludge valorization has already created micro-enterprise opportunities, enabling local communities to generate income while addressing waste management challenges. Biogas produced from sludge has been successfully utilized for cooking, electricity generation, and industrial processes, contributing to energy self-sufficiency and reducing reliance on fossil fuels (UNEP, 2020). Moreover, the commercialization of composted sludge as organic fertilizer enhances local agricultural productivity, reduces expenditure on synthetic fertilizers, and strengthens food security.

Social acceptance plays a pivotal role in the success of these initiatives. Participation of local communities in decision-making, collection, and distribution ensures that valorization programs are socially inclusive and culturally appropriate. Awareness campaigns emphasizing the safety, environmental benefits, and economic potential of treated sludge increase adoption rates and promote long-term sustainability.

In Korhogo, implementing integrated sludge valorization strategies could transform a major urban sanitation challenge into a driver of circular urban development. By linking waste management with energy production, agriculture, and local employment, valorization initiatives can contribute to resilient and sustainable city growth, turning environmental and health risks into economic and social assets.

## **Governance, social acceptance, and regulatory framework**

The success of sludge valorization is closely linked to effective governance, community engagement, and robust regulatory frameworks. Several obstacles must be addressed to ensure sustainability:

**Lack of tailored public policies and regulatory frameworks:** Many West African cities lack specific legislation for sludge management, treatment standards, and reuse guidelines. Without clear regulatory mechanisms, informal practices dominate, increasing public health and environmental risks.

**Low awareness among citizens:** Communities often perceive sludge as purely waste, ignoring its potential for resource recovery. Misconceptions about safety, odor, and hygiene further limit acceptance.

**Skepticism among end-users:** Farmers and households may hesitate to use treated sludge, fearing contamination or crop damage. Overcoming these barriers requires education, demonstration projects, and evidence-based communication.

Experiences from cities such as Ouagadougou and Lomé highlight key factors for successful implementation:

Institutional collaboration between municipalities, NGOs, and private actors.

Participatory planning, where communities contribute to decision-making, monitoring, and maintenance.

Technical training for workers and local entrepreneurs involved in sludge collection, treatment, and reuse.

Public awareness campaigns, demonstrating both the safety and benefits of treated sludge through pilot projects and real-world applications.

In Korhogo, adopting similar approaches could foster community trust, institutional capacity, and policy coherence, enabling sustainable sludge valorization. Ultimately, governance mechanisms, social acceptance, and regulatory oversight form the triad of success

necessary to translate scientific and technical possibilities into practical, health-promoting, and environmentally sustainable solutions.

## **discussion**

### **Public health and population protection**

The data analyzed indicate that poor sanitation sludge management constitutes a major public health risk, particularly in secondary cities in Africa such as Korhogo. In these urban centers, rapid population growth and insufficient sanitation infrastructure create conditions in which untreated sludge is frequently disposed of in informal areas, drainage channels, and peri-urban agricultural lands. This practice exposes communities to microbial pathogens such as *Escherichia coli*, *Salmonella* spp., *Shigella*, and various helminths, as well as viruses responsible for gastrointestinal and waterborne diseases (Tra et al., 2024; WHO, 2018).

Comparative evidence from other African cities, including Accra (Ghana) and Ouagadougou (Burkina Faso), suggests that a lack of formalized sludge treatment is associated with higher morbidity, particularly among children under five, pregnant women, and immunocompromised individuals (Tra et al., 2024). Consistent with this pattern, communities adjacent to unregulated sludge disposal sites in the sub-region have been reported to experience a markedly higher burden of diarrheal disease than areas served by formal treatment and disposal systems, underscoring the direct health risks of improper sludge management — although city-specific incidence figures for Accra could not be independently verified for this review and should be checked against the primary sources before publication.

Sludge valorization emerges as a critical public health intervention rather than merely an environmental or economic opportunity. Transforming sludge through processes such as composting, anaerobic digestion, or thermal treatment significantly reduces microbial loads, making sludge safer for handling, reuse, or disposal. The transformation process interrupts transmission pathways for pathogens, minimizing direct contact with humans and preventing potential outbreaks.

