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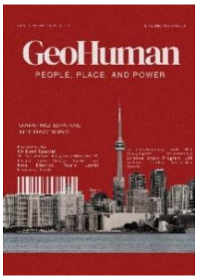

Balancing Ecology and Livelihoods in Waste Management: A Systematic Review of Sustainable Development Strategies

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ABSTRACT

Waste management is a critical aspect that requires careful handling to maintain ecological balance. This study aims to analyze how ecological fulfillment and human livelihood can coexist through efficient and sustainable waste management. Method: This study employs a Systematic Literature Review (SLR) approach using data from the Scopus database to examine the concept of harmonizing ecology and livelihoods. Results: The findings indicate that harmonizing these two aspects requires a dual approach. First, technological interventions, such as bioremediation using microbes and heavy metal stabilization, are essential for the ecological restoration of polluted areas. Second, socio-economic strategies, specifically the "integrated conservation and development model," are crucial for linking waste processing to economic incentives. Practical implications: Waste management policies cannot rely solely on technical disposal methods. Instead, they must adopt an ecosystem service approach that transforms waste into an economic resource, ensuring that community livelihoods are improved and environmental sustainability is maintained.

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Introduction

Development across various sectors, such as infrastructure, housing, and industry, contributes significantly to economic growth but also poses a potential risk of creating major environmental problems, particularly in waste management (Das, 2017; Mngomezulu et al., 2024). With rapid urbanization and expansion of major cities, the volume of waste generated by the development sector continues to escalate, threatening environmental quality. Waste generated during the development process, specifically construction and building material waste, can contaminate water, soil, and air, negatively impacting human health and ecosystems. This necessitates a more sustainable approach to ensure that the development process does not cause excessive environmental damage. Therefore, it is crucial to explore the nexus between ecological fulfilment and human livelihoods in the context of waste management during the development process.

Sustainable development has become the cornerstone for addressing global challenges, such as environmental degradation, climate change, and social inequality (Izah et al., 2025). Waste management is a critical aspect that must be handled carefully to maintain ecological balance. Numerous studies have indicated that inefficient waste management during the development process can lead to severe environmental degradation, including soil, water, and air pollution. Inefficient waste management in the construction industry significantly contributes to environmental degradation. The construction industry is a major global contributor to waste, resulting in substantial environmental impacts, such as landfill space depletion, resource scarcity, and pollution (Lee & Noor, 2006). Inefficient waste management practices result in the release of toxic substances, non-biodegradable materials, and increased greenhouse gas emissions, all of which contribute to pollution.

Conversely, more environmentally friendly approaches, such as recycling and waste repurposing, can help minimize the negative impact of development on the environment. Recycling, reusing, and salvaging waste can yield cost savings (Kralj 2008). The role of construction system managers is to direct and guarantee pollution reduction and prevent the negative impacts of environmental contamination. Consequently, efficient and sustainability-based waste management has become an urgent necessity in development planning and execution (Shajidha & Mortula, 2025). Human livelihoods, especially for communities dependent on the development sector, must be prioritized to achieve a balance between economic progress and environmental conservation. A central issue is ensuring that waste-generating sectors continue to provide economic benefits without compromising the ecosystem's quality.

An ecosystem-based approach that aligns development goals with natural resource conservation, including improved waste management, is a pivotal step in mitigating potential conflicts between economic needs and environmental sustainability. Furthermore, local community participation plays a vital role in enhancing the effectiveness of waste management programs because they possess a deeper understanding of local conditions and needs. Studies suggest that active community engagement can result in better resource allocation and more efficient waste management. For instance, in rural Maharashtra, community involvement has enhanced resource allocation and raised awareness of sustainable waste management methods (Kadam, 2024).

