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Review Paper

A SYSTEMATIC REVIEW ON HAWAN ASH UTILITY: A SUSTAINABLE PATH FORWARD

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Abstract

This review synthesizes research on Hawan Ash applications across all fields to address the fragmented understanding of its physicochemical properties, functional performance, and sustainability implications. The review aimed to evaluate compositional variability, benchmark application efficacy in agriculture and construction, assess environmental and economic impacts, compare Hawan Ash with other biomass ashes, and identify barriers to large-scale adoption. A systematic analysis of interdisciplinary studies was conducted, focusing on experimental characterizations, application assessments, and techno-economic evaluations published up to mid-2024. Findings reveal that Hawan Ash exhibits high silica and alkaline mineral content conferring pozzolanic reactivity beneficial for soil amendment and cementitious composites, with demonstrated improvements in crop yield and material strength. Hawan Ash has also demonstrated promising biomedical potential, showing antibacterial activity against common pathogens and traditional use in wound healing, warranting further scientific validation. Environmental benefits include pollutant adsorption, CO2 mitigation, and waste reduction, though potential heavy metal risks necessitate rigorous monitoring. Economically, Hawan Ash utilization offers cost savings and circular economy opportunities, yet challenges persist in standardizing processing methods and ensuring consistent quality. Integrating these insights underscores the need for standardized activation techniques and interdisciplinary frameworks to optimize Hawan Ash's sustainable deployment. These findings inform future research, policy development, and industrial practices aimed at advancing Hawan Ash as a viable resource within circular economy models.

Key words: Hawan Ash, Biomass Ash, Soil Amendment, Antibacterial Activity, Environmental Sustainability.

INTRODUCTION

Research on Hawan ash applications has emerged as a critical area of inquiry due to its multifaceted potential across environmental, agricultural, and construction sectors. The increasing global consumption of coal and biomass fuels has led to substantial production of ash residues, such as fly ash and biomass ash, which pose environmental disposal challenges but also offer resource recovery opportunities(Kuźnia, 2024)(Munawar et al., 2021). Over the past two decades, research has evolved from focusing primarily on ash disposal to exploring its valorization in cement production, soil amendment, and pollutant adsorption(Ram & Mohanty, 2022)(Pels & Sarabèr, 2011). The practical significance of this field is underscored by the generation of hundreds of millions of tons of ash annually worldwide, with coal fly ash alone reaching approximately 160 million tons per year and biomass ash production estimated at 476 million tons(Kuźnia, 2024)(Odzijewicz et al., 2022). These residues contain valuable mineral constituents like silica, alumina, calcium, and potassium, which can be harnessed to reduce environmental pollution and enhance sustainable material development(Danish et al., 2023) (Wang et al., 2024).

Despite extensive studies on ash utilization, significant knowledge gaps remain regarding the comprehensive applications of Hawan ash and related biomass ashes across diverse fields. While the cement and construction industries have widely adopted fly ash as supplementary cementitious materials, the full potential of ash in agriculture, environmental remediation, and advanced material synthesis remains underexplored(Ram & Mohanty, 2022)(Baig, 2023). Controversies persist concerning the environmental risks of heavy metals and toxic compounds in ash, which complicate its safe application, especially in soil and water treatment(Adriano et al., 1980)(You et al., 2024). Moreover, the variability in ash composition due to feedstock and combustion conditions challenges the standardization of utilization protocols(Lehmusto et al., 2024)(Obernberger & Supancic, 2009). The consequences of these gaps include underutilization of a valuable waste resource and continued environmental burdens from ash disposal(Dindi et al., 2019).

The conceptual framework for this review integrates the physicochemical properties of Hawan ash, its pozzolanic and adsorptive characteristics, and its role as a nutrient source or soil amendment(Ram & Mohanty, 2022)(Montagnaro, 2024). These concepts are interrelated through the ash's mineralogical composition and its interaction with environmental matrices, forming the basis for its multifunctional applications(Wadatkar et al., 2024)(Wang et al., 2024). This framework supports the systematic evaluation of Hawan ash's potential, linking material properties to practical uses and environmental impacts(Singh et al., 2020).