Moreover, the indirect health benefits of sludge valorization are considerable. By reducing disease incidence, communities experience lower pressure on local healthcare services, which often operate with limited capacity in secondary cities like Korhogo. Fewer disease cases reduce hospital admissions and healthcare costs, increase school attendance among children, and improve adult productivity, generating broader socio-economic benefits. For example, pilot sludge treatment initiatives that reduce gastrointestinal disease prevalence could plausibly translate into measurable gains in adult work productivity and school attendance, although the review did not identify a verifiable primary source quantifying this effect for Ouagadougou, and such a figure should not be cited until confirmed against the original study.

Lastly, public health improvements are closely linked to community awareness. Educating residents about safe handling practices, hygiene measures, and the benefits of treated sludge reinforces health gains and encourages acceptance of valorization initiatives. In Korhogo, awareness campaigns integrated with community-based collection and treatment could play a decisive role in reducing disease burden while fostering local ownership of sanitation solutions.

## Environmental sustainability

Sludge valorization also provides substantial environmental benefits, particularly in urban contexts with limited arable land and fragile ecosystems. Untreated sludge contributes to soil and water pollution, releasing high concentrations of nitrogen and phosphorus that promote eutrophication in rivers and lakes (Odirile et al., 2024). Eutrophication leads to algal blooms, oxygen depletion, and the collapse of aquatic ecosystems, affecting water quality and biodiversity.

By contrast, treated sludge applied to agricultural soils or urban green spaces enhances soil fertility, restores degraded lands, and promotes sustainable urban agriculture. Evidence from West African cities suggests that composted sludge increases organic matter content, improves soil structure, and enhances nutrient availability for crops (Nartey et al., 2021). Field trials of fecal-sludge-derived compost fertilizer across six agro-ecological zones in Ghana reported yield increases of 12% for tomato, 27% for rice and maize, and 30% for pepper compared to standard fertilization (Nartey et al., 2021), illustrating the potential of sludge valorization to support local food security.

Despite these benefits, residual environmental risks must be carefully considered. Some sludge may contain heavy metals, persistent organic pollutants, or micropollutants, which could accumulate in soil or crops if proper treatment and monitoring are not conducted. UNEP (2020) emphasizes the importance of environmental monitoring programs to measure metal content, pathogen reduction, and nutrient balance, ensuring that valorization practices do not inadvertently create new environmental or health risks.

In Korhogo, even small-scale sludge treatment initiatives could have significant environmental impacts, reducing contamination in rivers, canals, and residential areas. Moreover, integrating sludge valorization into urban planning—such as using treated sludge for landscaping, reforestation, or urban agriculture—can improve ecosystem services, increase carbon sequestration, and mitigate urban heat island effects. By combining technical treatment methods with environmental oversight, Korhogo could develop a model of sustainable urban sanitation that balances resource recovery with ecological protection.

## **Socio-economic opportunities and local development**

Sludge valorization presents considerable socio-economic opportunities, transforming a waste problem into a productive resource. Beyond health and environmental improvements, treated sludge supports the circular economy, contributing to organic fertilizer production, energy generation through biogas, and job creation across collection, treatment, and distribution sectors.

Several West African studies illustrate these benefits. In Burkina Faso, community-based composting initiatives have created stable income sources for micro-enterprises, while reducing urban pollution. Local entrepreneurs involved in biogas production have successfully supplied renewable energy for cooking and small-scale electricity generation, decreasing dependence on charcoal or fuelwood and contributing to climate change mitigation. Participatory models that involve residents in collection and reuse can enhance both social acceptance and economic viability.

For Korhogo, implementing sludge valorization programs could:

Generate local employment in collection, treatment, and distribution of treated sludge.

Provide renewable energy, such as biogas for cooking or electricity generation, contributing to energy self-sufficiency.

Support urban and peri-urban agriculture with safe, nutrient-rich fertilizers, reducing dependence on chemical inputs and increasing food security.

Stimulate micro-enterprise development, enabling residents to profit from compost, biogas, or other value-added products derived from sludge.

General economic reasoning suggests that integrated sludge valorization could reduce municipal sanitation costs, improve waste management efficiency, and generate revenue streams from treated products, although this review did not identify a dedicated economic model for Korhogo or a comparable secondary city to substantiate the scale of these effects. Over time, these initiatives foster resilient local economies while simultaneously addressing pressing environmental and public health challenges.

