

The Role of Harmonized Solid Waste Management in Mitigation of Wastes and Climate Change in Calabar South

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ABSTRACT

The exponential increase in solid waste generation in Calabar South, Nigeria, presents a multidimensional urban and climate challenge, mostly driven by demographic expansion and intensified commercial activities. The current waste management system marked by open dumping, poor collection logistics, and weak institutional coordination proves insufficient. Waste accumulation obstructs urban drainage, leading to severe flooding, particularly during the prolonged wet season. Climate-induced events, such as rising sea levels and erratic rainfall, further destabilize landfills and hinder waste logistics. Also, waste scavengers operating without regulation also interfere with designated disposal systems, disrupting waste integrity, generating odor, and increasing the risk of air and water contamination. The introduction of a Harmonized Solid Waste Management (HSWM) strategy becomes essential to address these challenges. HSWM proposes an integrated approach that promotes waste segregation at source, logistical efficiency, stakeholder synergy, and material valorization. It is a framework that will treat waste not as an environmental burden but as a potential economic resource. Additionally, the framework promotes industrial accountability and localized solutions such as domestic production of receptacles. Therefore, implementing the HSWM model in Calabar South is critical for mitigating urban flooding, reducing greenhouse gas emissions, and achieving long-term sustainability.

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Introduction

Solid wastes are commonly defined as discarded or superfluous non-liquid materials, often categorized as garbage or refuse, in contrast to liquid wastes, which are termed effluent. According to the American Public Works Association cited in [1], solid waste encompasses unwanted materials designated for disposal, characterized by minimal liquid content. Climate change and solid waste are profoundly interconnected because sustainable waste management has a synergistic effect on climate change mitigation. The integrated nature of solid waste with the physical environment demands effective management techniques. Aside from the detrimental impact on aesthetics, the disadvantages of waste cuts across economic and environmental deterioration. Moreover, the inefficiency of waste management in Nigeria has frequently been attributed to poor policy implementation, this generalized perspective often overlooks the deeply ingrained disregard for environmental regulations among many Nigerians [2]. This behaviour has become deeply entrenched; perhaps consistent public reorientation programs may be necessary to foster environmental consciousness among urban populations. Although Agunwamba decried that public enlightenment programs lacked the needed coverage, intensity, and continuity to correct

the apathetic public attitude towards the environment in the past. These are salient points to be considered for a harmonized waste control [2].

Research conducted by Emri et al. amongst locals of Calabar South stated that 43.43% of people state that there's a total absence of disposal facilities to facilitate waste collection within their streets; while 37.88% of respondents reported an inadequacy in the provided collection waste receptacles where many are in deteriorating conditions [3]. Furthermore, it has been observed that quantifying Nigeria's solid waste crisis presents significant challenges. This is largely from inadequate management frameworks and inefficient urban planning, which create a disparity between waste generation and collection capacity. Municipal authorities often struggle to manage the daily accumulation, as refuse produced within hours exceeds what sanitation services can feasibly remove [4]. Consequently, unregulated landfills proliferate along peri-urban highways and streets, with a notable absence of designated public bins, producing waste mountains. This systemic failure leads to widespread environmental encroachment of solid wastes in the streets, and drainage systems become obstructed by windblown debris. Faced with mounting refuse, residents and commercial entities frequently resort to open burning of waste in thoroughfares [5].

The exponential generation of solid waste in Calabar South arise primarily from two interrelated anthropogenic drivers: unprecedented demographic expansion and accelerated economic productivity. As Nigeria’s population growth continues unabated, concomitant increases in consumption patterns have generated a corresponding escalation in solid waste and climate extreme events (flooding). This unsustainable trajectory necessitates the development of more effective waste management paradigms that address both the scale and complexity of contemporary waste streams. Hence, the introduction of HSWM strategy.

Solid Waste Collection and Disposal Practices in Calabar South Waste materials are gathered, transported, and discarded in nearby bushy areas, where they are sometimes incinerated or interred. This is the common waste disposal practice in Calabar South. Additionally, refuse is disposed of in ravines. These disposal

practices create conducive environments for the proliferation of disease-carrying organisms such as flies, mosquitoes, and other insects, while also attracting and harbouring rodents [6]. Based on numerous observations in Calabar South, sanitary landfilling remains underdeveloped. In many locations, the absence of designated landfill sites has resulted in widespread reliance on open dumping as the primary method of waste disposal.

