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# Unequal location, unequal access: the spatial analysis of solid waste disposal services in Northern Ghana

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**Abstract**
Urban centres in Ghana continue to expand to areas with difficult accessibility, severely impacting location decisions on solid waste disposal sites (SWDS). This study uses the location theory to examine the spatial distribution of SWDS in urban Ghana. Methodologically, it uses the nearness neighbour tool, which is a key component in GIS for spatial analysis. The results show that the distribution of SWDS was clustered, randomized, and skewed. The distribution was influenced by accessibility and the ability to pay for waste management services. For these reasons, high-density populated communities were serviced through the central container collection system, while high-class residential areas benefited through the door-to-door collection system. Access to regular waste collection was challenging for the majority in low-class residential neighbourhoods and peri-urban communities. It is argued that unequal access to waste management services raises important policy issues. The unserved communities are more likely to be exposed to the potential negative impact of poor solid waste management. It is further argued that if vulnerability and location are linked to deprivation, it is necessary to understand how and why this has happened.

**Keywords** Waste collection · Waste disposal · Spatial distribution · Communal containers

## 1 Introduction

For the past twenty years, the world's population growth has increasingly occurred in urban areas. The literature indicates that the rate of urbanization combined with the overall growth of the world population could increase the world urban population by 2.5 billion people in 2050 [1, 2]. Usually, urbanization creates opportunities and enhances the quality of life. For instance, the World Bank estimated 2019 that globally, the average Gross Domestic Product (GDP) per capita grew by almost 56% between 2010 and 2018, with an average annual growth above 6% [3]. Much progress was made in improving most human development indicators within the same period. In sub-Sahara Africa, the Human Development Index (HDI) improved by 34.9% [1], while the figure for countries in the Organisation for Economic Co-operation and Development (OECD) grew by 14% in the same period [1]. This trend is not a novelty, and projections are that the rate of global urban growth will grow remarkably (3.5% per year) over many decades [4, 5].

Economic growth and rapid urbanization have also triggered a deluge of waste. Solid waste is now ubiquitous on the land, rivers, coasts, and oceans [1, 6, 7]. Open and uncontrolled dumping and burning waste cause horrendous air pollution [1]. According to the World Bank, as of 2020, the world generated 2.24 billion tonnes of solid Waste [8]. Also,

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waste generation in Africa is estimated to be 244 million tonnes annually by 2025 [9]. Collecting and disposing of waste in an environmentally friendly manner has thus become one of the major challenges for city managers. As opined by Volsuuri et al. [10], poor solid waste management is the easiest indicator of poor governance in the local government sector of Ghana. Waste collection and disposal are fundamental steps toward effective waste management and form a major cost component of solid waste management [11, 12]. It is estimated that of the total expenditure on solid waste management in Ghana, 70–80% is spent on collection, transportation, and disposal [13]. Considering the tight budget state authorities operate under, efficient distribution of collection containers is important to enhance the effective collection and disposal of waste.

However, collection and disposal have remained a major problem for African state authorities [14]. The global waste management outlook shows that the rate of solid waste collection in Africa varies between 25 and 70%, with an average collection of about 55% [15]. About 37.5% of the collection is through the communal container system [1]. Collection services can summarily be described as unreliable, irregular, and inefficient. Waste collection strategies vary greatly between countries, cities, and even between areas of the same city [3, 16]. Depending on the spatial plan and area income level, collection can be done by any method: wheelbarrows, manual tricycles, motor tricycles, bola taxis, mini-compact trucks, and large compact or dump trucks to long trailers [17]. While the standard collection rate should be 100%, global collection rates vary from 39% for low-income countries to 96% for high-income countries [3, 15].

