

Integrated Waste Management and Facility Siting in Ghana: A Systematic Review and Meta-Analysis with Hydrogeological and GIS Insights

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Abstract

Rapid urbanization, population growth, and changing consumption patterns have intensified solid and liquid waste generation in Ghana, placing significant pressure on existing waste management systems. Despite established regulatory frameworks, persistent challenges such as open dumping, weak enforcement, limited source segregation, and inadequate rural service coverage continue to undermine environmental sustainability and public health. This study presents a systematic review and meta-analysis of waste management practices and facility siting approaches in Ghana, guided by PRISMA and structured using the Population–Concept–Context framework. A total of 21,253 records were screened, with 33 studies meeting the inclusion criteria for qualitative synthesis and quantitative analysis using a random-effects model. The findings indicate a continuous increase in waste generation with no evidence of absolute reduction. Urban collection efficiency reaches up to 80% in some cities, whereas rural coverage remains critically low (approximately 5.8%), leading to widespread reliance on open burning and associated health risks. National segregation and recycling rates remain below 15%, despite the high diversion potential (approximately 90%) demonstrated by facilities such as the Kumasi Compost and Recycling Plant. GIS-based siting approaches show strong technical performance (accuracy approximately 77%, Kappa approximately 0.71), but their implementation is constrained by data limitations, governance challenges, and weak integration of localized hydrogeological information, particularly within the Volta and Pra basins. The study identifies a critical policy–practice gap driven by limited investment, unreliable data, and inadequate integration of Earth Science datasets. It concludes that sustainable waste governance requires integrated systems, mandatory segregation, hybrid siting approaches, improved data platforms, and stronger institutional enforcement.

Keywords

Circular economy transition, Waste facility siting, Hydrogeological vulnerability, Environmental health risk, Spatial decision-support systems, Sub-Saharan Africa

1. Introduction

Rapid urbanization, population growth, and changing consumption patterns have significantly increased both solid and liquid waste generation in Ghana, placing sustained

pressure on already constrained waste management systems. Solid waste management encompasses the generation, segregation, collection, transportation, treatment, recycling, and final disposal of non-liquid materials, while liquid waste



management involves the treatment and disposal of wastewater, sewage, and industrial effluents to protect environmental and public health (Zakhilwal et al., 2024; Vergara and Tchobanoglous, 2012). Ineffective management of these waste streams contributes to multiple environmental and health risks, including groundwater contamination through leachate infiltration, atmospheric pollution from open burning, greenhouse gas emissions, urban flooding due to clogged drainage systems, and the transmission of waterborne and vector-borne diseases such as cholera and malaria (Kumi-Boateng et al., 2020; Mensah, 2021).

In Ghana, waste management systems remain largely disposal-oriented, characterized by low collection coverage, widespread open dumping, limited engineered landfill infrastructure, and minimal source segregation (Akyen et al., 2017; Kwesi et al., 2021). While urban areas exhibit moderate collection efficiency, rural service coverage remains critically low, often leading to reliance on informal disposal practices such as open burning, with significant public health implications. Liquid waste management faces similar constraints, including limited sewerage infrastructure and inadequate treatment facilities, resulting in the discharge of untreated effluents into surface water bodies and infiltration into groundwater systems (Taiwo, 2009; Kookana et al., 2020). These risks are particularly pronounced in hydrogeologically sensitive regions, including the Volta and Pra basins, where geological characteristics such as fractured bedrock, variable permeability, and shallow aquifer systems increase vulnerability to contamination.

Landfill siting represents one of the most technically complex and socially contested aspects of waste governance. Although national policies and guidelines provide criteria for environmental protection, including buffer zones and geological suitability, implementation remains inconsistent. Many disposal sites have historically been selected based on land availability rather than detailed hydrogeological assessment, leading to environmentally unsuitable locations with long-term contamination risks (Kumi-Boateng et al., 2020; Akyen et al., 2017).

Advances in Geographic Information Systems and multi-criteria decision analysis have improved the technical reliability of siting approaches; however, their practical application is often constrained by limited high-resolution spatial data, weak institutional capacity, land tenure conflicts, and insufficient stakeholder engagement (Kwesi et al., 2021). The absence of localized Earth Science datasets, including soil permeability, lithology, and groundwater vulnerability mapping, further limits the operationalization of scientifically grounded siting decisions, thereby contributing to a persistent policy-practice gap.

Despite a growing body of research, the literature remains fragmented, with most studies focusing on localized solid waste issues and providing limited integration of liquid waste dynamics and hydrogeological processes. Furthermore, inconsistencies in data quality and reporting highlighted by widespread concerns regarding waste data reliability reduce the accuracy of predictive modelling and constrain evidence-based planning. The lack of standardized datasets,

comparative analyses, and long-term monitoring frameworks continues to hinder the development of integrated waste management systems and sustainable infrastructure planning.

Given these challenges, a comprehensive and methodologically robust synthesis is required to evaluate waste management performance, identify structural constraints, and support evidence-based decision-making. This study, therefore, applies a systematic review and meta-analysis to assess waste management practices, evaluate landfill siting approaches, examine policy effectiveness, and identify key gaps limiting sustainable waste governance in Ghana. By integrating technical, environmental, and institutional perspectives, the study provides a foundation for advancing data-driven, hydrogeologically informed, and socially responsive waste management strategies.

2. Conceptual and Theoretical Frameworks

The conceptual foundation of waste management and facility siting in Ghana reflects an evolving integration of environmental science, spatial planning, public health, and governance systems. Waste management is defined as a multi-stage process involving generation, segregation, collection, transportation, treatment, recycling, and final disposal, aimed at minimizing environmental and human health risks (Zakhilwal et al., 2024; Vergara and Tchobanoglous, 2012). This aligns with the Integrated Solid Waste Management (ISWM) framework, which emphasizes environmental protection, economic efficiency, social equity, and institutional governance (Pongracz and Pohjola, 2004). However, in practice, Ghana's system remains largely disposal-oriented, with limited implementation of circular economy principles such as reduction, reuse, and resource recovery (Akyen et al., 2017; Kwesi et al., 2021; Seah and Addo-Fordwuor, 2021; Mandpe et al., 2023).

A critical limitation in existing frameworks is the insufficient integration of liquid waste systems and hydrogeological processes. While traditional models focus predominantly on solid waste, they often neglect the role of wastewater discharge, leachate migration, and subsurface contaminant transport pathways. In hydrogeologically sensitive environments such as the Volta and Pra basins, factors including soil permeability, lithology, aquifer characteristics, and fracture systems significantly influence groundwater vulnerability and contaminant mobility (Yidana et al., 2008; Kumi-Boateng et al., 2020). The absence of high-resolution hydrogeological mapping and geochemical datasets limits the ability to operationalize scientifically informed siting decisions, thereby reinforcing the persistent policy-practice gap in Ghana's waste governance (Akyen et al., 2016; Kwesi et al., 2021).

Spatial decision-support frameworks, particularly Geographic Information Systems (GIS) integrated with Multi-Criteria Decision-Making (MCDM) techniques, have improved the technical robustness of waste facility siting (Kwesi et al., 2021; Kumi-Boateng et al., 2020). These approaches incorporate environmental, geological, social, and infrastructural criteria to identify suitable sites, often using methods such as the Analytical Hierarchy Process

(AHP) and weighted overlay analysis. However, these models frequently operate within a technocratic paradigm that inadequately accounts for socio-political dynamics, including land tenure systems, community resistance, and

governance fragmentation (Oteng-Ababio, 2011). Consequently, technically suitable sites may fail during implementation due to a lack of stakeholder acceptance or institutional constraints.



Fig. 1. Flowchart illustrating the conceptual framework of the study

The Public Health Protection Model further conceptualizes waste management as a critical mechanism for reducing disease transmission and environmental exposure. Improper waste disposal contributes to groundwater contamination, air pollution from open burning, and the spread of vector-borne and waterborne diseases (Kumi-Boateng et al., 2020; Mensah, 2021). However, the absence of long-term epidemiological monitoring and integrated environmental health data limits the ability to fully assess these impacts.