Nigeria generally lacks reliable data on solid waste generation, collection, composition, and disposal practices. Nevertheless, in 2019, it was estimated that approximately 66,826 tonnes of solid waste were produced daily by 106 million urban residents. This value is projected to increase to 125,473 tonnes per day by 2040, corresponding with an anticipated urban population of 199 million [7].

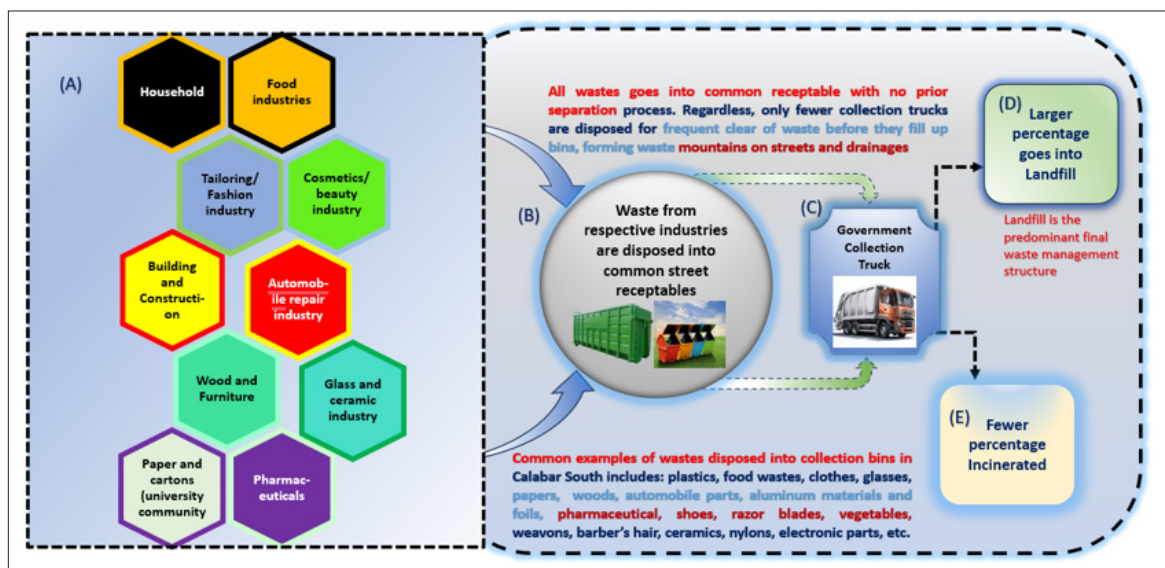


Figure 1: Typical Waste Collection and Management Mechanism in Calabar South

Figure 1 presents the linear and inefficient waste collection system prevalent in Calabar South, illustrating systemic failures across the collection, disposal, and recovery stages. The Households and diverse businesses (food, construction, pharmaceuticals, etc.) dispose all waste streams organic, recyclable, and hazardous into undifferentiated street receptacles. This lack of source segregation intensifies downstream processing incompetence. Additionally, inadequate government collection infrastructure results in infrequent waste evacuation. More so, chronic shortages of collection trucks allow receptacles to overflow, forming “waste mountains” that obstruct drainage systems. This is a key contributor to urban flooding. Approximately 90% of collected waste enters landfills, the dominant endpoint, despite limited capacity and environmental risks (leachate, methane emissions). A negligible fraction (<10%) undergoes incineration, often without energy recovery or emissions control, contributing to low air quality. Furthermore, in the current waste a management pathway, the absence of valorization pathways (e.g., material recycling, energy recovery) and poor institutional coordination among stakeholders represent critical challenges that the HSWM framework seeks to address through structured waste stream segregation, enhanced collection logistics, and circular economy integration.