## **Governance and institutional framework**

The effectiveness of sludge valorization is closely tied to institutional capacity and supportive public policies. Weak governance, fragmented responsibilities, and inadequate regulation are among the primary obstacles to sustainable sludge management in African cities (Lerebours et al., 2021).

Experiences in Lomé (Togo) and Ouagadougou demonstrate that effective governance requires:

Structured sludge collection and treatment systems, ensuring consistent coverage and preventing informal dumping.

Quality assurance for valorized products, including pathogen reduction monitoring, nutrient content assessment, and verification of environmental safety.

Active involvement of municipalities, NGOs, and private actors, creating accountability, resource mobilization, and technical support.

In Korhogo, where centralized infrastructure and regulatory oversight are limited, developing an integrated institutional framework is essential. This framework should include clear mandates for municipal authorities, partnerships with community organizations, and mechanisms for participatory monitoring, ensuring both technical efficiency and social legitimacy.

Capacity building is also critical. Municipal staff, community facilitators, and micro-entrepreneurs require training in treatment technologies, monitoring protocols, and regulatory compliance. Such initiatives strengthen institutional capacity and promote long-term sustainability of sludge valorization programs.

## **Social acceptance and community perception**

Community acceptance is a fundamental determinant of the success of sludge valorization initiatives. Negative perceptions about the safety and hygiene of treated sludge can hinder adoption, particularly for agricultural or domestic applications.

Studies indicate that awareness-raising, training, and practical demonstrations significantly increase community acceptance. Demonstration plots using composted sludge, biogas cooking trials, and participatory workshops have been successful in Burkina Faso and Ghana, improving residents' willingness to engage in collection, treatment, and reuse activities (UNEP, 2020).

Involving residents directly in program implementation fosters a sense of ownership and collective responsibility, improving operational efficiency and compliance. Participatory approaches also facilitate social learning, where community members share knowledge, report non-compliance, and act as local champions for safe sludge practices.

For Korhogo, integrating social engagement into sludge valorization programs is critical. Community workshops, school-based education, and farmer cooperatives could serve as platforms to disseminate knowledge, demonstrate safe practices, and build trust in treated products. Long-term engagement ensures that the benefits of sludge valorization are sustained and socially embedded.

## **Regional comparisons and lessons for Korhogo**

A comparative perspective provides valuable lessons for Korhogo. Cities with structured pilot programs such as Ouagadougou and Accra demonstrate tangible health, environmental, and economic benefits resulting from systematic sludge valorization. In contrast, cities lacking environmental monitoring and regulatory frameworks often struggle with informal disposal, low community acceptance, and limited socio-economic impact.

Key lessons include:

Integration of technical, social, and regulatory dimensions is essential for success. Valorization programs must combine effective treatment, participatory approaches, and regulatory oversight.

Community engagement and technical training increase adoption, compliance, and sustainability.

Monitoring and evaluation systems enable adaptive management, ensuring that risks are minimized and benefits maximized.

For Korhogo, these lessons suggest the need for an integrated strategy that includes:

Investment in sludge treatment infrastructure.

Active involvement of local communities and stakeholders.

Tailored regulatory frameworks and institutional coordination.

Continuous education, awareness campaigns, and training programs.

## **Future research perspectives**

While this study highlights the conceptual and practical benefits of sludge valorization, further research is required to operationalize these findings in Korhogo:

**Energy and agronomic potential:** Quantitative studies should assess biogas yield, nutrient recovery efficiency, and crop performance using treated sludge.

**Health and environmental impact quantification:** Epidemiological and ecological studies are needed to measure pathogen reduction, disease incidence changes, and environmental contamination trends.

**Economic and regulatory modeling:** Feasibility studies should evaluate cost-effectiveness, potential revenue streams, and optimal governance structures for urban African contexts.

**Pilot participatory programs:** Testing small-scale valorization initiatives with community engagement will provide insights into social acceptance, operational efficiency, and scalability.

By addressing these research gaps, Korhogo could develop a locally adapted, sustainable model of sanitation sludge valorization that maximizes health, environmental, and economic outcomes.

## **Challenges and Limitations of Sludge Valorization**

While sludge valorization offers significant public health, environmental, and socio-economic benefits, several challenges and limitations must be considered to ensure sustainable implementation in cities like Korhogo. Understanding these barriers is crucial for designing realistic and effective strategies.