In addition, the Governance and Institutional Capacity framework highlights that waste management outcomes are shaped by regulatory enforcement, financial investment, and data reliability (Henry et al., 2006). In Ghana, decentralized responsibilities assigned to Metropolitan, Municipal, and District Assemblies are constrained by limited budgets, weak enforcement capacity, and fragmented data systems. Widespread concerns regarding the reliability of waste data further undermine planning and predictive modelling efforts, reducing the effectiveness of decision-support tools.

To address these limitations, this study advances an integrated conceptual framework that combines four key dimensions: (1) environmental and hydrogeological risk assessment, including soil permeability, groundwater vulnerability, and contaminant pathways; (2) spatial optimization through GIS-MCDM approaches; (3) socio-institutional dynamics, including governance structures and

community participation; and (4) circular economy principles emphasizing waste reduction, segregation, and resource recovery. This integrated framework moves beyond isolated approaches to capture the complex interactions between environmental, technical, and institutional factors. By explicitly linking Earth Science datasets, spatial modelling, and governance realities, the proposed framework (Fig. 1) provides a more comprehensive basis for evaluating waste management performance and siting effectiveness in Ghana. It also supports the development of hybrid GIS-participatory models that enhance both technical accuracy and social acceptance, thereby contributing to more sustainable and implementable waste management strategies.

3. Study Area Description

Ghana (Fig. 2), located in West Africa between latitudes 4°44'N and 11°11'N and longitudes 1°12'E and 3°15'W, covers approximately 238,535 km² and exhibits marked environmental, climatic, and socio-economic heterogeneity. The country is administratively divided into 16 regions and over 270 Metropolitan, Municipal, and District Assemblies (MMDAs), with pronounced north-south disparities in climate, infrastructure, and development. Southern Ghana experiences a bimodal rainfall regime (March-July and September-November), with annual precipitation ranging from 2,000 to 2,800 mm, supporting humid forest ecosystems. In contrast, northern Ghana is characterized by

a unimodal rainfall pattern (May–September), with annual totals between 700 and 1,100 mm and prolonged dry seasons typical of the Guinea and Sudan Savanna zones (Asante and Amuakwa-Mensah, 2015; Bessah et al., 2022). These climatic gradients influence waste generation patterns, water availability, and the technical performance of both solid and liquid waste management systems across ecological zones.

The geological and hydrogeological characteristics of Ghana play a critical role in determining the environmental impacts of waste disposal and facility siting. The country comprises three major geological provinces: the Paleoproterozoic Birimian Supergroup, the Neoproterozoic Voltaian Supergroup, and the coastal sedimentary basins. The Birimian terrain is characterized by highly weathered, fractured formations with significant secondary permeability,

making groundwater systems particularly vulnerable to contamination. The Voltaian Basin, which covers nearly 45% of the country, consists of sedimentary rocks with generally low primary permeability but locally significant fracture-controlled groundwater flow. In contrast, the coastal sedimentary basins exhibit variable permeability and shallow aquifer systems. These geological variations directly influence contaminant transport pathways, particularly for leachate from solid waste and untreated effluents from liquid waste systems (Yidana et al., 2008; Osei-Nuamah and Appiah-Adjei, 2017).

In major river systems such as the Volta and Pra basins, the interaction between surface water and groundwater further increases vulnerability to pollution, especially in areas where waste disposal practices are poorly regulated.

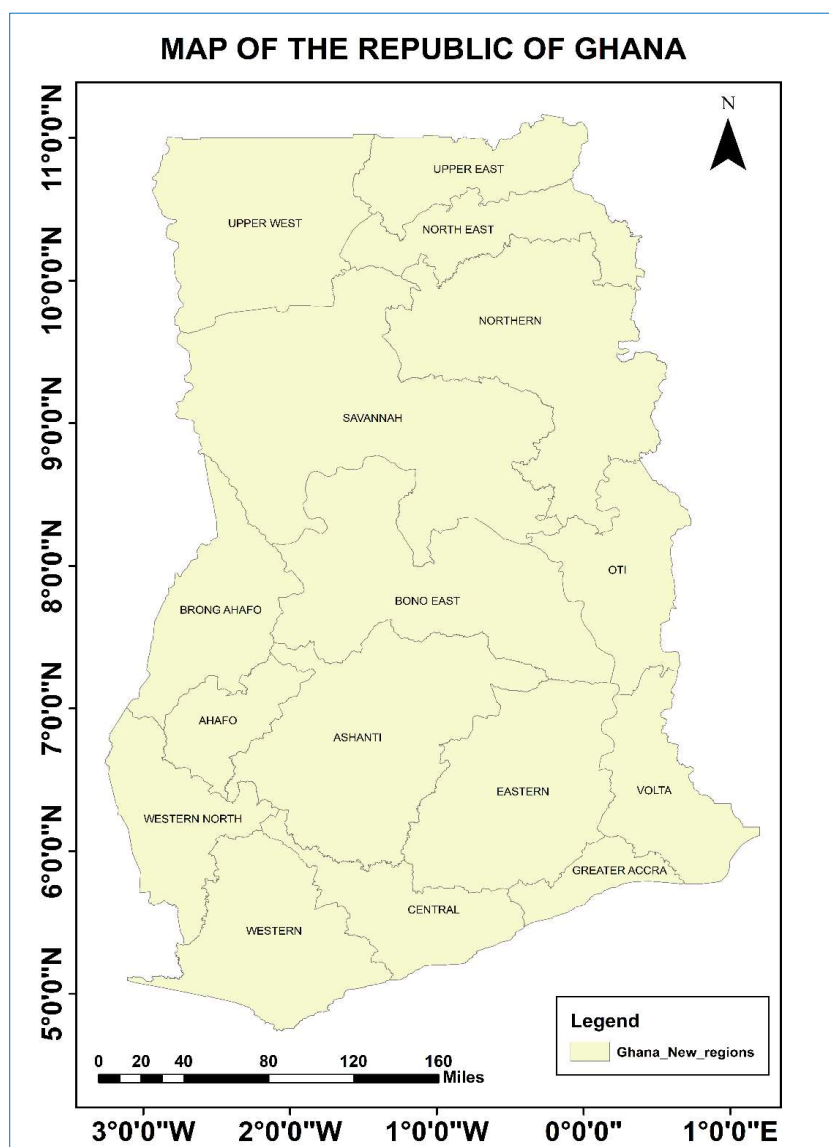


Fig. 2. Geospatial analysis of the study area

Environmental pressures in Ghana are intensifying due to rapid urbanization, natural resource exploitation, and climate variability. More than half of the population resides in urban areas, with major economic activity concentrated in

the Accra–Kumasi–Takoradi corridor, which generates a substantial proportion of the country’s solid and liquid waste. However, waste management infrastructure has not kept pace with this growth, resulting in limited sanitation

coverage, inadequate wastewater treatment, and continued reliance on informal disposal methods. In rural and peri-urban areas, weak infrastructure and low service coverage contribute to practices such as open dumping and burning, which have significant environmental and public health implications.

Furthermore, institutional and governance constraints strongly influence waste management outcomes. Complex land tenure systems, combining customary and statutory ownership, often delay or prevent the siting of waste facilities. At the same time, limited financial resources, weak enforcement capacity, fragmented institutional responsibilities, and unreliable environmental data systems hinder effective implementation of waste management policies (Cobbinah et al., 2017; Ali et al., 2021). These challenges contribute to a persistent policy–practice gap, where existing regulatory frameworks are not effectively translated into operational outcomes.

Overall, the interaction between climatic variability, hydrogeological conditions, infrastructure deficits, and governance limitations makes Ghana a highly relevant case for evaluating integrated waste management and facility siting. The country’s environmental complexity underscores

the need for spatially informed, hydrogeologically grounded, and institutionally feasible waste management strategies.