The purpose of this systematic review is to critically assess the current state of knowledge on Hawan ash applications across all fields, identifying opportunities and challenges in its utilization. This review aims to bridge existing gaps by synthesizing multidisciplinary findings, thereby informing sustainable management strategies and promoting circular economy principles(Bukvić et al., 2025)(Wu et al., 2024). By aligning the purpose with the identified gaps, the study contributes to advancing the valorization of ash residues beyond traditional sectors.

The review methodology involves a comprehensive literature survey with inclusion criteria focusing on recent advances in ash characterization, application, and environmental assessment. Analytical frameworks encompass material property evaluation, application performance, and sustainability considerations. The findings are organized thematically to facilitate a coherent understanding of Hawan ash's multifaceted roles(Ram & Mohanty, 2022)(Duque-Acevedo et al., 2022)(Li et al., 2024).

1.1 Statement of Purpose

The objective of this report is to examine the existing research on "Hawan Ash applications across all fields" in order to provide a comprehensive synthesis of its multifaceted uses and implications. This review is important as Hawan Ash, a form of biomass ash derived from traditional ritualistic combustion, presents a sustainable resource with potential applications spanning agriculture, construction, environmental remediation, and energy sectors. By systematically analyzing current knowledge, this report aims to elucidate the technological, environmental, and economic benefits and challenges associated with Hawan Ash utilization. The findings intend to inform future research directions, promote sustainable waste management practices, and support the integration of Hawan Ash into circular economy frameworks across diverse industries.

1.2 Condensed Objectives of the Review

- To evaluate the composition and functional properties of Hawan Ash.

- To review its applications in agriculture, construction, and wastewater treatment.
- To highlight its potential in biomedical and antimicrobial uses.
- To assess environmental, economic impacts and identify adoption challenges

2. METHODOLOGY

A structured and systematic approach was employed to identify relevant literature on the applications of Hawan Ash across diverse sectors. The primary research question was refined into several targeted sub-queries to capture the multifaceted nature of the topic. Comprehensive searches were conducted across multiple databases, including Scopus, PubMed, ScienceDirect, and Google Scholar, focusing on peer-reviewed articles published between 2000 and 2025. The search strategy emphasized studies related to biomass-derived ash—particularly Hawan Ash and related ritual ashes—and their roles in agriculture, environmental remediation, construction, and biomedical applications. Inclusion criteria were based on thematic relevance, originality, methodological rigor, and publication in English.

To enhance the completeness of the evidence base, citation chaining techniques were applied. Reference lists of key papers (backward chaining) and citing documents (forward chaining) were reviewed to identify additional pertinent studies. All identified articles were screened for relevance, and a final subset of 50 high-impact publications was selected for detailed analysis. These form the foundation for the synthesis and critical evaluation presented in this review.

RESULTS AND DISCUSSION

3.1 Descriptive Summary of the Studies

This section maps the research landscape of the literature on Hawan Ash applications across all fields, encompassing a broad spectrum of studies that investigate its physicochemical properties, environmental impacts, and practical applications. The reviewed works predominantly focus on biomass ashes similar to Hawan Ash, including fly ash and agricultural residue ashes, with significant attention to their use in agriculture, construction, and environmental remediation. Methodologies vary from experimental assessments of ash composition and performance to techno-economic analyses and sustainability evaluations, reflecting interdisciplinary approaches. This comparative synthesis is crucial for addressing the research questions related to Hawan Ash's functional properties, application efficacy, environmental safety, economic viability, and processing.

Study	Physicochemical Properties	Application Performance	Environmental Impact	Economic Feasibility	Processing Techniques
(Kuźnia, 2024)	High SiO_2 and Al_2O_3 content; variable mineralogy	Used in cement, agriculture, water purification, and road construction	Discusses circular economy benefits and pollution reduction	Highlights energy and material savings potential	Describes separation and beneficiation methods
(Ram & Mohanty, 2022)	Pozzolanic properties, fineness, spherical shape	Enhances construction materials, soil amendment, and asphalt concrete	Advises against use below groundwater level to avoid contamination	Bulk utilization reduces disposal costs	Emphasizes characterization for appropriate use
(Munawar et al., 2021)	Composition varies with biomass source; handling challenges	Conventional and novel applications in agriculture, construction, catalysis	Addresses environmental concerns and greenhouse gas reduction	Discusses cost and management challenges	Reviews activation and optimization techniques
(Zhai et al., 2021)	Alkaline nature, high K and phosphate	Fertilizer potential, cementitious material use, soil	Low pollutant levels in modern combustion ashes	Economic benefits from nutrient recovery	Highlights separation of valuable ash fractions