Predominant Climate Change Events in Calabar South

The climatic pattern in Calabar, located along the West African coastline, is largely influenced by the interplay of two dominant

atmospheric circulation systems namely the moist southwesterly monsoon winds and the dry northeasterly trade winds. These air masses are responsible for delineating the region’s bimodal seasonal structure, comprising a prolonged wet season from April to October and a relatively shorter dry season extending from November through March of the succeeding year. The nomenclature of these seasons is logically tied to rainfall distribution, with the wet season characterized by high precipitation levels. Notably, the dry season is often introduced by the intrusion of the Harmattan, a dry, dust-laden wind originating from the Sahara region causing a transient episode of low visibility and cooler temperatures, typically between December and January [8]. This seasonality is not only ecologically significant but also informs waste accumulation cycles and challenges waste logistics in the urban management systems of Calabar. Despite its distinct two-season climatic system, Calabar being a tropical city consistently receives approximately 4 to 5 hours of uninterrupted daily solar radiation. Particularly, this pattern of sunshine exhibits minimal seasonal variability, maintaining relative uniformity throughout the year [9]. Calabar has always witnessed a localized climatic response characterized by increased rainfall frequency but reduced intensity [10]. Moreover, because Calabar is bordered to different tributaries and even the South Atlantic Ocean, rising sea levels and coastal erosion threaten dumpsites located in low-lying coastal zones, leading to contamination of water bodies [11]. In fact, flooding is the major climate events that threatens Calabar.

In flood-vulnerable communities of Calabar South, including Ekpo Abasi, Atamunu, Edibe Edibe, Goldie, and Edim Etop, changes in rainfall patterns have emerged as indicators of climate change, leading to ecological imbalances and modifications in the structure of the local vegetation zones [12]. Of great consequences, the shifting rainfall pattern has contributed to increased wind erosion, desertification, soil degradation, and coastal flooding in Calabar [10]. In fact, Calabar records Nigeria’s highest mean annual rainfall (2,859.84 mm), with 31% occurring as extreme events (≥ 50 mm/day) in just 12 days [8]. Also, deseasonalized data show a slight increase (1.9 mm) over 19 years, suggesting subtle shifts [8]. Practically, extreme rainfall correlates with total annual precipitation, implying intensified events in wetter years. Furthermore, heavy rainfall events can overwhelm drainage systems and destabilize landfill structures [11]. Rainfall affects four critical areas within the metropolis of Calabar, which may include; agriculture, health, infrastructure, and waste management. Although, the dynamics between solid waste accumulation and rainfall exhibit a complex bidirectional relationship, wherein it remains analytically ambiguous whether waste deposition precedes and influences hydrological responses or, conversely, whether precipitation events promote inefficiencies in waste management. Regardless of the sequence, both variables are intricately interlinked, contributing to compounded environmental impacts.

Ekpoh identified multiple factors contributing to flooding, ranging from natural phenomena to human-induced disruptions [13]. While high-intensity rainfall, prolonged precipitation, melting ice caps, and sea-level rise are significant natural triggers, anthropogenic activities exacerbate flooding in urban areas. A critical cause of flooding highlighted is the blockage of drainage systems and rivers due to waste congestion, which stems from deliberate poor waste disposal practices by residents, especially in Calabar South. This obstruction prevents proper water flow, worsening flood severity during heavy rains. Additionally, factors such as siltation, absence of drainage channels, excessive concretization (reducing infiltration), and urban encroachment into floodplains further aggravate the problem [13]. Unlike natural causes like tsunamis or dam failures, the persistent neglect of waste management and drainage maintenance in Calabar South stands out as one of the most debilitating and preventable causes of recurrent flooding, demanding urgent policy interventions and public awareness campaigns.