In Ghana, effective solid waste collection and disposal remains an illusion. Collection coverage varies greatly among cities, ranging from 28% in Wa to 80% in Accra [14, 18, 19]. Solid waste collection in the country is carried out by both formal and informal sectors [7]. In addition to inadequate collection containers (skips and wastebins), container distribution is influenced by local politics and community pressures. The absence of an appropriate and efficient collection system results in indiscriminate dumping in drains and open spaces in many cities and towns nationwide. Various stakeholders have introduced new waste collection fleets or treatment plants to nib the problem. Still, the success rate has not been the highest due to the lack of local capacity to maintain equipment appropriately. Distribution imbalances of collection and disposal infrastructure create proximity and accessibility challenges leading to illegal dumping [17]. Meanwhile, LeBlanc, [20] argued that efficient placement and collection of waste containers in cities is an important waste management phase.

Over the years, waste management planners have tried several innovative ways to sustainably manage solid waste in several Ghanaian cities [21]. This is evidenced by the speed, scale, scope, and complexity of partnerships and policies that have been developed. Nonetheless, the efforts are being hampered by a lack of data on the right quantities of containers, number of disposal sites, and spatial distribution pattern, which is *sine quo non* for effective planning and decision-making by municipal authorities [7]. The national solid waste management strategy acknowledges the ineffective solid waste management service delivery in the country [19]. Also, the strategy emphasizes the inadequate and ineffective distribution of waste containers in communities, leading to indiscriminate dumping. With this background information, this study investigated the effect of the location of solid waste containers on management services in selected cities in northern Ghana. Specifically, the nearest neighbour tool, a key component in GIS, was used to assess the location pattern and coverage of waste collection points and disposal sites in the selected cities. In addressing the aim of the study, waste collection systems and the factors that influence these systems were examined. These factors include those that influenced the location of existing waste management facilities and how they impact sustainable waste management. Overall, the intention is to generate empirical data to guide effective solid Waste planning in Ghana. The rest of the paper is divided as follows: the introduction is followed by the literature exposition on location analysis. The methodology is presented in section three, while the results and discussions follow in sections four and five, respectively. The last section concludes and provides recommendations for policy consideration.

## 2 Location analysis

Historically, location analysis is a well-established technique in regional science. The concept is often applied to understand the distribution of resources, goods, and services in a particular geographical space [22]. In its broadest sense, it is also used to determine where an event or a phenomenon can best be organized to achieve the best results. Scholars credited for pioneering the concept include Johann Heinrich von Thunen, Walter Christaller, August Lösch, Alfred Weber, and Harold Hotelling. For instance, von Thunen, in 1826, used location theory to explain the reasons for different land uses in agriculture. Weber [23] focused on factory location in terms of the best location that minimizes transportation costs and enhances profit maximization. Hotelling [24], studied the location strategies of two firms and their prices, considering demand, transport cost, and competition. On his part, Christaller [25] conceptualized human settlements as a system and developed the theory of centrality to explain the spatial organization of towns and cities. These groundbreaking works set the foundations for location analysis by showing how location choices are linked to different economic activities.

The concept has become a popular conventional planning approach based on earlier theorization. For instance, Fischer et al. [26] and Nijkamp and Ratajczak [27] have used the concept to understand the spatial distribution of housing and labour markets, urban agglomerations, regional growth disparities, industrial clusters, spatial innovations, and environmental resource scarcity dynamics. The original concept focused on descriptive characteristics associated with organizing a certain phenomenon in space. However, making locational decisions for various purposes has expanded beyond the descriptive nature to a more authoritarian concept. Significantly, several location theories have been developed to support real-world applications, especially in the distribution of urban services [28]. The location theory that guides the distribution of urban services forms the basis of this current research work. The increasing application of the concept in most developing countries has been brought about by data availability, including population distribution, transportation networks, land uses, and terrain information. These data have been spatially explicit about assisting in the mapping and locating activities. For instance, the population of specific communities and their associated road networks connecting them are easily shown on maps. In addition, spatial location characteristics are now directly linked to the distribution of city social services, job creation, poverty reduction interventions and zoning procedures.