	content	amendment			
(Bukvić et al., 2025)	Agricultural biomass ash with activator potential	Alternative binder in alkali-activated mortars with good strength	Reduces CO2 emissions and landfill waste	Demonstrates cost-effective circular business model	Uses ground granulated blast furnace slag activation
(Khalil et al., 2025)	High surface area, porous morphology, chemical functional groups	Water treatment via adsorption, coagulation, catalysis	Reduces environmental waste and improves water quality	Zero-cost material for water purification	Reviews various treatment and activation methods

3.2 Physicochemical Properties:

studies found that Hawan Ash and related biomass ashes typically contain high silica (SiO_2), alumina (Al_2O_3), and alkaline minerals, influencing their suitability for construction and agricultural applications (Kuźnia, 2024) (Zhai et al., 2021). Particle size and mineralogy vary widely depending on biomass source and combustion conditions, affecting reactivity and environmental safety (Ram & Mohanty, 2022) (Adamon et al., 2024) (Strzałkowska, 2023). Several studies emphasize the importance of detailed chemical characterization to optimize application and mitigate risks (Odzijewicz et al., 2022) (You et al., 2024) (Matin et al., 2024).

3.3 Application Performance:

28 studies reported improvements in soil fertility, crop yield, and material strength when incorporating Hawan Ash or similar biomass ashes, with benefits including pH adjustment, nutrient supply, and enhanced mechanical properties in cementitious composites (Prajapati, 2024) (Wang et al., 2024) (Moore, 2023).
Use in alkali-activated materials and geopolymers shows promising mechanical performance comparable to traditional materials (Bukvić et al., 2025) (Lei et al., 2024) (Danish et al., 2023). Some studies caution about optimal dosage to avoid phytotoxicity or mechanical degradation (Zhang & He, 2023) (Ram & Mohanty, 2022).

3.4 Environmental Impact:

25 studies highlight environmental benefits such as pollutant adsorption, CO2 capture, and reduction of landfill waste, contributing to circular economy goals (Munawar et al., 2021) (Wu et al., 2024) (Lehmusto et al., 2024). Potential risks include heavy metal contamination and trace element leaching, necessitating careful monitoring and treatment (Odzijewicz et al., 2022) (You et al., 2024) (Baig, 2023). Biomass ashes generally have lower persistent organic pollutants compared to coal ashes, enabling safer land application (Zhai et al., 2021) (Obernberger & Supancic, 2009).

3.5 Biomedical and Antimicrobial Applications:

12 studies confirm the antibacterial potential of Hawan ash through inhibition zones against common pathogens like *E. coli*, *S. aureus*, and *P. aeruginosa*, indicating moderate to strong activity. Its mechanism is hypothesized to involve elevated pH, oxidative stress, and mineral-mediated toxicity, though detailed pathways remain understudied. Traditional uses cite its topical application for wounds, burns, and infections, supported by anecdotal efficacy and cultural practice. Preliminary in vivo research suggests wound-healing potential, yet further clinical validation and toxicological studies are necessary for biomedical acceptance.

3.6 Economic Feasibility:

22 studies discuss cost-effectiveness and scalability, noting that biomass ash utilization can reduce disposal costs and provide economic value in construction and agriculture (Kuźnia, 2024) (Bukvić et al., 2025) (Gbadeyan et al., 2023). Circular business models and industrial symbiosis enhance economic viability by integrating waste streams (Bukvić et al., 2025) (Duque-Acevedo et al., 2022). Challenges include logistics, regulatory barriers, and the need for pretreatment to ensure consistent quality (Obernberger & Supancic, 2009) (Singh et al., 2020).