Solid Wastes as Contributor to Climate Change

Solid waste contributes approximately 5% of global greenhouse gas (GHG) emissions primarily through methane (CH₄), carbon dioxide (CO₂), and nitrous oxide (N₂O), mainly from the decomposition of organic matter in landfills [11]. Conversely, climate change itself exacerbates waste management challenges by increasing extreme weather events such as floods, droughts, and heatwaves, all of which impact collection, transport, treatment, and disposal systems. Similarly, the study by Ewona is assess the complex interplay between waste-related air pollutants and environmental health, with direct implications for climate change in Calabar, Cross River State [14]. Waste emissions such as carbon dioxide (CO₂), sulfur dioxide (SO₂), nitrogen oxides (NO_x), methane (CH₄), volatile organic compounds (VOCs), and suspended particulate matter (SPM) were assessed. Although many pollutants were detected at low or undetectable levels during the study period, episodic spikes in CH₄ and SPM, especially during the wet season, signal localized anthropogenic and waste-related causes. These emissions contribute to poor air quality and intensify Greenhouse Gas (GHG) effects. Additionally, Etim et al. performed a comparative evaluation of atmospheric conditions in Calabar, revealing elevated levels of key air pollutant parameters in Calabar South [15]. The study attributed these adverse air quality trends, road network congestion, possibly, to insufficient waste regulation and disposal practices.

During waste treatment, harmful substances are often released into the environment, serving as contributing components to GHG effects. For instance, the incineration of municipal and industrial wastes leads to the emission of highly toxic pollutants such as dioxins, furans, and heavy metals, which are by-products of incomplete combustion [16]. Although the adoption of waste incineration has grown significantly as a dual-purpose waste management strategy, serving to both minimize landfill volumes through mass reduction and generate recoverable energy via electricity production [17].

Climate change also significantly disrupts waste management systems by altering waste generation patterns, impairing collection infrastructure, and complicating disposal processes. Table 1 below presents how specific climate events impact urban waste management.

Table 1: Impact of Climate Events on Solid Waste Control

Climate event	Change in climate	Impact on waste management
Temperature	hot temperature	High temperatures increase microbial activity in organic waste, boosting anaerobic decomposition in landfills and uncontrolled dumpsites. Increased consumption of packaged beverages, elevating plastic waste volumes. Increases workload for workers due excess wastes.
	Cold temperature	Leachate production rises, contaminating soil and groundwater. Increase pest and insects within collection locations. Production of malodours.
Precipitation	High precipitation	Affect slope stability on waste management site. Disrupt waste collection infrastructures.
Sea Level rise	High sea level	Inundation of waste management facilities increases erosion of coastal areas. Causes flooding.

Modified from Gichamo & Gökçekuş in alignment with the context of Calabar South [11].

The Role of HSWM as Strategy to Mitigate Solid Wastes and Climate Change

A harmonized waste management strategy refers to an integrated, coordinated, and standardized approach to handling waste that ensures consistency across sectors, stakeholders, and levels of government with the aim of making waste management efficient, sustainable, and aligned with broader goals such as public health, environmental protection, and climate action. Similarly, conventional concepts like Integrated Solid Waste Management (ISWM), which prioritizes waste prevention, reuse, recycling, and energy recovery over open dumping and landfilling can be likened to HSWM [11]. However, while ISWM emphasizes the circular economy and the sustainable valorization of waste, the HSWM framework extends beyond this scope by strategically integrating and coordinating cross-sectoral stakeholders. HSWM seeks to institutionalize multi-agency collaboration, such as public, private, and community actors as co-drivers in the systemic planning and execution of waste management interventions.

The role of HSWM extends to industries as well. For instance, in Calabar, where municipal waste management is predominantly handled by the government, the ethical responsibility of industries to manage their own waste streams remains critically under-enforced. According to Enuoh et al., manufacturing firms, particularly in Nigeria, often overlook waste management as a vital component of Corporate Social Responsibility (CSR), treating it instead as a routine operating expense with minimal strategic value [18]. However, this perspective is both environmentally and economically shortsighted. In flood-prone urban centers like Calabar, it has been emphasized that indiscriminate waste disposal increases ecological degradation, obstructs drainage systems, and intensifies flooding [10,12]. Therefore, firms can no longer operate as isolated profit-maximizing entities but must engage proactively with host communities to maintain a sustainable operational environment. Ethical obligations, including proper waste disposal, recycling initiatives, and pollution control, must be embedded within corporate values, not only to meet rising environmental expectations but also to secure social legitimacy and long-term profitability [18]. Where the government remains the sole waste handler, industries must be held accountable through policy frameworks that mandate waste minimization, reuse, and environmental remediation. This is a part of HSWM and equally an innovative waste management practices that could transform environmental liabilities into revenue-generating opportunities, promoting both business viability and environmental sustainability in Calabar and similar urban contexts in Nigeria.

