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# Environmental Health Risks and Community-Based Pathways for Sustainable Solid Waste Management in Biu, Northeastern Nigeria

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**ABSTRACT**
Diabetes mellitus remains a major metabolic disorder requiring safer and affordable therapeutic alternatives. This study evaluated the safety profile, in vitro antidiabetic activity, and phytochemical composition of a formulated polyherbal syrup (PHS) prepared from *Vernonia amygdalina*, *Moringa oleifera*, *Zingiber officinale*, *Allium cepa*, and *Allium sativum*. Aqueous extracts of onion, garlic, and ginger were obtained by decoction of 20 g powdered samples in 100 mL distilled water at 40 °C for 3 h, while fresh leaves of *Moringa oleifera* and *Vernonia amygdalina* were extracted by manual juice expression and filtration. The extracts were combined with honey to produce the polyherbal syrup. Acute toxicity evaluation in albino rats using oral doses of 1000–16000 mg/kg body weight revealed no mortality or visible signs of toxicity, indicating an $LD_{50}$ greater than 16000 mg/kg. Sub-acute toxicity studies conducted at doses of 25–400 mg/kg also showed no adverse behavioural or physiological changes. In vitro antidiabetic assays revealed that PHS is concentration-dependent. The PHS exhibited $IC_{50}$ values (µg/mL) of 8.88 for glucose uptake, 2.55 for α-amylase inhibition, and 3.50 for α-glucosidase inhibition, compared with the standard drug acarbose which showed $IC_{50}$ values of 3.55, 1.89, and 3.39 µg/mL respectively. Although the standard drug showed slightly higher potency, the PHS demonstrated comparable α-glucosidase inhibitory activity. GC–MS profiling revealed numerous bioactive phytochemicals including 2,3-dihydro-3,5-dihydroxy-6-methyl-4H-pyran-4-one, 5-hydroxymethylfurfural, thymine, n-hexadecanoic acid, and octadec-9-enoic acid. The combined presence of these compounds suggests possible synergistic pharmacological interactions responsible for the observed antidiabetic effects. These findings indicate that the formulated polyherbal syrup is safe and possesses promising antidiabetic potential.

**Keywords:** Solid waste management, Open burning, Environmental health, Community participation, GIS buffer analysis, Circular economy

## INTRODUCTION

The mismanagement of solid waste is a major environmental and public health problem in low and middle income urban and semi-urban communities around the world (Barimah *et al.*, 2025; Pernebayev & Aitimbetova, 2025; Zhang *et al.*, 2024). In 2016, 2.01 billion tonnes of municipal solid waste (MSW) were generated globally, and the amount is expected to rise to 3.4 billion tonnes by 2050, most of which in areas that have the least developed collection and treatment systems (Kaza *et al.*, 2018; Maalouf & Mavropoulos, 2022). Open dumping and open burning of waste introduce greenhouse gas (GHGs), fine particulate matter, dioxins and furans into the atmosphere and leachate from unlined dumpsites pollutes the soils and groundwater resources (Njoroge *et al.*, 2021; Sharma & Dubey, 2021; Vega *et al.*, 2022). Additionally, waste deposits can provide breeding grounds for disease vectors, exacerbating the risk of outbreaks in targeted areas (Mohan, 2020).

Nigeria produces about 32 million tonnes of solid waste every year, although only a small proportion is formally collected in most cities, and in many semi-urban and rural areas, there is no collection services for solid waste (Adekola, 2021; Azeez *et al.*, 2022). Only approximately 20% of this waste is being collected in formal systems, and only about 10% of the waste is being recycled, while the rest of the waste is either dumped, burned, or landfilled (Odiboh, 2026). The environmental impacts of this condition as air pollution from burning, blocked drainage and flooding, soil and water pollution, and increased vector density have been widely reported in northern Nigeria and other locations (Bukar, 2022; Mshelia, 2024; Musa *et al.*, 2023). Municipal solid waste burning is responsible for 29% of fine particulate matter emissions, and significantly drives respiratory illness burden in affected populations (Kapwata *et al.*, 2026; Mekonnen, 2026). The findings of the study conducted in Jos South LGA have shown that 57% of the households used open burning of waste regularly, with the major contributing factor being the failure of waste collection system (Lar &Ahmed, 2026).