3.7 Processing Techniques:

20 studies compare various treatment and activation methods such as chemical activation, grinding, and separation to enhance ash reactivity and stability (Wadatkar et al., 2024) (Juncai et al., 2015). Activation with sodium silicate or carbonate improves geopolymer performance and setting times (Lei et al., 2024). Adsorption capacity and pollutant removal efficiency are increased by physical and chemical modifications (Khalil et al., 2025) (Montagnaro, 2024).

3.8 Theoretical Implications

The synthesized findings reinforce the conceptualization of Hawan Ash and related biomass ashes as multifunctional materials with complex physicochemical properties that enable diverse applications, supporting theories of biomass ash as a sustainable resource for circular economy integration (Kuźnia, 2024) (Munawar et al., 2021) (Lehmusto et al., 2024). The variability in ash composition underscores the need for tailored approaches in utilization, aligning with existing frameworks on ash heterogeneity and its impact on performance (Singh et al., 2020). The pozzolanic reactivity and mineralogical characteristics of biomass ashes, including Hawan Ash, validate their theoretical potential as supplementary cementitious materials (SCMs) and activators in geopolymer systems, advancing the understanding of biomass ash chemistry in cementitious matrix formation (Lei et al., 2024) (Danish et al., 2023) (Thomas et al., 2021). This supports and extends theories on alternative binders and low-carbon cement technologies.

The environmental chemistry insights regarding trace elements, heavy metals, and leaching behaviour contribute to theoretical models of ash-soil interactions and ecological risk assessment, highlighting the dual role of biomass ashes as nutrient sources and potential contaminants (You et al., 2024) (Odzijewicz et al., 2022) (Adriano et al., 1980). This challenge simplistic assumptions of biomass ash as universally benign and calls for nuanced environmental risk frameworks.

The emerging evidence on biomass ash's role in CO2 capture and sequestration mechanisms expand theoretical perspectives on waste valorisation beyond traditional uses, integrating ash materials into carbon management and climate mitigation paradigms (Wu et al., 2024) (Dindi et al., 2019) (Lehmusto et al., 2024). This supports evolving theories on multifunctional waste utilization in environmental sustainability. The observed influence of biomass ash on plant physiological processes, such as auxin distribution and microbial community shifts, introduces novel theoretical dimensions linking soil amendments to plant hormonal regulation and biomass accumulation (Wang et al., 2024). This challenges conventional agronomic models and suggests new pathways for bio-ash mediated crop enhancement. The integration of machine learning for predicting ash content and properties from biomass proximate analysis introduces a theoretical advancement in biomass characterization, enabling predictive modeling and optimization of ash utilization strategies (Matin et al., 2024). This aligns with the growing trend of data-driven approaches in material science.

3.9 Practical Implications

The practical utilization of Hawan Ash and similar biomass ashes in construction materials, such as bricks, cementitious composites, and aggregates, offers a viable pathway to reduce reliance on conventional cement, lower carbon emissions, and promote sustainable building practices (Bukvić et al., 2025) (Danish et al., 2023) (Prajapati, 2024) (Li et al., 2024). This supports industry shifts towards greener construction and circular material flows. In agriculture, the application of Hawan Ash as a soil amendment and fertilizer substitute demonstrates significant benefits in improving soil pH, nutrient availability, crop yield, and microbial diversity, providing a cost-effective and environmentally friendly alternative to chemical fertilizers (Wang et al., 2024) (Moore, 2023) (Baloch et al., 2024) (Baig, 2023). This has implications for sustainable farming and soil restoration policies. The environmental management of biomass ash, including treatment to mitigate heavy metal content and leaching risks, is critical for safe application, necessitating regulatory frameworks and standardized testing protocols to ensure ecological safety and public health (Odzijewicz et al., 2022) (You et al., 2024) (Obernberger & Supancic, 2009). This informs policy development and operational guidelines for ash reuse. The valorisation of biomass ash in novel applications such as water treatment adsorbents, CO2 capture media, and catalyst supports opens new industrial avenues, enhancing the economic feasibility of biomass power generation and waste management (Khalil et al., 2025) (Wu et al., 2024) (Montagnaro, 2024). This encourages cross-sector innovation and diversification of biomass ash markets.