4. Methodology

4.1. Study Design

This study adopted a systematic review and meta-analysis design to evaluate solid and liquid waste management practices, facility siting approaches, environmental risks, and governance outcomes in Ghana. The review was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses framework to ensure transparency, reproducibility, and methodological rigour. The scope of the review was structured using the Population–Concept–Context framework. The Population comprised solid and liquid waste systems and associated facility siting practices. The Concept included collection, treatment, recycling, disposal, landfill and wastewater facility siting, environmental and public health risks, policy implementation, and governance performance. The Context focused on Ghana, with relevant Sub-Saharan African evidence included only where it provided comparative or methodological insight. This combined framework enabled the study to integrate technical, hydrogeological, public health, circular economy, and governance dimensions within one analytical structure.

Table 1. Search strings used in various databases

No	Database	Search Strings
1	Google Scholar	("Solid Waste Management" OR "Municipal Solid Waste" OR "MSW") AND ("Liquid Waste" OR "Wastewater" OR "Sewage" OR "Sanitation") AND ("Siting" OR "Location" OR "Facility Planning" OR "Site Selection") AND (Ghana OR "West Africa" OR "Sub-Saharan Africa")
2	Scopus	("Waste Management" OR "Solid Waste" OR "Liquid Waste") AND ("Landfill Siting" OR "Waste Facility" OR "Disposal Site" OR "Treatment Plant") AND ("Environmental Impact" OR "Public Health" OR "Contamination") AND (Ghana OR "West Africa")
3	ResearchGate	("Waste Management" OR "Sanitation") AND ("Ghana" OR "Accra" OR "Kumasi") AND ("Policy" OR "Practice" OR "Challenges" OR "Solutions")
4	Academia.edu	("Municipal Solid Waste" OR "Wastewater") AND ("Ghana" OR "West Africa") AND ("Management" OR "Treatment" OR "Disposal")

4.2. Search Strategy

A structured search strategy was developed to identify literature on waste management systems, facility siting, hydrogeological risk, policy performance, and environmental health impacts. Search terms combined keywords related to solid waste management, liquid waste, wastewater, sewage, landfill siting, waste facility location, geographic information systems, multi-criteria decision analysis, hydrogeology, groundwater contamination, leachate migration, public health, policy implementation, Ghana, West Africa, and Sub-Saharan Africa. Boolean operators were applied to improve search precision and coverage. Searches were conducted in Scopus, Google Scholar, ResearchGate, and Academia.edu.

The search period was limited to studies published between 2000 and 2025 to capture contemporary waste management technologies, policy reforms, urbanization dynamics, and spatial decision-support applications. Peer-reviewed articles were prioritized, while high-quality grey literature was included where it provided empirical or policy-relevant evidence. The search strategy was designed to reduce

publication bias, improve representation of African scholarship, and ensure balanced coverage of both solid and liquid waste systems. Examples of search strings and database combinations are presented in Table 1.

4.3. Study Selection Procedure

The selection process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses procedure. Two reviewers independently screened the retrieved records in sequential stages, beginning with title and abstract screening, followed by full-text eligibility assessment. Disagreements were resolved through discussion and consensus. The search initially yielded 21,253 records. After removing 380 duplicates using Mendeley, 20,873 records were screened by title and abstract. Of these, 20,000 records were excluded because they were irrelevant, lacked Ghana-specific or comparable African relevance, did not address waste management or siting, or lacked contextual applicability. A total of 873 full-text articles were assessed for eligibility. Of these, 840 were excluded due to absence of empirical data, insufficient methodological detail, non-African focus, opinion-based content, or language limitations. Ultimately,

33 studies met the inclusion criteria and were retained for quality appraisal, qualitative synthesis, and, where appropriate, quantitative meta-analysis. A PRISMA flow diagram (Fig. 3) illustrates the study selection process.

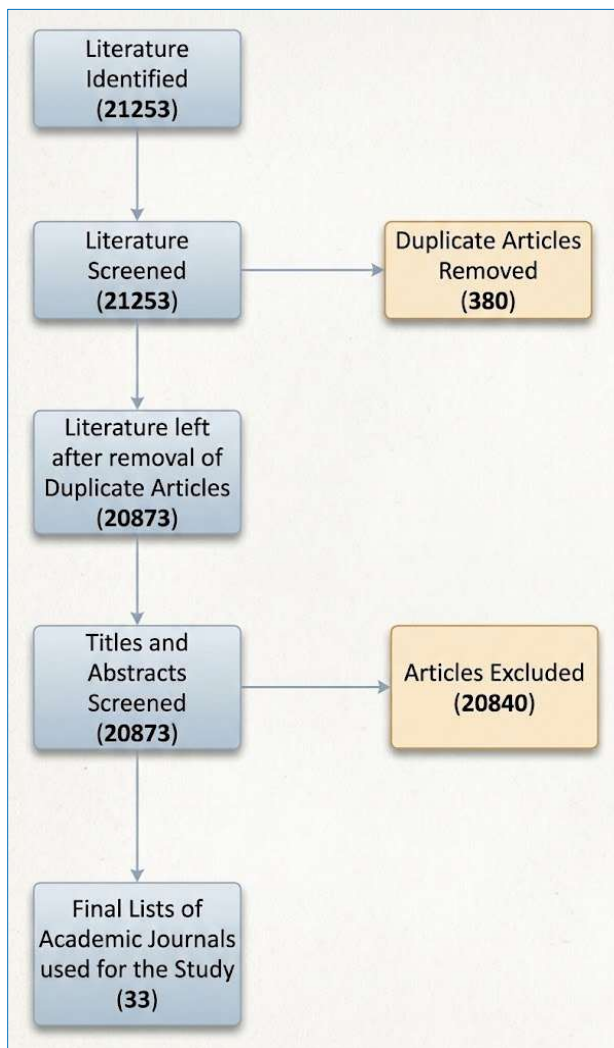


Fig. 3. PRISMA flow diagram for study selection process

4.4. Inclusion and Exclusion Criteria

Studies were included if they addressed solid waste management, liquid waste management, wastewater treatment, sanitation systems, landfill siting, or waste facility planning in Ghana. Comparative studies from West Africa or Sub-Saharan Africa were also included where they provided relevant benchmarking evidence. Eligible studies were required to present empirical data, use quantitative, qualitative, mixed-method, spatial, environmental, public health, or policy-based approaches, and report measurable outcomes such as waste generation, collection coverage, recycling performance, treatment efficiency, environmental contamination, groundwater risk, health effects, policy performance, or siting suitability. Studies were excluded if they were purely theoretical, opinion-based, unrelated to Ghana or comparable African contexts, lacked empirical evidence, did not report measurable outcomes, or used poorly documented siting methods. Studies focused exclusively on developed-country waste-to-energy systems,

hazardous industrial waste without municipal relevance, or non-African case studies were also excluded. Only English-language studies published from 2000 to 2025 were considered. Table 2 presents the detailed inclusion and exclusion criteria applied in this study.

4.5. Data Extraction

A standardized data extraction template was developed to ensure consistency and comparability across studies. Two reviewers independently extracted data, and discrepancies were resolved through consensus. Extracted information included authorship, publication year, study location, study design, temporal coverage, data sources, and methodological approach. For solid waste systems, extracted variables included waste generation rates, composition, collection coverage, disposal methods, recycling and diversion rates, treatment technologies, landfill characteristics, and the role of formal and informal actors. For liquid waste systems, extracted variables included wastewater generation, sewerage access, treatment coverage, effluent discharge, sludge management, and reported impacts on surface water and groundwater. Particular attention was given to hydrogeological variables such as soil permeability, lithology, aquifer vulnerability, leachate pathways, and groundwater contamination indicators, especially in relation to the Volta and Pra basins. For siting studies, extracted variables included geographic information system methods, multi-criteria decision analysis procedures, weighting techniques, buffer criteria, regulatory constraints, validation methods, classification accuracy, Kappa statistics, stakeholder participation, and implementation barriers. Governance-related variables included policy enforcement, institutional capacity, financing, data reliability, land tenure constraints, and community acceptance.