These pressures are exemplified by the Biu local government area of Borno State, which is the headquarters of the Biu local government area. The growth of population associated with educational centres, trade and relative stability has led to an increase in household and business waste generation, but the organised waste collection services haven't managed to keep

up (Aliyu *et al.*, 2020). Although agricultural residue burning, electronic waste, and abattoir residues have been the subject of prior studies, there is no study that brings together the various practices of municipal solid waste, spatial exposure of residences to dumps, health perceptions, and community-ready interventions. From the environmental management point of view, three key requirements are identified: quantification of exposure pathways via setback violations, burning emissions, and drainage blockages; characterisation of the waste stream to match treatment options, such as composting, recycling, and residual disposal; and design of the interventions that are capable of being sustained by communities under resource constraints. Children and informal workers are involved in waste handling, which is likely to add to child protection and workers health and safety issues that can be resolved through institutional safeguards (UNICEF, 2021). Women, who are responsible for managing household waste on a day-to-day basis, are important stakeholders who can play a vital role in the design of segregation and leadership of committees which will enhance the adoption of source separation in the home (Green & Patel, 2024).

In the Nigerian urban setting, the environmental and health hazards of bad disposal of solid waste are well documented. According to Nasarawa State studies, open dumping, open burning, and indiscriminate dumping in drainage channels are the common activities associated with the increased cases of malaria, typhoid fever, cholera, and dysentery among others (Olayinka & Abdulsalam, 2026). Oslo-Minna has been found to have about 50% of buildings within 100-300-m buffer zones from open dumpsites, making residents very susceptible to the spread of diseases (Kassah *et al.*, 2016). Likewise, the concentration of pollutants at the dumpsites in Delta State is highest at the source and decreases rapidly with distance from the dumpsites, as seen in the health risk characterisation showed that the concentration of $PM_{2.5}$ and $PM_{10}$ pollutants at the dumpsites exceeded WHO guideline values several folds (Aliyu *et al.*, 2020). Goje (2022) reported that out of a total of twenty-seven (27) open dumpsites in Zaria, Kaduna state, 25 of the sites were inadequately placed relative to residential areas.

The objective of this study was therefore to map and characterize of solid waste disposal in Biu, identify the composition of disposed waste, evaluate disposal practices and collection frequency, and identify reported environmental and health impacts as well as community perceptions, and a participatory and environmentally sustainable management framework for the study area. The study combines spatial analysis and community-based assessment, which presents a holistic view of the challenges of solid waste management in the semi-arid urban environment of the North-eastern region of Nigeria and the context-specific pathways for sustainable intervention. It was hypothesized that there would be significant differences in location of Biu in context to practice of solid waste management and related environmental health risk due to poor waste collection, indiscriminate disposal and poor waste management practices in areas.

## MATERIALS AND METHODS

### Study Area

Biu town is the administrative headquarters of Biu Local Government Area in Borno State, Nigeria. The town is situated on the Biu Plateau at an elevation of approximately 685 m above sea level. The climate is tropical wet–dry with a clear rainy season from May to October and a dry season from November to April. The temperature range is approximately 18 °C to 38 °C. The population has increased rapidly in the last few decades, resulting from natural increase, rural-urban migration, and the presence of educational institutions such as the Nigerian Army University Biu. The town is a business center for the surrounding agricultural regions. Its economy is mainly based on farming (sorghum, millet, cowpea, cotton) and commerce. The study frame comprised five wards, namely, Dugja, Galdimare, Sulumtha, Yawi, and Zarawuyaku (Figure 1).