Another significant challenge lies in minimizing the impact of waste from development activities without diminishing community livelihood potential, particularly in areas dependent on natural resources (H. Wu et al., 2025). Therefore, it is essential to develop waste management policies that support socio-ecological sustainability. One solution that warrants further examination is the utilization of green technologies and community-based systems capable of optimizing waste treatment processes. Green strategies can be considered for implementing waste-to-energy (WtE) projects at the municipal level. The sustainability framework for WtE implementation, which encompasses appropriate waste treatment technologies as well as waste collection and transportation, is examined and explored through complex and structured discussions. Lessons learned from successful WtE implementation in certain cities will assist other cities in replicating these efforts and even creating better waste and energy management by adopting examples of WtE project implementation in various countries (Ramadan et al., 2023).

Technologies such as microbe-based waste treatment systems and constructed wetlands offer viable alternatives for efficient waste treatment, reducing negative environmental impacts, and simultaneously providing economic benefits to local communities (Qiu et al., 2022). Ultimately, the fulfillment of ecological needs and human livelihoods must proceed in tandem without mutually compromising one another, especially in the context of rapid development. An environmentally friendly and participatory approach to waste management can act as a bridge between development necessities and environmental conservation, thereby creating a mutually supportive and sustainable system. Therefore, this study aims to analyze how ecological fulfillment and human livelihoods can coexist through more efficient and sustainable waste management.

Methodology

This study adopted a mixed-method approach that combined a systematic literature review with empirical spatial analysis. First, regarding the literature review, data were collected from the Scopus database to examine the coexistence of ecological fulfilment and human livelihoods. The search utilized the keywords "sustainability," "human livelihoods," and "ecological balance." The selection process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol to ensure transparency. Initially, the search yielded 540 documents that were screened. After applying strict inclusion criteria, limiting results to peer-reviewed journal articles published between 2015-2025 and written in English and removing duplicates, 25 articles were selected for the final analysis. The documents were analyzed using thematic content analysis to identify reciprocal relationships between social and natural systems.

Subsequently, the empirical component was located at the Pasar Lama Fish Landing Site in Kaur Regency, Bengkulu. This phase employed a quantitative descriptive approach using spatial statistical methods. Primary data were obtained from eight fishermen through in-depth interviews, participatory mapping, and global positioning system (GPS) tracking. The snowball sampling technique was applied to select respondents, ensuring the reliability of the data regarding the coordinates and types of Fish Aggregating Devices (FADs). The spatial data were then analyzed to map the distribution patterns and density of fishing grounds.

Result and Discussion

Harmonizing Ecological Processes and Human Livelihoods

Ecological processes and human livelihoods can coexist if development approaches are grounded in an integrated framework. This framework must consider waste management, the application of green technology, and the active participation of local communities. Optimizing innovations such as building information Modelling (BIM), prefabricated construction, and digital platforms for waste management, while simultaneously implementing sustainable models and community-based conservation development, can support a balance between environmental conservation and livelihood enhancement. Fu et al., (2022) argue that to address sustainability challenges in the Anthropocene era, a strong nexus between human and natural systems is essential. They proposed a conceptual cascade framework consisting of four main components: pattern, process, service, and sustainability. This framework links landscape patterns with ecological processes, connects ecological processes with ecosystem services, and ultimately drives socio-ecological sustainability.

To ensure that ecological preservation and human livelihoods can coexist with the reality of surging waste production, several key strategies have been identified:

Management of Heavy Metal Content in Waste

In metropolitan areas, construction waste is a primary driver of environmental pollution, resulting in soil, water, and air contamination, habitat destruction, and alterations to the landscape. These impacts reduce local biodiversity, disrupt microbial communities, and threaten the resilience of ecosystems. Notably, composite materials and fine residues within Construction and Demolition Waste (C&DW) exhibit ecotoxicological effects, inhibiting plant growth and earthworm reproduction at concentrations exceeding 10–25% (Molla et al., 2024).