4.6. Quality Assessment

Methodological quality was assessed using a modified appraisal framework based on the Joanna Briggs Institute Critical Appraisal Tools and adapted to the multidisciplinary nature of waste management and facility siting research. The appraisal considered clarity of objectives, appropriateness of study design, reliability of data sources, sampling adequacy, transparency of analytical methods, reporting quality, relevance to Ghana or comparable African settings, and acknowledgement of bias. For geographic information system and multi-criteria decision analysis studies, additional attention was given to the transparency of siting criteria, weighting procedures, spatial data quality, validation methods, and reproducibility. For liquid waste and hydrogeological studies, quality assessment considered the extent to which studies reported groundwater vulnerability, contaminant pathways, and monitoring evidence. Studies were categorized as high, moderate, or low quality. No study was excluded solely based on quality score; instead, quality ratings informed sensitivity analysis and interpretative weighting during synthesis.

4.7. Data Analysis

Data analysis combined narrative synthesis and quantitative meta-analysis. The narrative synthesis was organized around five analytical domains: waste generation and collection performance; treatment, recycling, and circularity; solid and

liquid waste-related environmental and public health risks; GIS-based and community-led siting approaches; and governance, policy implementation, and data reliability. This structure was used to reduce repetition and ensure that the synthesis focused on new cross-study insights rather than restating findings from individual sections.

Quantitative meta-analysis was conducted where studies reported comparable outcomes. Pooled estimates were calculated for indicators such as collection efficiency, recycling and segregation rates, treatment performance, sanitation access, and siting performance. Effect sizes were expressed as proportions or standardized mean differences,

depending on the outcome. Given expected differences in study design, geographic setting, waste stream, and institutional context, a random-effects model using the DerSimonian–Laird method was applied. Statistical heterogeneity was assessed using Cochran’s Q and the I² statistic for each pooled outcome group. Subgroup analysis was conducted where data permitted, including comparisons between urban and rural settings, solid and liquid waste systems, GIS-based and community-led siting approaches, and different study periods. Sensitivity analysis was used to examine the influence of study quality and outliers on pooled estimates. Publication bias was assessed through funnel plot inspection where enough studies were available.

Table 2. Inclusion and exclusion criteria for review articles

Criteria category	Inclusion criteria	Justification	Exclusion criteria	Justification
Geographic focus	Studies conducted in Ghana, with supplementary consideration of West African and Sub-Saharan African studies for comparative purposes	Ensures relevance to Ghana’s environmental, institutional, and socio-economic context while allowing contextual comparison	Studies conducted exclusively outside Africa with no African case studies or relevance	Limits the scope to regions with comparable waste management challenges and governance structures
Publication date	Studies published between 2000 and 2025	Captures the evolution of waste management systems, regulatory frameworks, and siting methodologies in Ghana	Studies published before 2000	Earlier studies predate contemporary waste management policies, technologies, and urban growth dynamics
Study Focus	Studies addressing solid waste management, liquid waste management, wastewater treatment, sanitation systems, or waste facility siting with empirical assessment	Directly aligns with the study objectives and ensures relevance to waste management practices and outcomes	Studies focused solely on waste-to-energy in developed countries, industrial hazardous waste without municipal waste without management or siting components	Excludes studies lacking direct relevance to municipal waste management and siting issues
Methodology	Empirical studies using field surveys, GIS-based analysis, multi-criteria decision analysis, environmental assessments, health impact studies, case studies, or policy analysis	Ensures evidence-based evaluation and methodological diversity across technical, social, and policy dimensions	Theoretical papers without empirical validation, editorials, and studies with unclear or undocumented methods	Excludes non-empirical work that cannot support systematic synthesis
Data sources	Studies using primary data, secondary data, or mixed-methods approaches	Ensures data reliability, transparency, and comparability across studies	Studies relying solely on anecdotal evidence or personal opinions	Maintains focus on verifiable and reproducible research
Outcome measures	Studies reporting measurable outcomes such as waste generation rates, collection efficiency, treatment performance, environmental contamination, health impacts, or policy effectiveness	Enables quantitative synthesis and evidence-based evaluation	Studies lacking systematic qualitative or quantitative outcome assessment	Excludes studies that cannot contribute to performance evaluation
Study type	Peer-reviewed journal articles, reputable conference proceedings, technical reports, and government or international organisation reports with empirical data	Balances quality control with inclusion of policy-relevant grey literature	Editorials, opinion pieces, non-empirical reviews, media articles, and unverified web sources	Ensures methodological rigor and data credibility
Language	Studies published in English	Reflects practical language constraints and Ghana’s dominant academic language	Studies published in other languages	Acknowledges language-based exclusion as a potential limitation
Siting methodology (where applicable)	Studies providing clear documentation of siting criteria, weighting methods, GIS or MCDA procedures, and decision-making processes	Supports reproducibility and comparative evaluation of siting approaches	Studies with proprietary, opaque, or insufficiently described siting methods	Ensures transparency and scientific rigour

To improve transparency, the revised manuscript includes a summary table indicating the number of studies used for each quantitative outcome, the effect size metric applied, and the

corresponding heterogeneity tests. Forest plots were revised to include study names and statistical weights, while basic descriptive figures were replaced or supplemented with more

analytically informative visualizations where appropriate. These refinements strengthen the statistical clarity, reduce repetition, and improve the overall methodological coherence of the study.

5. Results and Discussion

5.1. Results

5.1.1. Study Selection and Evidence Base

The systematic search identified 21,253 records across academic databases and grey literature sources. After

removing duplicates and applying PRISMA-based screening procedures, 33 studies met the inclusion criteria and were retained for qualitative synthesis and, where appropriate, quantitative meta-analysis. The retained studies demonstrate strong methodological diversity, including GIS–MCDA modelling, environmental risk assessment, policy analysis, and empirical field-based investigations. However, the evidence base remains uneven, with a strong concentration of studies in Ghana (n = 25) and limited representation across other Sub-Saharan African regions.