### **Technical Challenges**

Technical limitations often constrain the adoption of sludge valorization. Many secondary African cities lack adequate treatment infrastructure, including anaerobic digesters, composting facilities, or safe storage sites. Without proper infrastructure, sludge may remain partially untreated, posing residual health and environmental risks. In addition, variability in sludge composition—such as moisture content, organic matter concentration, and contaminant levels—can affect the efficiency of composting, biogas production, and other treatment methods (Odirile et al., 2024). Seasonal variations, such as increased rainfall, can also disrupt collection and treatment operations, leading to sporadic environmental contamination.

### **Economic and Financial Constraints**

Financial limitations represent a significant barrier. Establishing treatment facilities, purchasing equipment, and maintaining operational systems require substantial investment. Municipal budgets in secondary cities like Korhogo are often constrained, making it challenging to sustain long-term operations. While micro-enterprises and public-private partnerships can alleviate some financial burdens, initial capital costs and limited access to credit can hinder project scaling. Moreover, the economic viability of sludge valorization depends on market acceptance of products such as compost or biogas, which can fluctuate depending on local demand and price sensitivity.

### **Regulatory and Institutional Limitations**

A weak regulatory environment is a recurrent limitation in African cities. In the absence of clear policies, legal frameworks, and enforcement mechanisms, informal disposal practices often continue, undermining health and environmental protection efforts. Institutional fragmentation—where multiple agencies have overlapping responsibilities—can lead to inefficiencies, lack of accountability, and poor coordination. Capacity gaps in municipal agencies, including limited technical expertise and insufficient monitoring capabilities, further constrain effective governance.

### **Social and Cultural Barriers**

Social acceptance remains a critical challenge. Cultural perceptions of human waste as dangerous or taboo can lead to resistance against the use of treated sludge, even when it is safe. Misinformation or lack of awareness about treatment processes may reduce community

participation and hinder project sustainability. Engaging local communities through awareness campaigns, training programs, and participatory approaches is therefore essential, but these efforts require time, resources, and consistent communication.

## **Environmental Risks and Uncertainties**

Although sludge valorization generally reduces environmental contamination, residual risks remain, particularly when sludge contains heavy metals, organic micropollutants, or persistent pathogens. Improperly treated sludge may lead to soil and water contamination, posing long-term risks for agriculture and public health (UNEP, 2020). Continuous monitoring, risk assessment, and quality assurance protocols are necessary to minimize such risks. Additionally, climate-related challenges, such as flooding or high temperatures, may compromise the effectiveness of treatment systems, requiring adaptive management strategies.

## **Recommendations to Overcome Challenges**

To address these limitations, a multi-pronged strategy is recommended for Korhogo:

Invest in decentralized treatment facilities that are adapted to local conditions and sludge composition.

Secure financial support through public-private partnerships, grants, and microfinance schemes to ensure long-term operational sustainability.

Develop and enforce regulatory frameworks that define standards for collection, treatment, reuse, and monitoring.

Strengthen institutional coordination between municipal agencies, health authorities, and community organizations.

Promote community engagement and awareness campaigns to build social acceptance and reduce cultural resistance.

Implement environmental monitoring and risk assessment protocols to identify and mitigate residual contamination.

By acknowledging and addressing these challenges, Korhogo can maximize the benefits of sludge valorization while minimizing health, environmental, and socio-economic risks, ultimately creating a sustainable urban sanitation model.

## Conclusions

This study highlights the critical importance of sanitation sludge valorization as a strategic lever for improving public health, protecting the environment, and fostering local socio-economic development in secondary African cities, with a specific focus on Korhogo, Côte d'Ivoire. The literature reviewed indicates that inadequate sludge management remains a major source of health risks and environmental degradation, particularly in rapidly urbanizing contexts characterized by limited infrastructure and weak institutional capacity (WHO, 2018; Tra et al., 2024).

From a public health perspective, the literature reviewed indicates that untreated sanitation sludge contains high concentrations of pathogenic microorganisms capable of contaminating water resources and exposing populations to waterborne and vector-borne diseases. Experiences from West African cities such as Accra and Ouagadougou show that the absence of structured treatment and valorization systems significantly increases morbidity, especially among vulnerable populations (Tra et al., 2024). In this context, sludge valorization through controlled treatment processes—such as composting and anaerobic digestion—emerges as an effective preventive public health intervention, capable of reducing microbial loads and limiting direct human exposure.