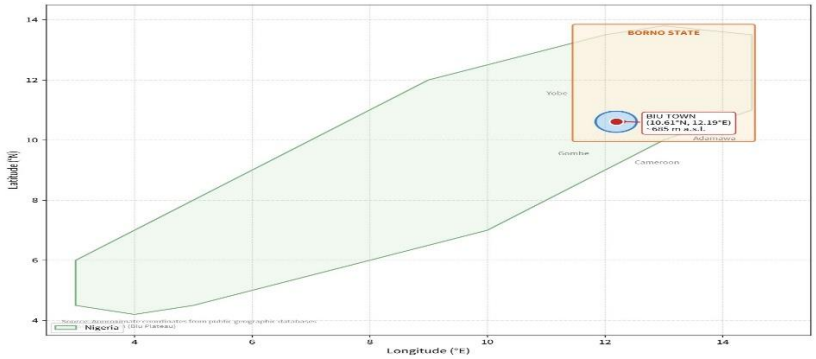


Figure 1: Map of the study area

### Research Design and Sampling

The design of this study was a mixed method study with cross sectional survey design; collecting quantitative data by structured questionnaire and qualitative data by field observation and key informant interview. Geographic information system (GIS) techniques were employed to create the map of the waste disposal locations and perform buffer analysis. The study population consisted of the households of the five wards. A sample size of 399 was determined using a formula by Taro Yamane with a margin of error of 5% for an estimated population base. There were 14 sub-wards from which 380 questionnaires were sent and 359 questionnaires were received (94.5% response rate). Following data screening, 348 responses were retained for analysis.

### Data Collection Instruments

The data were gathered by means of a structured questionnaire that included information on the demographic data, waste disposal practices, frequency of waste collection, the impact on health, and waste management perception. The questionnaire was pre-tested in 20 respondents in non-study ward. Photographic documentation of field observations was made at each identified waste disposal site. Handheld GPS was used to record disposal site geographic coordinates.

**Data Analysis**

Quantitative data were analysed using IBM SPSS Statistics Version 26. Data were analysed and presented through descriptive statistics (frequencies, percentages) in tables and graphs. Field observations were used to gather qualitative data, which was then thematically analysed. The distances between the waste disposal sites and residential areas were measured using buffer analysis in ArcGIS. Residential proximity and buffer zones of 100 m (national FEPA-related guidance) and 300 m (international guidance - UNEP) were established around each disposal site.

## RESULTS AND DISCUSSION

**Waste Composition and Environmental Implications**

The approximate composition of organic material 45%, plastics 30%, paper 15% and glass/metal 10% was determined by field characterisation (Figure 2). The profile is representative of semi-urban areas in developing countries where consumption of fresh foods increases the organic fraction (Kaza *et al.*, 2018; World Bank, 2019). The high organic component facilitates composting as a key diversion strategy that can mitigate methane emissions from dump sites and provide nutrients to local soil (Chukwuma *et al.*, 2020). The significant plastic content emphasizes the importance of organized collection to reduce long-term soil, drain and waterway pollution (Geneva Environment Network 2023; Moses *et al.*, 2021; Sarin *et al.*, 2020). The matching of treatment options to composition is an important principle in environmentally sound waste management and as circular-economy practice (Espuny *et al.*, 2021; Stahel, 2020).

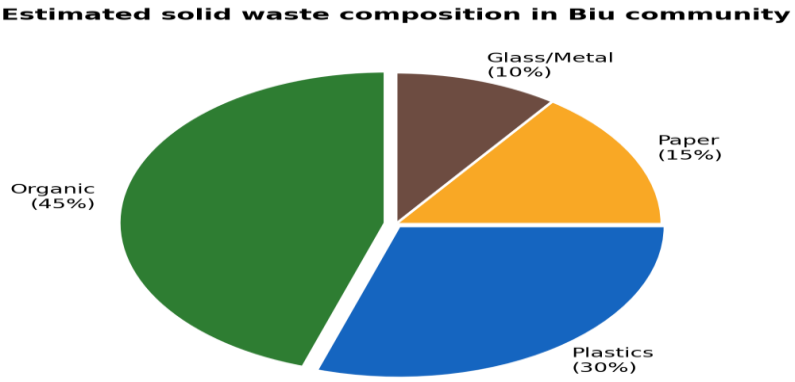


Figure 2: Estimated composition of solid waste in Biu community

**Disposal Agents, Methods, and Collection Frequency**

Errand boys (29.5%) and children (26.2%) were the two most common agents for disposal, with hired agents (24.5%) and self-disposal (19.8%) coming next (Figure 3; Table 1). Children's participation in waste management activities introduces issues such as child protection and occupational exposure, including exposure to sharp objects and the presence of pathogens (UNICEF, 2021; Musa *et al.*, 2023). The main disposal systems were open burning (49.6%), community initiatives (24.8%), local authority pickup (15.6%), and hired services (10.0%) (Figure 3). Collection was largely reactive with 67.1% of households stating their waste was removed when it became a nuisance and none stating it was collected weekly on schedule (Figure 4). The high prevalence of open burning is similar to what has been observed in other environments in Nigeria and Africa where formal services are limited (Mshelia, 2024; Rogers, 2022), and is attributed to the lack of any alternative fuel sources and the environment. Open burning is a source of particulate matter, carbon monoxide, volatile organic chemicals, polycyclic aromatic compounds, dioxins and furans, all of which have known health impacts including respiratory health effects (Sharma & Dubey, 2021; Vega *et al.*, 2022). This practice is largely attributed to the lack of formal waste collection infrastructure, as 70% of the respondents in the context within Nigerian studies attributed it to this (Lar & Ahmed, 2026).