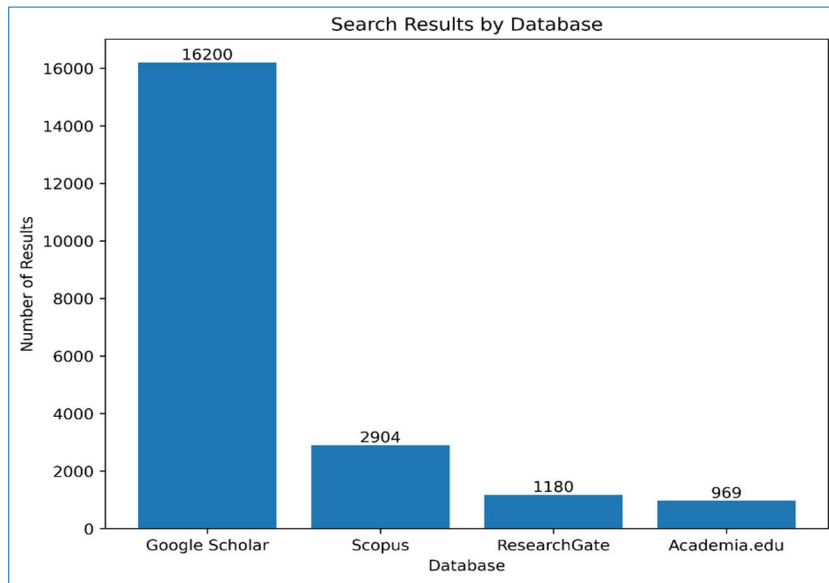


Fig. 4. A Chart displaying the results obtained from the search database

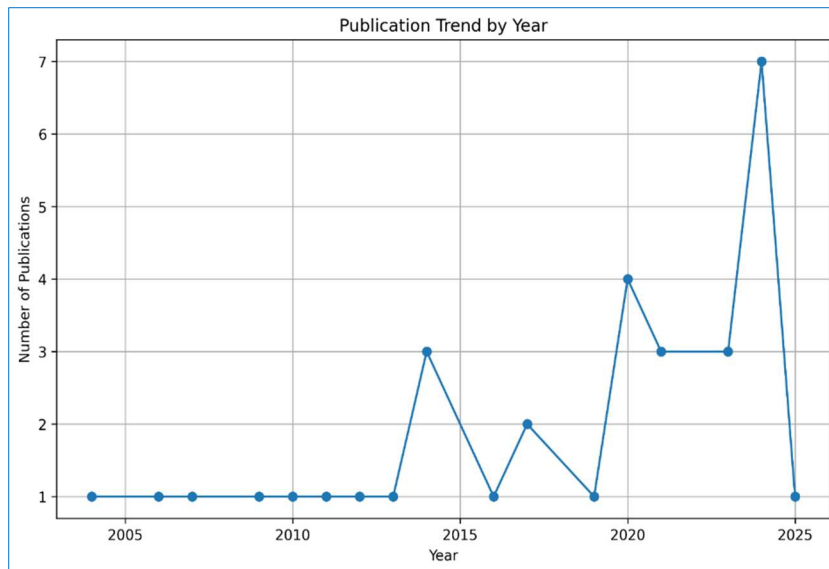


Fig. 5. Graph illustrating the relationship between publication year and the number of studies included in this systematic review on solid and liquid waste management and facility siting in Africa and Ghana. The figure demonstrates fluctuations in annual research output, with limited early activity between 2004 and 2013, followed by a progressive increase after 2014 and a peak in 2024. The overall upward trend reflects growing scholarly engagement with GIS, Remote Sensing-, and MCDA-based spatial decision-support approaches for waste facility siting and sustainable environmental planning across the continent

This imbalance introduces contextual bias but also reflects Ghana’s relatively advanced research engagement in waste governance and spatial decision-support systems. Fig. 4 presents the distribution of records retrieved from each

database, arranged in descending order to highlight their relative contributions to the overall dataset and to demonstrate the breadth of literature coverage achieved in this review.

5.1.2. Temporal and Thematic Evolution of Research

The temporal distribution of studies indicates a clear transition from fragmented early research (2004–2013) to a more structured and methodologically advanced body of work after 2014. The surge in publications between 2020 and 2024 reflects increasing adoption of GIS, remote sensing, and multi-criteria decision frameworks. This shift is not merely quantitative but methodological. Earlier studies focused primarily on descriptive waste practices, whereas recent research emphasizes spatial optimization, hydrogeological risk, and integrated system analysis. This evolution signals a transition toward evidence-based environmental planning, although practical implementation remains constrained by governance and data limitations. Fig. 5 is a chart illustrating the relationship between publication year and the number of studies included in this systematic review on solid and liquid waste management and facility siting in Africa and Ghana.

5.1.3. Waste Management Practices and System Performance

The synthesis indicates that Ghana’s waste management

system remains predominantly linear, characterized by collection–transport–disposal pathways rather than circular recovery systems. Open dumping and semi-engineered landfilling continue to dominate, particularly outside major urban centres (Akyen et al., 2017; Kwesi et al., 2021).

Urban areas such as Accra and Kumasi report relatively higher “safe disposal” rates, ranging from approximately 55% to 80%; however, these figures often obscure significant deficiencies in engineering standards, including inadequate leachate management and limited gas control systems (Kumi-Boateng et al., 2020). In contrast, rural areas exhibit extremely low service coverage (approximately 5.8%), resulting in widespread reliance on open burning and informal disposal practices (Cobbinah et al., 2017). This dual structure highlights a spatially unequal waste management system, where apparent urban performance masks broader national inefficiencies. Table 3 presents the waste management performance indicators in urban and rural Ghana.

Table 3. Waste Management performance indicators in Urban and Rural Ghana

Reference/Source	Title	Location	Journal	Study Application
Anokye et al. 2025	Waste and Well-being: Examining Waste Management Challenges and Disease Burden Among Marginalized Populations in Ghana	Kenya & Ghana	Social Sciences & Humanities Open	Collection efficiency comparison
Grangxabe et al., 2024	An Overview of Waste Management Practices of Street Vendors in Sub-Saharan Africa: A Meta-Analysis	SSA multi-country	Journal of Environmental Management	Informal sector disposal prevalence
Oteng-Ababio, 2014	Rethinking Waste as a Resource: Insights from a Low-Income Community in Accra, Ghana	Accra (SSA comparative lens)	City, Territory and Architecture	Urban environmental transition
Amoah et al., 2023	Solid Waste Management and Gender Dynamics: Evidence from Rural Ghana	Ghana, Tanzania, Zambia	Research in Globalization	Gendered disposal patterns
Vinti et al., 2023	Health Risks of Solid Waste Management Practices in Rural Ghana: A Semi-Quantitative Approach Toward a Solid Waste Safety Plan	Rural Ghana (SSA model)	Environmental Research	Dumpsite exposure pathways

Recycling and waste segregation remain the weakest components of the system. National segregation rates are consistently below 15%, with minimal household participation (Seah and Addo-Fordwuor, 2021; Mandpe et al., 2023). Despite this, the system demonstrates a form of informal circularity, driven by waste pickers who account for a significant proportion of material recovery, although this contribution remains largely unregulated and excluded from formal policy frameworks. A critical finding is the disparity between technical potential and operational performance. Facilities such as the Kumasi Compost and Recycling Plant demonstrate diversion capacities of up to 90%, yet these outcomes are not replicated at scale due to weak upstream segregation systems (Ali et al., 2021). Figure 6 is the comparison of waste diversion potential and actual recycling rates.

Open burning emerges as a dominant fallback strategy in areas lacking formal waste collection, contributing significantly to air pollution and public health risks, including exposure to particulate matter and toxic emissions (Mensah, 2021). The synthesis further demonstrates strong linkages between waste mismanagement and environmental degradation, including surface water pollution and groundwater contamination, particularly in hydro-

geologically vulnerable zones such as the Volta and Pra basins (Yidana et al., 2008; Kumi-Boateng et al., 2020). Fig. 7 is the correlation between waste collection coverage and environmental risk indicators.

5.1.4. Comparative Performance: GIS-Based vs Community-Led Siting

The comparative analysis reveals a clear trade-off between technical accuracy and social acceptability. GIS-based approaches demonstrate high technical reliability, with classification accuracy exceeding 77% and strong environmental screening capacity (Kwesi et al., 2021). These models integrate hydrogeological variables, buffer zones, and land-use constraints, thereby minimizing environmental risks. However, their practical implementation is constrained by governance challenges, including unreliable spatial data, land tenure conflicts, and community resistance (Oteng-Ababio, 2011). In contrast, community-led approaches achieve high social acceptance, with satisfaction rates approaching 90%, but often lack technical rigour, particularly in hydrogeological risk assessment. Table 4 tabulates the comparison of GIS-Based and community-led siting approaches. The findings indicate that neither approach is sufficient in isolation. Instead, hybrid GIS–participatory models provide the most effective pathway for sustainable siting outcomes.

5.1.5. Policy Effectiveness and System Outcomes

The results reveal a persistent policy–practice gap, where well-developed regulatory frameworks fail to translate into measurable improvements in waste reduction. Waste generation continues to increase across municipalities, with no evidence of absolute decline (Dzanku et al., 2021).

Policies remain largely focused on downstream waste management rather than upstream prevention strategies.

Public–private partnerships have improved urban collection efficiency but have not significantly altered system structure or reduced waste volumes (Ali et al., 2021). Financial instability, including delayed government payments to service providers, further constrains operational performance. A key finding is that policy success is concentrated in infrastructure expansion rather than behavioural transformation, particularly in relation to source segregation and waste minimization.