As illustrated in **Figure 1**, heavy metals (e.g., Cd, Zn, Pb, and Cu) from construction waste accumulate in the soil, lowering pH levels and increasing organic carbon, with Cd and Mn posing the highest ecological risks due to their mobility and bioavailability. Long-term contamination suppresses soil microbial diversity and function, impairing plant health and altering nutrient cycling, although certain microbial groups adapt by producing specific enzymes. For instance, in the soil of an informal construction waste dumpsite in Beijing, China (G. Wu et al., 2022), results indicate that long-term disposal of construction waste in riverbeds can reduce soil pH values, increase soil organic carbon content, and influence the total amount and distribution of heavy metals. Furthermore, the dumpsite contaminates the external soil environment, with Cd, Zn, Pb, and Cu being identified as characteristic pollutants.

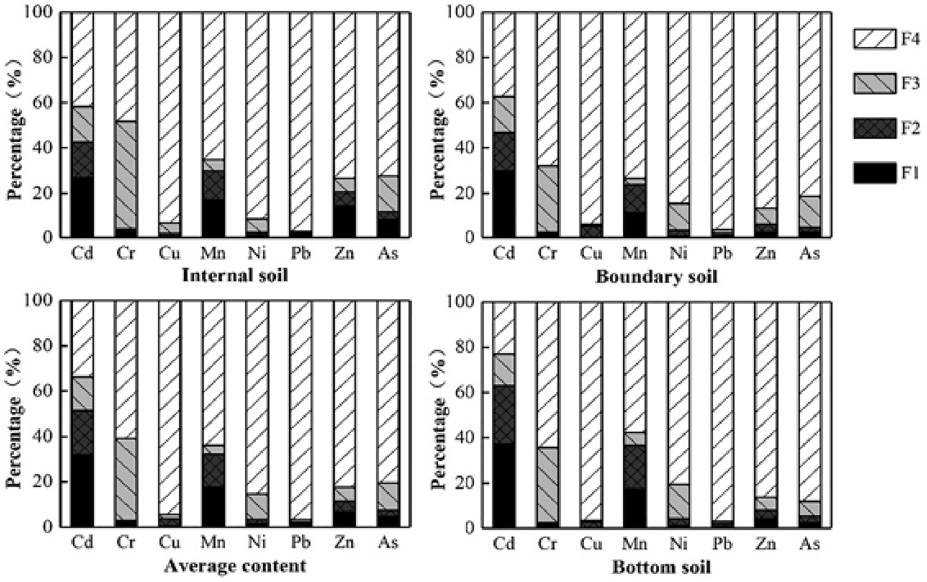

Figure 1: Heavy Metal Content in construction waste at a riverbed in Beijing, China
(Source: G. Wu et al., 2022)

Management of Heavy Metal Content in Waste

The management of heavy metals in waste highlights the potential of phosphate-enriched biochar derived from sewage sludge to adsorb and stabilize heavy metals in contaminated soil (Yuan et al., 2016). Sewage sludge was pyrolyzed at various temperatures to produce biochar, a process that alters the structural properties of the resulting material (Tomczyk et al., 2020). Soil incubation experiments were conducted by adding phosphate-modified biochar to contaminated soil and maintaining it for one month. Heavy metals were extracted using the CaCl2 extraction method, a standard protocol for assessing bioavailability, and were analyzed using atomic absorption spectrophotometry (Zhang et al., 2022). This extraction technique was selected to isolate the exchangeable metal fraction, which represents the primary risk for plant uptake and leaching into groundwater. Consequently, the analysis provides a more accurate evaluation of the efficacy of biochar in mitigating ecological toxicity than total metal concentration measurements.

The results indicated that phosphate amendment significantly enhanced the capacity of biochar to immobilize heavy metals through precipitation mechanisms (Han et al., 2017). Soil was amended with 2.5 wt. % phosphate-enriched sewage sludge biochar led to a reduction in bioavailable Cd (by 65–82%), Zn (40–75%), and Pb (52–88%) across various pyrolysis temperatures. Specifically, phosphate-amended biochar reduced Cd and Zn mobility more effectively than non-amended biochar, with a significant decrease in their concentrations in soil extracts. For Cu and Pb, the effectiveness varied with the pyrolysis temperature and phosphate amendment, highlighting the importance of optimizing for specific metal contaminants. Biochar produced at elevated pyrolysis temperatures (500 °C) exhibited increased ash content and pH, which enhanced its ability to retain heavy metals and limit their mobility (H. Li et al., 2017); (Mbasabire et al., 2025).