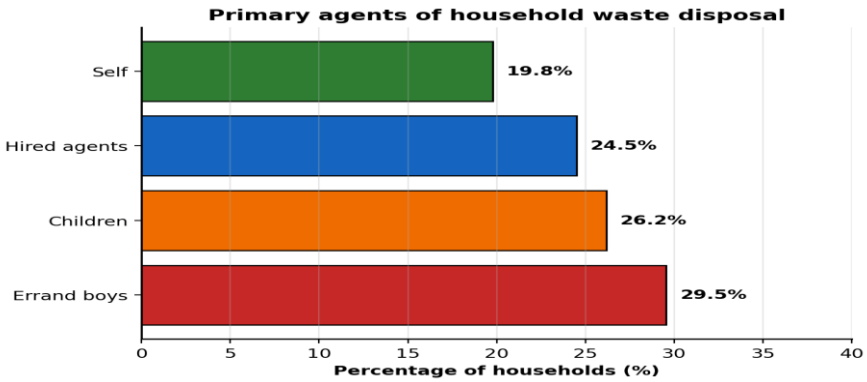


Figure 3: Primary agents of household waste disposal

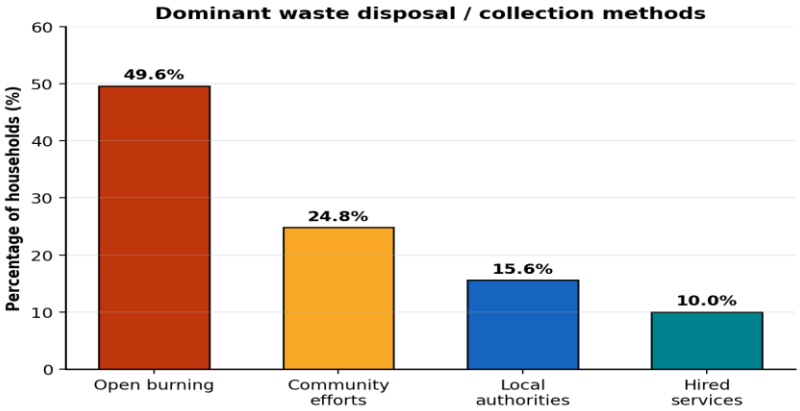


Figure 4: Dominant waste disposal and collection methods

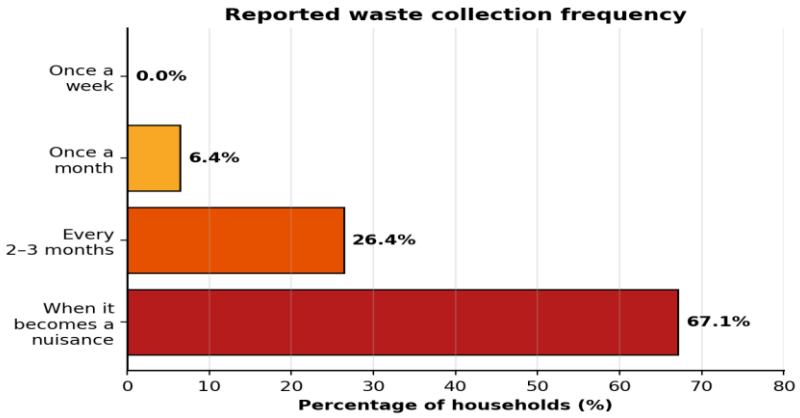


Figure 5: Reported frequency of waste collection

**Table 1: Waste Disposal Agents and Methods (N = 359)**

| Category | Response | Frequency | % |
|---|---|---|---|
| Disposal agent | Errand boys | 106 | 29.5 |
| | Children | 94 | 26.2 |
| | Hired agents | 88 | 24.5 |
| | Self | 71 | 19.8 |
| Method | Open burning | 178 | 49.6 |
| | Community efforts | 89 | 24.8 |
| | Local authorities | 56 | 15.6 |
| | Hired services | 36 | 10.0 |