In recent years, one area where location analysis has been widely applied is the siting of waste management facilities [29, 30]. The application of the concept in waste management studies is due to its ability to be integrated with Geographic Information Systems (GIS). GIS systems are specifically designed to store, manage, process, analyze and display spatial and non-spatial data. According to Kontos et al. [31], GIS integrates spatial data such as satellite images, maps, and aerial photographs, among others, with non-spatial data to aid solid waste planning, including collection routes, transportation, customer service, transfer stations, and final disposal sites. Adu-Boahen and Boateng [32], designed a solid waste collection system using a GIS-based vehicle tracking system to demonstrate the link between GIS and solid waste management services. The system determined the investment cost between final disposal sites and community boundaries. GIS has also been employed for planning the distribution of waste bins, vehicle routes, and the location of compost plants [28, 33].

Conceptually, the literature is conclusive that location analysis focuses on identifying the most appropriate place where economic activity, social activity, or resource can be cited for human interactions. In locational analysis, locus and geographic space are key factors to be considered. As observed by Nijkamp and Ratajczak [27], the most important question that is answered by the concept is the reason behind the choice of a particular point and the economic, social, and environmental implications of such a decision. In applying the concept to solid waste management analysis, four components are considered: waste service customers' location, waste containers that will be located, and a metric that indicates distances or times between customers and waste containers [34]. These components are key factors that ensure the appropriate allocation of resources and services to customers. With a location analysis, one can tell if a local government authority considered the abovementioned components in planning and implementing a service contract concerning waste management.

## 3 Methodology

### 3.1 Study area

The study was conducted in three major cities in northern Ghana: Tamale, Bolgatanga, and Wa (Fig. 1). These cities were selected based on population, urbanization, economic activities, and waste generation rate stated in the [35] report. Tamale is the regional capital of the northern region of Ghana and is the city with the largest urban population in the northern ecological zone, with an estimated land size of 646.90180 km$^2$ [36]. The city has an estimated population of 374,744 (35). The increasing middle class has heightened consumption patterns, increasing the quantity of solid waste generated, estimated at 176 tonnes per day [35].

Bolgatanga, usually called Bolga, is in northeastern Ghana and lies in the Red Volta Valley, approximately 161 km from Tamale. It covers an area of 729 km$^2$ and functions as the administrative capital of the Upper East Region. In 2010, there were about 131,550 people in the city, generating about 29 tonnes of solid waste per day. By 2021 the population had increased to 139,864, generating about 66 tonnes of solid waste daily. On the other hand, Wa is in the northwestern part of Ghana and covers an area of approximately 1,180 square kilometres [35]. The city plays dual administrative and political