Utilization of Microbes to Decompose Wetland Pollutants

Waste significantly alters the microbial community structures in wetlands, which in turn affects the pollutant removal efficiency (Y. Li et al., 2014). Liu et al. (2019) demonstrated that bacterial communities in constructed wetlands play a crucial role in decomposing organic and inorganic pollutants, with their dynamics strongly influenced by environmental conditions such as nutrient availability, pH, temperature, and vegetation type (Ibekwe et al., 2016). These findings are particularly relevant for managing development-generated waste, which is often rich in organic matter, heavy metals, and excess nutrients, where constructed wetlands offer an eco-friendly treatment solution for contaminated runoff from residential and industrial areas (Saeed et al., 2014). By leveraging specific bacterial communities, such as *Proteobacteria* and *Chloroflexi*, these systems assist in decomposing organic matter and lowering pollutant levels (Fang et al., 2021). Thus, waste management has evolved beyond merely reducing waste volume to actively leveraging the natural role of microorganisms to restore water and soil quality.

In metropolitan areas, restoring polluted urban rivers is critical for protecting aquatic and human health. As shown in **Figure 2**, treatment wetlands coupled with microbial electrochemical systems (MES) have emerged as a key research focus because of their high pollutant removal efficiency and small footprint (Srivastava et al., 2020). Specifically, wetland bed coupling with a close-circuit microbial electrochemical system (WB-CMES) offers an innovative solution for reducing pollutants such as nitrates and organic compounds, which often originate from industrial or domestic waste. By combining biological and electrochemical processes, this system stabilizes microbial ecosystems and enhances nitrification and denitrification, effectively mitigating the environmental impact of liquid waste in urban areas (Xu et al., 2018). This technology is applicable across various sectors, including industry and agriculture, and offers a viable pathway to reduce water pollution and enhance overall environmental sustainability (Qiu et al., 2022).

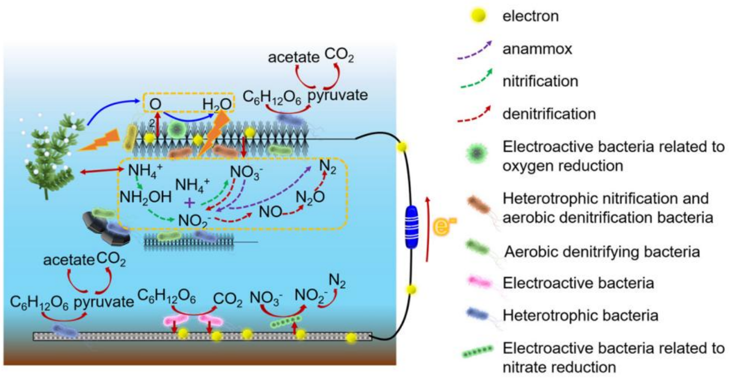

Figure 2: Utilization of Microbes to Decompose Carbon and Nitrogen Pollutants with WB-CMES
(Source: Qiu et al., 2022).

Integrated Conservation and Development Models

Case studies, such as the Annapurna Conservation Area Project (ACAP) in Nepal and ecology-based livelihood models in Southeast Asia, demonstrate that participatory governance, community empowerment, and diversified sustainable tourism can align conservation with socio-economic benefits (Schuett & Dahal, 2016). Integrated Conservation and Development Projects (ICDP) implemented in Nepal are widely regarded by researchers and practitioners as successful instances of balancing these dual goals. Under the authority of ACAP, a conservation-oriented NGO, the ICDP engages local communities in participatory resource management, ensuring that local governance choices support biodiversity (Baral, 2012). Specifically, one community within ACAP was found to possess a timber surplus that met conservation goals and could serve as a sustainable income source for local development (França et al., 2019). This evidence reinforces the notion that when communities are granted management rights, they are more likely to adopt sustainable practices that secure both their economic future and the area's ecological integrity.