The results are in line with the research findings of Tudun-Kauri and Angwa-Maina in Nasarawa State where the waste disposal pattern was predominantly open dumping, open burning, and indiscriminate disposal into drainageways (Olayinka & Abdulsalam, 2026). The collection of waste by the public sector is very irregular, as observed in Biu, where 67.1% of households reported the removal of waste when it is a nuisance, which is similar to the situation in other urban centres of Nigeria where waste collection service has been found to be inadequate.

**Disposal Sites and Setback Compliance**

Table 2 shows the location of 9 major disposal sites, which were mapped in the 5 wards. A few were within 50–100 m of houses, or beside roads, but not many were over 300 m. The results from buffer analysis showed that there was widespread non-compliance with both national (~100 m) and international (~300 m) residential setback guidance. This proximity also creates environmental and health burdens for nearby households and environmental justice issues (Garcia *et al.,* 2021; Ogunbode *et al.*, 2022). Roadside and unpaved-road sites present traffic and dust related burdens (Olowoporoku & Ganiyu, 2021; Yusuf *et al.,* 2022). Relocation or engineered containment of non-compliant sites is not simply a matter of behaviour-changing messages, environmental management responses must include this.

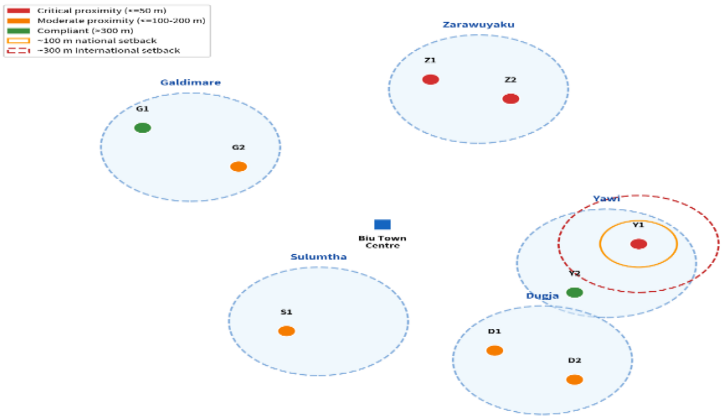


Figure 6: Schematic Spatial Distribution of Nine Major Waste Disposal Sites in the Study area

The spatial distribution of dumpsites in Biu (Figure 6) is similar to that of Zaria, Kaduna State where a GIS-based study identified that 25 of 27 landfills were situated inappropriately with respect to the residential population (Goje 2022). Likewise, approximately 50% of buildings were found to be in the 100 to 300-metre buffer zones around open dump sites, and the residents were considered as being highly vulnerable to disease transmission (Kassah *et al.*, 2016). The exposure gradient observed was near the source which is also the trend observed in health risk characterisation of dumpsites of Delta State, where the concentration of pollutants was highest at the source and decreased significantly with distance in the dumpsites (Aliyu *et al.*, 2020).

**Table 2: Characteristics of Major Waste Disposal Sites in Biu**

| Site | Ward | Setting | Proximity | Dominant waste |
|---|---|---|---|---|
| $Z_1$ | Zarawuyaku | Tarred road | ≤50 m | Mixed |
| $Z_2$ | Zarawuyaku | Tarred road | ≤50 m | Mixed |
| $G_1$ | Galdimare | Rural | >300 m | Agricultural/organic |
| $G_2$ | Galdimare | Untarred road | ≤100 m | Mixed, debris |
| $Y_1$ | Yawi | Residential | ≤50 m | Plastics-rich mixed |
| $Y_2$ | Yawi | Rural | >300 m | Agricultural |
| $S_1$ | Sulumtha | Mixed use | ≤150 m | Mixed, commercial |
| $D_1$ | Dugja | Abattoir area | ≤200 m | Organic, plastics |
| $D_2$ | Dugja | Residential | ≤100 m | Household mixed |

**Health and Environmental Impacts**

The most common association respondents had with waste sites were mosquito breeding (45.1%), sharp objects (25.1%), and pests and rodents (17.3%) (Figure 5). Bad odour (35.4%), air pollution due to burning (30.9%), drainage blockage (19.3%), and reduced aesthetics (14.5%) (Figure 6) were the primary environmental concerns. The overall level of dissatisfaction with the existing arrangements amounted to 86.6%. These patterns are consistent with evidence that waste accumulation has impact on risk of vector borne diseases, and that open burning is associated with health impacts, including respiratory health (Mohan, 2020; Vega *et al.*, 2022; WHO 2018). Plastic and other waste that makes its way into the drains exacerbate local flooding and additional environmental issues during rain.