In Calabar South, the practice of waste segregation at the point of generation is virtually nonexistent. This systemic lapse may be attributed to a combination of socio-cultural dispositions, informal

settlement patterns, and a conspicuous absence of enforceable legislative frameworks mandating source-level separation. The HSWM strategy thus emphasizes the institutionalization of a state-wide advocacy focused on the imperative of waste sorting at source. This approach is technically indispensable for optimizing downstream waste material recovery for enhanced recyclability. Current data indicates a municipal solid waste collection coverage of 41%–46%, with projections estimating a moderate increase to 60% by 2025 [7]. However, this progress remains spatially inequitable, as marginalized zones such as informal settlements, peri-urban ghettos, and low-income neighborhoods in Calabar South are persistently excluded from formal waste collection services. Thus, the HSWM is critical to bridging this gap and achieving inclusive environmental management to avoid climate events (tatr, 2016).

Waste scavengers are foreign or locals moving indiscriminately in search particular products around waste disposed locations. Their daily activities disrupt disposed wastes in designated points of waste collection. Hence exposing people to odor, allowing leaching of wastes and affecting the quality of air. On one hand, scavengers contribute to informal recycling by retrieving metals like iron and aluminum, plastics, and glass, reducing landfill pressure and promoting resource conservation [19,20]. However, their unregulated activities often disrupt organized waste collection systems by scattering refuse at designated dumpsites, leading to increased leachate, offensive odours, and air quality deterioration [21,22]. This disruption leads to urban drainage blockage, where uncollected or scattered waste impedes water flow during rainfall, increasing the risk of flooding and climate-related hazards [19,22]. Additionally, health and safety risks for scavengers, including exposure to hazardous materials and injuries from sharp or contaminated objects, are well documented [23,24]. While their recycling role is notable, policy enforcement is urgently needed to regulate scavenging activities. Integrating scavengers into formal systems, providing protective gear, and restricting access to dumpsites without oversight can mitigate environmental degradation and improve urban resilience to climate risks [25,26].

The high cost of waste receptacles has become a prevailing financial challenge for government and communities to independently purchase waste collection bins. This could be due to high inflation and dwindling foreign exchange. Nevertheless, actions to foster local production of sustainable waste collection facilities perhaps by strengthening local steel, iron or aluminum industries is a consideration in the HSWM framework. Conversely, the practices of the 3Rs in Calabar has not met the light of the day. Categorically, generated wastes in Calabar South are still candidates of landfill and few are incinerated. In the past years, waste management industry has placed limited interest on solid waste conversion to gases and other reuseable products. The HSMW seeks a unique collaborative approach to driving the 3Rs as highlighted in figure 2.