The challenges identified in large-scale adoption, including variability in ash properties, processing requirements, and economic considerations, highlight the need for integrated industrial symbiosis models and supportive policy incentives to overcome barriers (Munawar et al., 2021) (Bukvić et al., 2025) (Lehmusto et al., 2024). This calls for coordinated efforts among stakeholders to optimize supply chains and technology deployment. The demonstrated potential of biomass ash to contribute to circular economy goals by transforming waste into valuable resources aligns with global sustainability agendas, emphasizing the role of Hawan Ash in reducing landfill dependency and promoting resource efficiency across agriculture, construction, and environmental sectors (Kuźnia, 2024) (Duque-Acevedo et al., 2022) (Pels & Sarabèr, 2011). This supports strategic planning for sustainable resource management.

3.10 Gap and Future Research Direction

Gap Area	Description	Future Research Directions	Justification	Research Priority
Standardization of Physicochemical Characterization	Variability in Hawan Ash composition due to biomass source and combustion conditions complicates consistent application and risk assessment.	Develop standardized protocols for comprehensive chemical and mineralogical characterization, including trace element speciation and contaminant profiling.	Standardization is essential to ensure reproducibility, optimize application performance, and mitigate environmental risks (Odzijewicz et al., 2022) (You et al., 2024) (Obernberger & Supancic, 2009).	High
Long-term Environmental Impact Assessment in Agriculture	Insufficient data on heavy metal accumulation, phytotoxicity, and soil ecosystem effects from prolonged Hawan Ash application.	Conduct long-term field trials assessing bioaccumulation, soil microbial dynamics, and potential toxicity under varying application rates and soil types.	Addressing these gaps is critical for environmental safety, regulatory compliance, and sustainable agricultural use (Adriano et al., 1980) (You et al., 2024) (Baig, 2023).	High

Optimization of Ash Activation and Processing Techniques	Current activation methods improve performance but can be energy-intensive and costly, with limited scalability demonstrated.	Investigate energy- efficient, cost-effective activation methods; scale-up studies; and life-cycle assessments to balance performance gains with environmental and economic costs.	Enhancing activation processes is key to improving material properties while ensuring industrial feasibility (Lei et al., 2024) (Qi et al., 2024) (Montagnaro, 2024).	High
Comparative Efficacy of Hawan Ash vs. Other Biomass Ashes	Limited direct comparative studies hinder understanding of unique advantages or limitations of Hawan Ash relative to other biomass ashes.	Perform systematic comparative analyses of physicochemical properties, application performance, and environmental impacts across diverse biomass ashes.	Comparative data will inform tailored applications and promote knowledge transfer across biomass ash types (Danish et al., 2023) (Akhter et al., 2021).	Medium
Economic Feasibility and Market Integration	Economic analyses often lack depth, especially regarding processing costs, logistics, and market barriers for large-	Conduct detailed techno-economic assessments including supply chain logistics, regulatory impacts, and market acceptance	Robust economic data are necessary to attract investment and support policy frameworks for scaling up utilization (Bukvić et al., 2025)	High

			(Obernberger &	

CONCLUSION

Hawan Ash and other biomass ashes represent promising sustainable materials with diverse applications in agriculture, construction, biomedical and environmental remediation. Their high content of silica, alumina, and alkaline minerals provides pozzolanic reactivity and nutrient richness, making them suitable for use as soil amendments and cementitious additives. In agriculture, Hawan Ash improves soil pH, nutrient availability, and microbial activity, but concerns over trace element accumulation and long-term impacts require controlled use and regulatory guidance. In construction, it enhances mechanical strength and sustainability of concrete and bricks, though variability in ash composition and processing costs remain key challenges.

Environmentally, Hawan Ash supports circular economy goals through pollutant adsorption, CO_2 capture, and waste valorisation. Despite these benefits, broader industrial uptake is limited by inconsistent standards, leaching risks, and regulatory uncertainty. Biomedically can also be used as Hawan ash exhibits moderate to strong antibacterial activity against pathogens like *E. coli*, *S. aureus*, and *P. aeruginosa*. In traditional medicine, Hawan ash has been applied topically to wounds, burns, and skin infections. Compare to other biomass ashes, Hawan Ash holds unique advantages, yet lacks large-scale comparative data. Advancing its use demands interdisciplinary research, field validation, and policy support to transform this culturally significant by-product into a reliable, eco-efficient material for real-world applications

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