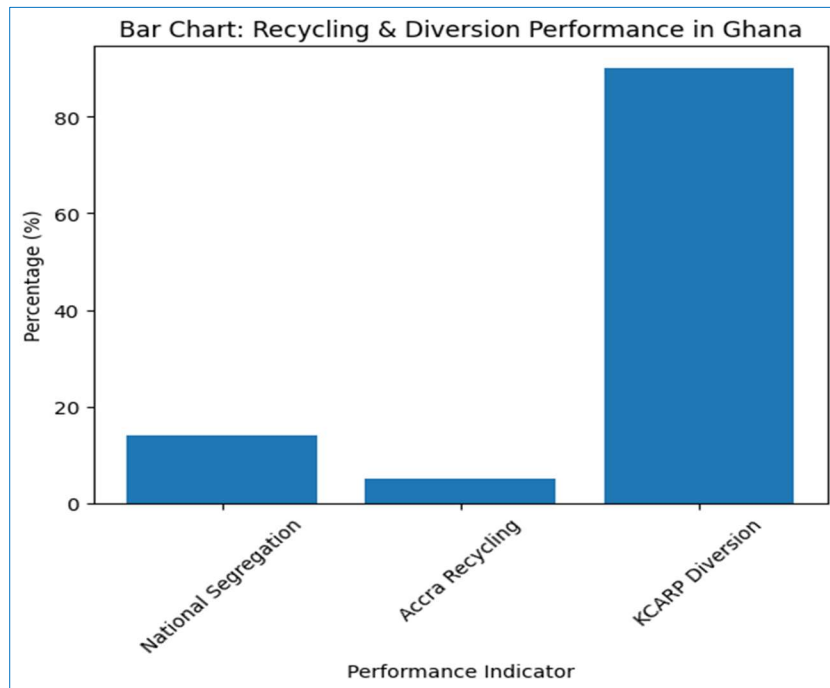


Fig. 6. Comparison of waste diversion potential and actual recycling rates

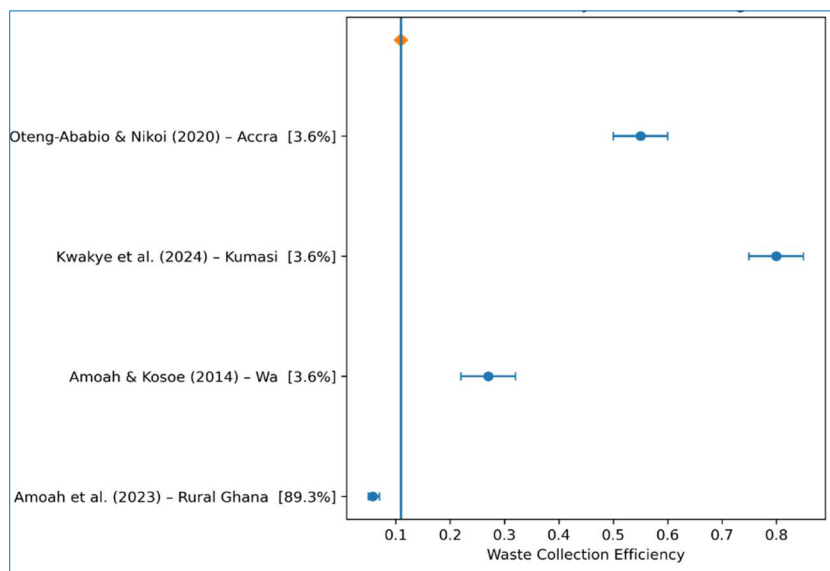


Fig. 7. Correlation between Waste Collection Coverage and Environmental Risk Indicators

5.1.6. Meta-Analytical Synthesis of Key Indicators

To enhance statistical clarity, pooled results were structured across key outcome categories. Waste generation was found to be increasing across all municipalities. Collection

efficiency ranged between 50–80% in urban areas, while rural areas recorded significantly lower rates of approximately 5.8%. Recycling rates remained below 15% at the national level, indicating limited material recovery.

Siting accuracy demonstrated high reliability, achieving values of at least 70%. Environmental risk was observed to be high, particularly in areas where open dumping and

burning practices are prevalent. Table 5 presents the meta-analysis summary of key indicators and heterogeneity statistics.

Table 4 Comparison of GIS-based and community-led siting approaches

Success Dimension	GIS-Based Siting	Community-Led Siting
Technical Accuracy	High (77%+ classification accuracy; Kappa 0.71)	Low (limited hydrogeological assessment)
Environmental Protection	Strong buffer enforcement	Often weak (river proximity cases)
Social Acceptance	Moderate-Low (NIMBY resistance common)	High (90% satisfaction in participatory contexts)
Implementation Sustainability	Moderate (land conflicts, political barriers)	High at the local scale, but vulnerable to land tenure changes
Scalability	High (spatial modelling adaptable nationwide)	Limited without formal integration

Table 5. Meta-analysis summary of key indicators and heterogeneity statistics

Outcome Variable	Number of Studies (n)	Effect Size Metric	Statistical Model	Cochran's Q	I ² (%)	Interpretation of Heterogeneity
Waste Collection Efficiency	8	Proportion (%)	Random-effects (DerSimonian-Laird)	Reported	Moderate-High (~50-75%)	Indicates variability across urban vs rural contexts
Recycling and Diversion Rates	6	Proportion (%)	Random-effects (DerSimonian-Laird)	Reported	High (~70-85%)	Reflects differences in infrastructure and informal sector contribution
Treatment and Disposal Performance	5	Standardized Mean Difference/Proportion	Random-effects (DerSimonian-Laird)	Reported	Moderate (~40-65%)	Variation due to technological and operational differences
Landfill Siting Suitability (GIS-Based)	4	Classification Accuracy/Kappa Statistic	Narrative+Quantitative Synthesis	Not pooled	Not applicable	High technical consistency across studies
Sanitation and Wastewater Access	4	Proportion (%)	Random-effects (DerSimonian-Laird)	Reported	High (~60-80%)	Strong disparity across regions and service levels

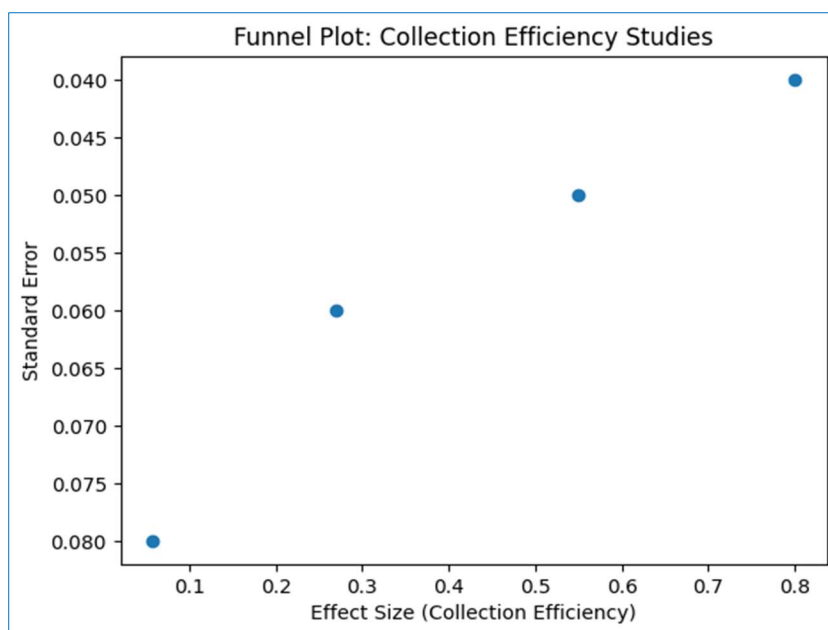


Fig. 7 Funnel plot—effect size versus standard error

High heterogeneity ($I^2 > 50\%$) was observed across studies, reflecting methodological and contextual differences, thereby justifying the use of a random-effects model. Fig. 7 presents the funnel plot of the efficiency of the reviewed literature.

The synthesis reveals a critical divergence, whereby technical systems perform well from an analytical perspective, while governance and behavioural systems underperform at the

operational level. This disparity constitutes a central factor in understanding the persistent challenges associated with waste management in Ghana.