Environmentally, sludge valorization contributes to the reduction of soil, surface water, and groundwater pollution by controlling nutrient discharges and limiting eutrophication processes (Odirile et al., 2024). The reuse of treated sludge as a soil amendment has been shown to improve soil fertility, restore degraded lands, and support urban and peri-urban agriculture, thereby reinforcing sustainable resource management practices (Nartey et al., 2021). Nevertheless, the presence of potential contaminants such as heavy metals and organic micropollutants highlights the necessity of rigorous monitoring frameworks and regulatory oversight to ensure environmental safety (UNEP, 2020).

Beyond health and environmental benefits, sludge valorization offers significant socio-economic opportunities. The development of local value chains around compost production, biogas generation, and sludge treatment services can create employment, stimulate micro-enterprises, and enhance local energy autonomy. Participatory valorization initiatives are widely thought to strengthen community ownership and improve social acceptance, which would be essential for long-term sustainability, though this review did not identify West African evidence directly quantifying that effect. For Korhogo, these opportunities align with broader objectives of circular urban development, transforming sanitation challenges into productive resources.

However, the study also underscores that successful sludge valorization cannot be achieved without an enabling governance and institutional framework. The lack of clear public policies, regulatory standards, and coordination among municipalities, health authorities, and private actors remains a major constraint in many secondary cities (Lerebours et al., 2021). Lessons drawn from Lomé and Ouagadougou emphasize the importance of municipal leadership, stakeholder engagement, awareness-raising programs, and technical capacity building to ensure effective implementation and sustainability of valorization initiatives.

In conclusion, sanitation sludge valorization represents a multidimensional solution that simultaneously addresses public health protection, environmental sustainability, and

socio-economic development in Korhogo. To fully harness its potential, integrated strategies are required, combining appropriate treatment technologies, community participation, regulatory frameworks, and continuous monitoring. While this study adopts a qualitative and conceptual approach, it provides a solid foundation for future research aimed at quantifying health impacts, assessing energy and agronomic potential, and testing pilot participatory valorization models adapted to the local context. Such efforts are essential to support evidence-based decision-making and promote resilient and sustainable urban sanitation systems in Côte d'Ivoire and across West Africa.

## References

- Lerebours, A., Scott, R., Sansom, K., & Kayaga, S. (2021). Regulating sanitation services in sub-Saharan Africa: An overview of the regulation of emptying and transport of faecal sludge in 20 cities and its implementation. *Utilities Policy*, 73, 101315. <https://doi.org/10.1016/j.jup.2021.101315>
- Nartey, E. G., Cofie, O., Gebrezgabher, S., & Nikiema, J. (2021). Crops and farmers' response to application of fecal sludge derived—Fortifer™ in different agro-ecological zones in Ghana. *Journal of Environmental Management*, 293, 112970. <https://doi.org/10.1016/j.jenvman.2021.112970>
- Odirile, P. T., Obuseng, V. C., Moshoeshe, M., Tshenyego, L., & Mbongwe, B. (2024). Assessment of faecal sludge quality, heavy metal contamination, and ecological risk: implications for sustainable agriculture. *Environmental Monitoring and Assessment*, 196(12), 1270. <https://doi.org/10.1007/s10661-024-13385-5>
- Tra, L. T. A., Dongo, K., Pessoa Colombo, V., Singh, S., & Chenal, J. (2024). Environmental and socio-economic determinants of fecal sludge emptying in Sub-Saharan Africa: A cross-sectional mixed-methods study in Abidjan, Côte d'Ivoire. *Environmental Science and Pollution Research International*, 31(58), 66497–66511. <https://doi.org/10.1007/s11356-024-35631-6>
- UNEP & IWMI. (2020). *Faecal sludge management in Africa: Socioeconomic aspects and human and environmental health implications*. United Nations Environment Programme. <https://wedocs.unep.org/20.500.11822/34350>
- WHO. (2018). *Guidelines on sanitation and health*. World Health Organization. <https://apps.who.int/iris/bitstream/handle/10665/274939/9789241514705-eng.pdf>