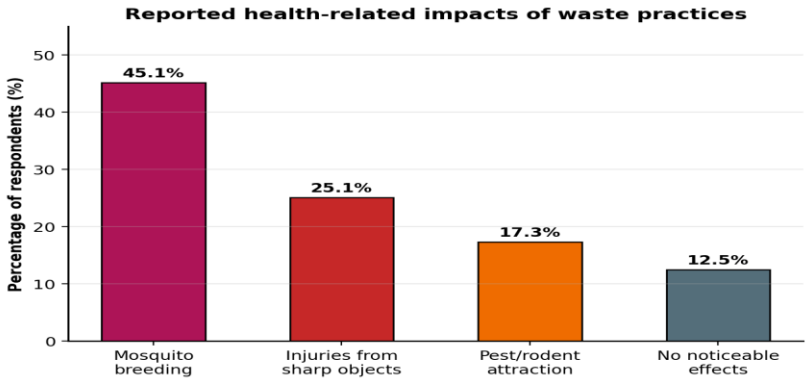


Figure 7: Reported health-related impacts of current waste practices

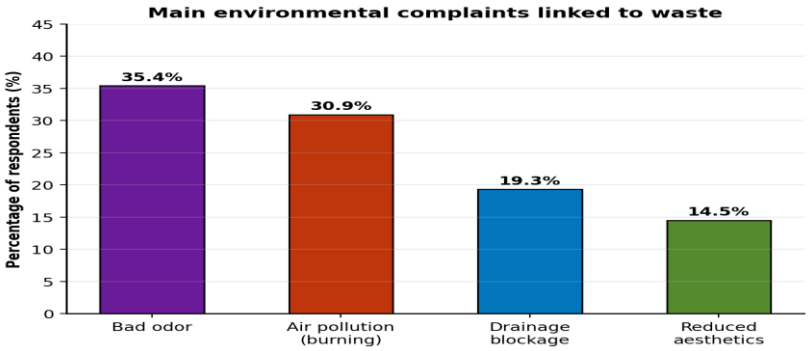


Figure 8: Main environmental complaints linked to solid waste

Complaints of health effects by respondents are similar to the results of other Nigerian studies. Tudun-Kauri and Angwa-Maina found that with the improper disposal of waste, there has been an increase in the incidence of associated diseases such as malaria, typhoid fever, cholera and dysentery (Olayinka & Abdulsalam, 2026). According to C²REST (2025), open burning of municipal waste results in the emission of harmful pollutants such as particulate matter ($PM_{2.5}$ and $PM_{10}$), dioxins, furans, and carbon monoxide, which are known to cause respiratory diseases like asthma, chronic obstructive pulmonary disease, and lung cancer. These documented health pathways are reflected in the perceived health risks reported in Biu, such as mosquito breeding and respiratory issues.

**Community Readiness and Policy Context**

Latent demand for improved systems is reflected in high dissatisfaction (86.6%) and existing collection (24.8%). Waste programmes that involve local community members and are built with transparency in fees and benefits, and with tangible environmental improvements, have been found to keep them engaged in others countries in Africa and Asia (Ahmed *et al.*, 2023; Green & Patel, 2024; Johnson & Lee, 2020; Smith *et al.*, 2024). A formal policy support, Nigeria's national solid waste policy and state environmental waste policies, exists but the problem of implementation is severe as funds, vehicles, and enforcement are all lacking in the secondary towns (Azeez *et al.*, 2022). Models based in the community supplement the local government's responsibility, organise the demand, minimise illegal dumping and generate social pressure for the scheduled services.