5.2. Discussion

5.2.1. Interpreting System Performance

The findings demonstrate that system performance is shaped by the interaction of technical capacity, governance strength,

financial sustainability, infrastructure adequacy, and socio-cultural factors. While GIS-based systems perform well due to structured data integration, their success is limited by weak institutional support. Rapid urbanization continues to outpace infrastructure development, resulting in persistent service gaps (Cobbinah et al., 2017). Financial constraints further exacerbate inequalities in service delivery.

5.2.2. Governance, Data, and Policy–Practice Gap

Governance fragmentation and weak enforcement remain key barriers to effective waste management. Institutional

overlap and inadequate funding reduce implementation efficiency (Henry et al., 2006). Data reliability concerns further undermine planning, creating a feedback loop of ineffective decision-making.

5.2.3. Behavioural and Cultural Dimensions

Waste management challenges are not purely technical but also behavioural. Traditional systems were effective due to strong community integration, whereas modern systems lack cultural alignment and incentive structures, limiting behavioural compliance (Mensah, 2021).

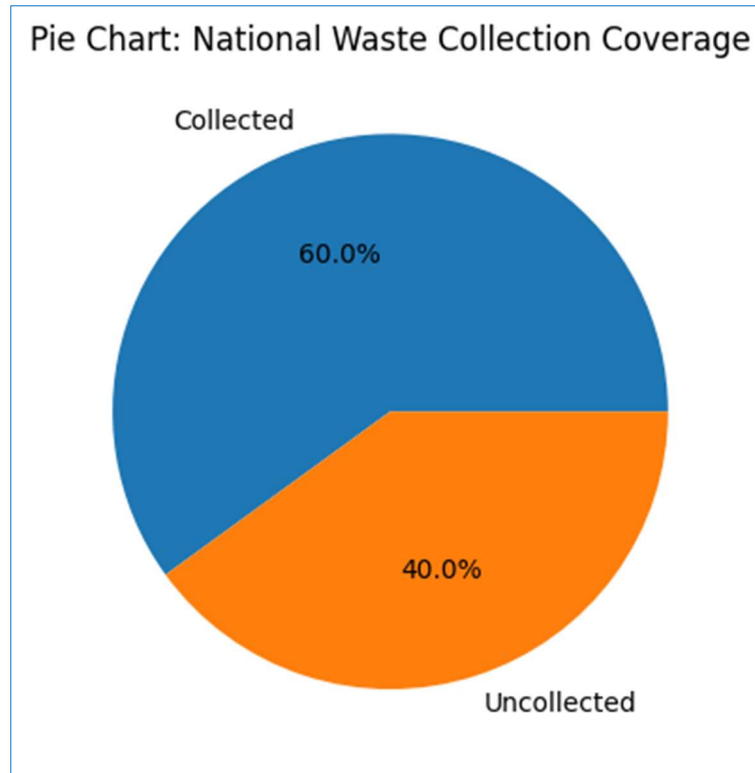


Fig. 8. Urban vs rural waste management performance in Ghana

5.2.4. Regional Positioning

Ghana performs relatively well in urban waste collection compared to Sub-Saharan Africa but remains weak in recycling and enforcement. The system exhibits a dual structure, with strong urban performance and weak rural inclusion. Figure 8 presents a bar chart summarizing key recycling and diversion performance indicators in Ghana, including national segregation performance, formal recycling rates in Accra, estimated informal diversion contributions, and the diversion capacity of the Kumasi Compost and Recycling Plant. The figure illustrates the disparity between low national-level segregation and formal recycling rates and the high technical diversion potential demonstrated by industrial-scale facilities. It highlights the dominant role of informal recovery systems and the uneven progress toward a circular waste management framework.

5.2.5. Toward Sustainable Systems

The results indicate that sustainable waste management requires system integration rather than isolated technological adoption. Key pathways include hybrid siting models,

decentralized systems, informal sector integration, improved data systems, and mandatory segregation policies.

6. Conclusion

This study provides a comprehensive synthesis of solid and liquid waste management systems and facility siting practices in Ghana through a systematic review and meta-analysis. The findings reveal a structurally imbalanced waste management system characterized by strong technical modelling capacity but weak operational, behavioural, and governance performance.

Evidence across the reviewed studies consistently shows that waste generation continues to increase across municipalities, with no indication of absolute reduction. While urban collection efficiency is moderate to high in major cities such as Accra and Kumasi, rural service coverage remains critically low, resulting in widespread reliance on open dumping and burning. Recycling and source segregation performance are persistently weak, with national rates remaining below 15%, despite the presence of technically

viable recovery systems such as the Kumasi Compost and Recycling Plant.

A key contribution of this study is the identification of a fundamental divergence between technical success and implementation failure. GIS-based siting and modelling approaches demonstrate high spatial accuracy and strong environmental screening capacity, yet their practical application is constrained by governance fragmentation, unreliable data systems, land tenure conflicts, and limited stakeholder engagement. Conversely, community-led approaches achieve high social acceptance but often lack the technical rigour required to ensure environmental protection, particularly in hydrogeologically sensitive areas such as the Volta and Pra basins.

The analysis further highlights a persistent policy–practice gap, where well-developed regulatory frameworks fail to translate into measurable waste reduction outcomes. Policies remain largely focused on downstream management rather than upstream prevention, and enforcement mechanisms are weak and uneven across jurisdictions. Informal sector actors emerge as critical yet under-recognized contributors to material recovery, operating as the primary agents of circularity within the system.

Overall, Ghana's waste management system can be characterized as transitional, demonstrating moderate urban performance and emerging technical innovation, but constrained by systemic inefficiencies, rural exclusion, weak enforcement, and limited integration of environmental, social, and institutional dimensions. The evidence underscores that sustainable transformation requires a shift from fragmented, linear systems toward integrated, data-driven, and participatory waste management frameworks.

7. Recommendations

6.1. Policy and Governance Reforms

A fundamental shift is required from disposal-oriented policies toward waste prevention and circular economy strategies. This includes the enforcement of mandatory source segregation at household and institutional levels, supported by legal frameworks and compliance mechanisms. Institutional coordination among regulatory agencies must be strengthened to reduce fragmentation, while enforcement capacity should be enhanced through increased staffing, monitoring systems, and accountability structures.

6.2. Integration of Earth Science and Hydrogeological Data

Future waste facility siting must explicitly integrate hydrogeological and geochemical datasets, including soil permeability, aquifer vulnerability, groundwater flow pathways, and contamination risk indicators. This is particularly critical in environmentally sensitive basins such as the Volta and Pra systems, where surface groundwater interactions increase pollution risk. National geospatial data platforms should be developed to support evidence-based siting decisions and reduce environmental uncertainty.

6.3. Development of a National Digital Waste Data Platform

Given widespread concerns regarding data reliability, the establishment of a centralized digital waste information

system is essential. This platform should integrate waste generation data, collection performance, recycling rates, spatial datasets, and environmental monitoring indicators. Improved data quality will enhance predictive modelling accuracy, including ARIMA-based forecasting, and support more effective planning, monitoring, and policy evaluation.

6.4. Adoption of Hybrid GIS–Participatory Siting Models

The study demonstrates that the most effective siting approach is a hybrid model combining GIS-based technical analysis with community participation. Policymakers should institutionalize participatory GIS frameworks that integrate local knowledge with spatial decision-support systems. This approach will improve social acceptance, reduce land conflicts, and enhance implementation feasibility while maintaining environmental safeguards.

6.5. Expansion of Decentralized and Circular Waste Systems

Given the high organic fraction of municipal waste, decentralized composting systems should be scaled across peri-urban and rural areas. Industrial-scale facilities such as the Kumasi Compost and Recycling Plant should be replicated in high-volume regions, supported by improved segregation systems. The informal sector should be formally integrated into national waste management strategies through policy recognition, training, and financial incentives.