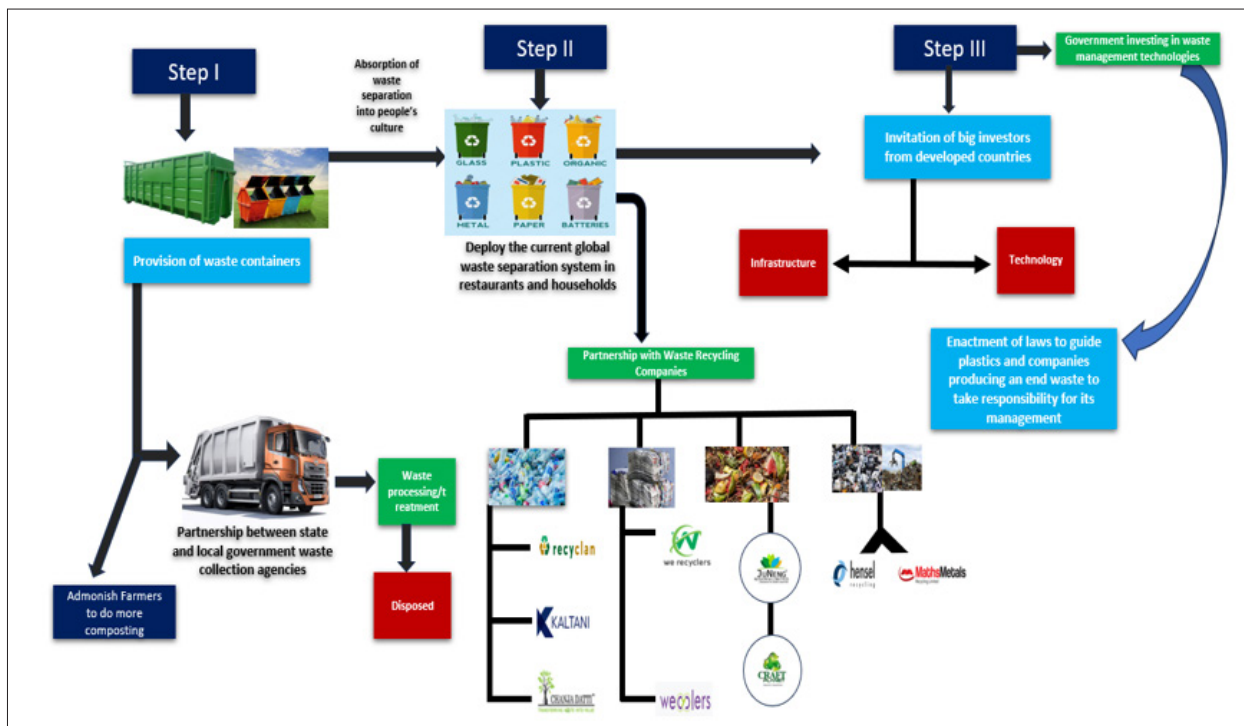


Figure 2: The HSWM Mechanism for Calabar South.

Figure 2 delineates a structured framework for HSWM tailored to flood-prone regions such as Calabar South, integrating a tripartite phased approach to mitigate waste-induced hydrological disruptions. Step I is termed “Waste Collection Optimization” and it focuses on logistical augmentation, advocating for the strategic deployment of high-capacity waste collection bins across all streets and identified waste accumulation hotspots. This step will eliminate antecedent of drainage blockages that could cause urban flooding. Step II which is the “Waste Stream Segregation and Institutional Synergy” will introduce a systematic waste categorization protocol, coupled with formalized partnerships with national and international waste management organizations. Such collaborations will be designed to leverage external expertise, funding, and policy frameworks to enhance local capacity. Finally, Step III otherwise called the “Advanced Waste Valorization harmonization” acknowledges the technological disparity between developing and industrialized nations, proposing a transnational knowledge-transfer mechanism. This phase will prioritize knowledge and skill exchange with advanced countries to adopt circular economy models, including waste-to-energy (WtE) conversion, material recovery for secondary production, and other industrialized valorization techniques, to transform waste into economic assets while reducing environmental liabilities. Recently, solid waste valorization demonstrates great potential for generating high-value nanomaterials. For example, Carbon nanotubes (CNTs) were synthesized from solid waste materials through controlled thermochemical conversion processes, with precise modulation of pyrolysis parameters including temperature gradients, pressure conditions, and heating rates [27].

Conclusion

The intricate relationship between solid waste and climate change in Calabar South unravels the widespread structural weaknesses in waste handling systems, particularly regarding collection, disposal, and resource recovery. The persistent absence of source-level segregation, coupled with inadequate infrastructure and a dependence on indiscriminate dumping, has contributed significantly to climate events, frequent urban flooding, and

elevated greenhouse gas emissions. The proposed Harmonized Solid Waste Management (HSWM) framework provides a structured alternative by emphasizing systematic waste separation, inter-agency cooperation, and the incorporation of advanced waste treatment methods such as waste-to-energy conversion and material reclamation. This approach will close logistical gaps, align institutional roles, and adapt best practices through strategic knowledge exchange. Nonetheless, the practical realization of this framework depends on the enforcement of coherent policies, public participation, and greater industrial responsibility. Going forward, emphasis should be placed on context-specific interventions, including the development of community-based initiatives and adaptable technologies that reflect local realities. The implementation of HSWM extends beyond environmental management; it represents a pragmatic avenue for improving urban resilience, safeguarding public health, and stimulating socio-economic advancement within Calabar South [28].

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