Furthermore, the utilization of organic waste, such as dry wood and fallen timber, which are ecologically considered "forest waste" can be processed and repurposed as building materials or fuel. This approach reduces resource wastage and minimizes the felling of trees. ACAP demonstrates efficiency in the forest waste processing cycle, which strongly supports a circular economy at the ecosystem level, where organic waste is transformed into productive resources without compromising the ecosystem (Pasakhala et al., 2017). Ultimately, integrating waste-to-resource strategies into conservation planning ensures that economic activities remain within the ecological carrying capacity of the region, thereby harmonizing development needs with environmental preservation.

Integrated Livelihood and Ecosystem Service Models

The Conservation-Compatible Livelihoods (CCL) framework advocates integrating local resource utilization with biodiversity conservation through multi-stakeholder participation and equitable benefit-sharing (Marx, 2015). Challenges to this approach include institutional inertia, unclear boundaries, and conflicts between conservation and development objectives (Duan and Wen, 2017). The CCL concept is highly relevant to waste management (HE & MIN, 2023), particularly in the context of protected areas, where sustainable natural resource utilization can encompass local resource-based waste management (Birben, 2019). Consequently, incorporating waste management into the CCL model transforms potential environmental liabilities into economic assets, thereby reinforcing synergy between ecological preservation and community well-being.

A crucial aspect of CCL is the synergy between biodiversity conservation and sustainable local resource utilization. Waste management can be integral to the CCL approach, wherein waste generated from community productive activities is managed in an eco-friendly way (Schreckenberg et al., 2010). This reduces the negative impacts on local ecosystems and enhances the community economy through recycling or utilizing waste for value-added products (Ghufran et al., 2024). This approach supports environmental and socioeconomic sustainability in protected areas and enriches pathways to achieving CCL by expanding the scope of waste management as part of broader conservation efforts.

Conclusion

This study underscores the critical importance of integrating waste management with sustainable development approaches, necessitating the synergy of green technology and active community participation. The utilization of advanced systems such as building information Modelling (BIM), prefabricated construction, and digital platforms for waste management, alongside community-based conservation models, establishes a necessary balance between waste mitigation and environmental protection. Furthermore, technical interventions, specifically the management of heavy metals in construction waste and the use of microbial electrochemical systems (WB-CMES) in constructed wetlands, serve as vital solutions for reducing ecological toxicity, particularly in pollution-prone urban regions.

Integrated conservation and development models, exemplified by the Annapurna Conservation Area Project (ACAP), demonstrate that local community empowerment can effectively align conservation goals with socio-economic benefits. Within the framework of Conservation-Compatible Livelihoods (CCL), local resource-based waste management offers a sustainable pathway in which waste is treated not merely as a byproduct but as an economic resource. This approach enhances community livelihoods while protecting biodiversity, thereby enriching conservation strategies by embedding waste management in a broader socio-ecological context.

Despite these contributions, this study has several limitations. First, the literature search was restricted to the Scopus database, which, while comprehensive, may exclude relevant studies indexed solely in other databases, such as the Web of Science or regional indices. Second, the screening criteria prioritized open-access articles to ensure transparency and reproducibility; this choice, however, limited the sample size and may have omitted significant findings from paywalled literature. Future research should consider a broader range of databases and include grey literature to capture a more holistic view of global waste management practices in the context of ecological harmony and livelihood.

Funding Declaration

This research did not receive any specific grants from any funding agency in the public, commercial, or not-for-profit sectors.

Competing Interests

The author(s) declare (s) no conflict of interest.

Data Availability

The datasets generated and/or analyzed during the current study are not publicly available due to ethics related to protecting the privacy and confidentiality of research participants but are available from the corresponding author on reasonable request.

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