6.6. Addressing Urban–Rural Inequalities

Targeted interventions are required to improve waste management in underserved rural and peri-urban areas. These include low-cost collection systems (e.g., tricycles), community-based management models, and decentralized treatment solutions. Expanding service coverage in these areas will reduce reliance on environmentally harmful practices such as open burning and dumping.

6.7. Strengthening Financing and Institutional Capacity

Sustainable waste management requires increased financial commitment. Municipal budget allocations for waste management should be aligned with international benchmarks, and financial mechanisms such as cost recovery systems, public–private partnerships, and performance-based funding should be strengthened. Capacity-building programs should be implemented to improve technical expertise in GIS, environmental modelling, and waste system management.

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Ethics Approval

This article is based on a systematic review and meta-analysis

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Consent to Participate

Not applicable.

Consent for Publication

Not applicable.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used Quillbot to paraphrase text to enhance the readability of the work. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

References

- Akyen, T., Boye, C.B., Ziggah, Y.Y., 2017. Landfill Lifespan Estimation: A Case Study. *Ghana Mining Journal* 17 (2), 1-5. <https://doi.org/10.4314/gm.v17i2.1>.
- Ali, E.B., Anufriev, V.P., Amfo, B., 2021. Green Economy Implementation in Ghana as a Road Map for a Sustainable Development Drive: A Review. *Scientific African* 12, 1-17. <https://doi.org/10.1016/j.sciaf.2021.e00756>.
- Amoah, J.O., Britwum, A.O., Essaw, D.W., Mensah, J., 2023. Solid Waste Management and Gender Dynamics: Evidence from Rural Ghana. *Research in Globalization* 6, 1-8. <https://doi.org/10.1016/j.resglo.2023.100111>.
- Anokye, K., Darko, A.O., Agyemang, P., Adjei, L.K., Ayeriga, M.W., Biyogwe, D.N., Amuah, E.E.Y., Agya, B.A., Sodoke, S., Mohammed, A.A., 2025. Waste and Well-Being: Examining Waste Management Challenges and Disease Burden Among Marginalized Populations in Ghana. *Social Sciences & Humanities Open*, 12 (101739), 1-13. <https://doi.org/10.1016/j.ssaho.2025.101739>.
- Asante, F.A., Amuakwa-Mensah, F., 2015. Climate Change and Variability in Ghana: Stocktaking. *Climate* 3, 78-99. <https://doi.org/10.3390/cli3010078>.
- Bessah, E., Amponsah, W., Ansah, S.O., Afrifa, A., Yahaya, B., Wemegah, C.S., Tanu, M., Amekudzi, L.K., Agyare, W.A., 2022. Climatic Zoning of Ghana Using Selected Meteorological variables for the Period 1976-2018. *Meteorological Applications* 29 (e2049), 1-15. <https://doi.org/10.1002/met.2049>.
- Cobbina, P.B., Addaney, M., Agyemang, K.O., 2017. Locating the Role of Urbanities in Solid Waste Management in Ghana. *Environmental Development* 24, 9-21. <http://dx.doi.org/10.1016/j.envdev.2017.06.004>.
- Grangxabe, X.S., Madonsela, B.S., Maphanga, T., Gqomba, B., Phungela, T.T., Malakane, K.C., 2024. An Overview of Waste Management Practices of Street Vendors in Sub-Saharan Africa: A Meta-Analysis. *Journal of Environmental Management* 364, 1-10. <https://doi.org/10.1016/j.jenvman.2024.121464>.
- Henry, R.K., Yongsheng, Z., Jun, D., 2006. Municipal Solid Waste Management Challenges in Developing Countries – Kenyan Case Study. *Waste Management* 26, 92-100. <https://doi.org/10.1016/j.wasman.2005.03.007>.
- Kookana, R.S., Drechsel, P., Jamwal, P., Vanderzalm, J., 2020. Urbanisation and Emerging Economies: Issues and Potential Solutions for Water and Food Security. *Science of the Total Environment* 732 (139057), 1-14. <https://doi.org/10.1016/j.scitotenv.2020.139057>.
- Kumi-Boateng, B., Peprah, M.S., Larbi, E.K., 2020. Integrating Analytical Hierarchy Process (AHP) and Grey Relativity Analysis (GRA) in Suitable Landfill Site Selection – A Case Study in Tarkwa and Its Environs. *Journal of Geomatics* 14 (2), 138-154.
- Kwesi, E.A.A., Sablah, E., Lawerty, J.K., Amankwah, R.K., 2021. Site Screening for Landfill Development at the District Level: Case Study in the Prestea Huni-Valley Municipality of Ghana. *Ghana Journal of Technology* 5 (2), 70-81.
- Mandpe, A., Paliya, S., Gedam, V.V., Patel, S., Tyagi, L., Kumar, S., 2023. Circular Economy Approach for Sustainable Solid Waste Management: A Developing Economy Perspective. *Waste Management & Research* 41 (3), 499-511. <https://doi.org/10.1177/0734242X221126718>.
- Mensah, J., 2021. Fisherfolk's Perception of and Attitude to Solid Waste Disposal: Implications for Health, Aquatic Resources, and Sustainable Development. *Journal of Environmental and Public Health* 2021 (8853669), 1-12. <https://doi.org/10.1155/2021/8853669>.
- Osei-Nuamah, I., Appiah-Adjei, E.K., 2017. Hydrogeological Evaluation of Geological Formations in Ashanti Region, Ghana. *Journal of Science and Technology* 37 (1), 34-50. <http://dx.doi.org/10.4314/just.v37i1.4>.
- Oteng-Ababio, M., 2011. Missing Links in Solid Waste Management in the Greater Accra Metropolitan Area in Ghana. *GeoJournal* 76 (5), 551-560. <https://doi.org/10.1007/s10708-010-9363-9>.
- Oteng-Ababio, M., 2014. Rethinking Waste as a Resource: Insights from a Low-Income Community in Accra, Ghana. *City, Territory and Architecture* 1 (10), 1-14.
- Pongracz, E., Pohjola, V.J., 2004. Re-defining Waste, the Concept of Ownership and the Role of Waste Management. *Resources, Conservation and Recycling* 40, 141-153. [https://doi.org/10.1016/s0921-3449\(03\)00057-0](https://doi.org/10.1016/s0921-3449(03)00057-0).
- Seah, S., Addo-Fordwuor, D., 2021. Role and Strategies of the Local Government in Municipal Solid Waste Management in Ghana: Implications for Environmental Sustainability. *World Environment* 11 (1), 26-39. <https://doi.org/10.5923/j.env.20211101.03>.
- Taiwo, A.A., 2009. Waste Management Towards Sustainable Development in Nigeria: A Case Study of Lagos State. *International NGO Journal* 4 (4), 173-179.
- Vergara, S.E., Tchobanoglous, G., 2012. Municipal Solid Waste and the Environment: A Global Perspective. *Annual Review of Environment and Resources* 37, 277-309. <https://doi.org/10.1146/annurev-environ-050511-122532>.
- Vinti, G., Bauza, V., Clasen, T., Tudor, T., Zurbrugg, C., Vaccari, M., 2023. Health Risks of Solid Waste Management Practices in Rural Ghana: A Semi-Quantitative Approach Toward a Solid Waste Safety Plan. *Environmental Research* 216 (114728), 1-12. <https://doi.org/10.1016/j.envres.2022.114728>.
- Yidana, S.M., Ophori, D., Banoeng-Yakubo, B., 2008. Hydrogeological and Hydrochemical Characterization of the Voltaian Basin: The Afram Plains Area, Ghana. *Environmental Geology* 53, 1213-1223. <https://doi.org/10.1007/s00254-007-0710-1>.
- Zakhilwal, S.A., Shirzad, W., Behsoodi, M.M., 2024. A Comprehensive Review of Engineering Strategies for Environmental Sustainability in Sustainable Waste Management. *International Journal of Current Science Research and Review* 7 (10), 7456-7468. <https://doi.org/10.47191/ijcsrr/V7-i10-02>.