Researchers in the Accra Metro Area of Ghana, found that communities are actively engaged in waste management, but insufficient education and enforcement efforts have occurred because of political interference and limited resources (Fichtel, 2022). There are various common strategies being used to encourage participation for communities in rural Rwanda, such as football tournaments, weekly community activities and paid service arrangements (Gasaka, 2026). But there are factors such as low technical capacity, low financial opportunities, and fewer waste management companies in rural areas which pose challenges to efforts. Indonesia's Batu City experience shows that full household participation in source separation can boost the recycling rate from around 10.5% to 28.1%, emphasising the significance of encouraging source separation at the household level as an integral part of improving the performance of Community-Based Waste Management Systems (CBWMs). The experience from Batu City in Indonesia demonstrates that the level of participation in source separation by the entire household can raise the recycling rate from around 10.5% to 28.1%, highlighting the importance of promoting source separation at the household level as a key element in improving the performance of CBWMs.

**Gender, Livelihoods, and Occupational Exposure**

Children and informal workers are significantly involved in disposal which poses child protection and occupational health concerns (UNICEF, 2021). Every community system should ban child labour in the collection of waste, ensure provision of basic protective equipment for waste collectors and arrange waste collection time so as not to require children to go to dumps. Household waste management is a daily chore for women, and their active involvement in waste segregation design and role in waste committee leadership positively affects the spread of source separation practices (Green & Patel, 2024). Formalizing informal errand workers into cooperative member is a system of turning existing labour force into secure and reliable service, and generate small income via collection fees or the sale of recyclable materials (Adeola & Ajayi, 2020). Previous studies on recycling programmes in Anambra State have highlighted the economic gains, such as employment opportunities and the generation of income, that have been realized, in addition to the various socio-economic development and public health benefits (Odiboh, 2026).

**Climate and Air-Quality Co-Benefits**

Open burning of mixed municipal waste generates black carbon and organic compounds that develop into methane and toxic products causing local air quality and climate impacts (Vega *et al.*, 2022). The diversion of organics to composting and plastics to recycling decreases the mass burned and the residual to be dumped. Dust caused by the unpaved access to dumps aggravates particulate exposure in a semi-arid environment like Biu (Yusuf *et al.*, 2022). Such an initiative with an environmental focus which reduces burning and centralises disposal at compliant facilities thus achieves climate, air-quality and health goals at the same time and is in line with Nigeria and Africa's commitments in short-lived climate pollutants (SLCPs) and waste-sector mitigation. Open burning is responsible for 29% of fine particulate matter and 11% of global black carbon emissions, and is responsible for more than 1.2 million deaths every year in African (Mekonnen, 2026). Methane emitted from organic decomposition of waste in landfills is a major source of greenhouse gas, and composting is a potential mitigation option for this effect.

**Implementation Sequence and Transferability**

A realistic scenario for Biu could be to start with community meetings to validate the framework and select a waste committee; to pilot waste segregation and twice weekly collection in one or two wards; to create a small compost pad

and recyclables gathering point; GPS to re-map and progressively close or fence non-compliant dumps; to organize school and radio campaigns; and to negotiate local by-laws to prohibit open burning near homes. Burning incidence, proportion of households segregating, tonnes composted and recycled, and resident satisfaction should be included as indicators for monitoring. Informal disposal, open burning and setback violations are common to all state's semi-urban centres such as Borno and neighbouring states. The evidence-base composition for the Biu, agent structure, perception of health and spatial non-compliance provides a framework for conducting a rapid assessment at other sites. The environmental agencies and universities have the option to use the survey and GIS protocol which are adaptable, and the five-pillar framework is applicable anywhere where the organic fraction is dominant and there is a willingness of the community to act.

## CONCLUSION

In Biu, informal disposal agents are prevalent, open burning is a significant practice, and there is limited frequency of solid waste collection and disposal sites that do not meet recommended residential setbacks. A substantial share of residents is aware of the environmental health hazards associated with these practices including vector breeding, injury hazards, odour, air pollution, and drainage failure. Practical composting/recycling opportunities exist in waste composition. A community-based solution that combines segregation, organics waste and plastics recovery, frequent collection and education can minimize exposure and pollution loads and meet the goals of a circular economy and environmental health. Current study area, and other similar semi-urban centres in the north-eastern region of Nigeria, should follow these steps to implement the pilot, monitor environmental and health outcomes and enact supportive local by-laws.

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