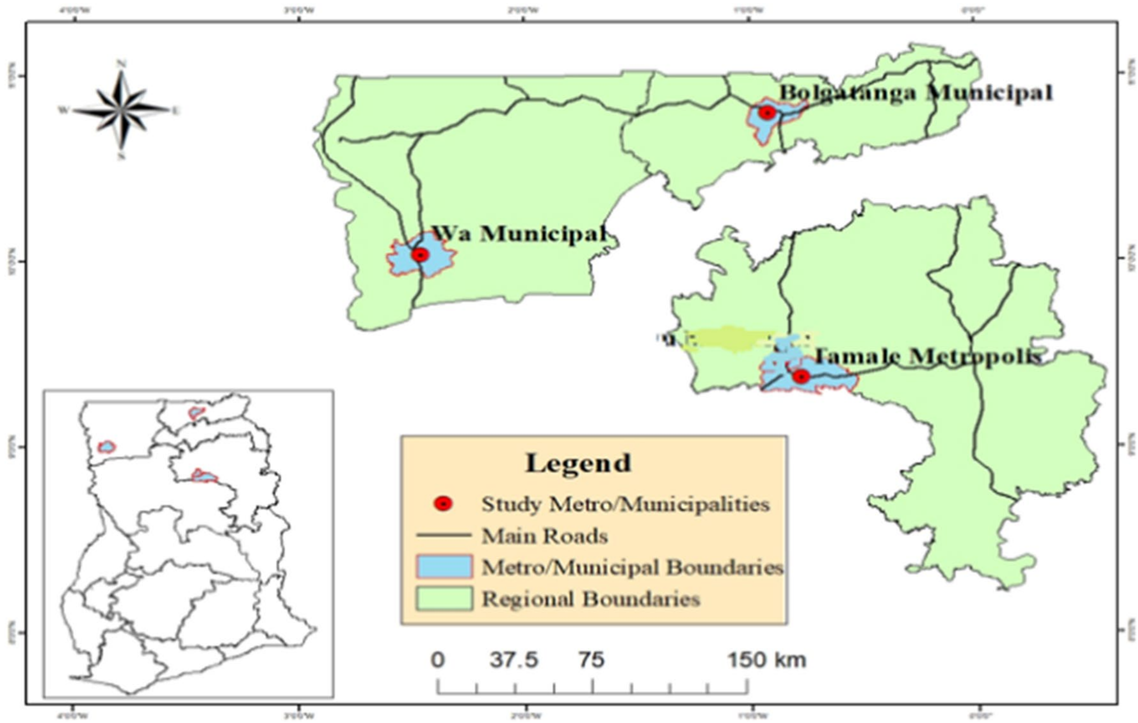


**Fig. 1** Map of the study communities

roles as the Upper West Region's municipal capital and regional capital. Based on figures from the 2021 population and housing census, the city's population has increased from 107,214 in 2010 to 200,672 in 2021, four times higher than the next populous settlements [35]. The population growth trend is reflected in the quantity of solid waste generated. In 2009, 12,563 tons of solid waste were generated. This figure doubled to 26,100 in 2013 [37]. Current figures indicate that the city generates 94 tonnes of solid waste daily [35].

## 4 Research design, sample size and sampling techniques

The study adopted a mixed-method approach using multiple data collection techniques; in-depth interviews, observation, and a global positioning system (GPS). Key informant interviews were conducted with 12 purposively selected participants from relevant agencies (Table 1). The participants were selected based on their knowledge and working experience in the waste management sector.

The interviews with the key informants probed issues such as the location of waste management sites, factors that influenced their location, customers, and vehicular access. The interviews were audio-recorded and transcribed. The transcripts were validated against the audio files and imported to NVivo software for analysis. The transcripts were thoroughly read to determine the patterns of views of participants. A follow-up process to classify views into sub-themes was undertaken. Through inductive analysis, sub-themes were merged into main themes. The results were presented

**Table 1** Departments and the number of participants selected for the interview

| Department/unit/Committee | Number of respondents | Designations |
|---|---|---|
| Waste management companies | 3 | Regional Managers, Operation Managers |
| Waste management department (WMD) | 3 | Director of Waste Management and Solid Waste Officer |
| Municipal environmental health Unit (MEHU) | 3 | Municipal Environmental Health Officer, officers in charge of solid waste |
| Local assembly subcommittees | 3 | Elected representative of the people |

as narratives supported by quotes from participants. Finally, the waste management department obtained secondary data on the percentage quantities of solid waste collected.

### 4.1 Model for location analysis of waste management sites

The study adopted the nearness neighbour tool to analyze the data concerning waste bin location. The nearness neighbour tool is a key component in GIS for analyzing the distribution of locations. It is appropriate for analyzing the distribution of waste collection containers. It provides information on how waste collection containers are clustered or uniformly distributed within the geographic space of any community under consideration. According to Naibbi and Umar [30], the tool determines how spatially observed measures compare with other locations. As a starting point, the GPS coordinates of household waste bins, communal containers, and disposal sites were taken with a mobile GPS device (Garmin 64 s). The data was then imported to ArcGIS, and the nearest neighbour index (NNI) was used to assess the distribution pattern of waste bins. NNI of 0 means exclusive clustered distribution (where there was no travel distance to collection containers). An NNI of 1 represents an absolute random distribution of containers (least travel distance), and an NNI above 1, implies a propensity to disperse. This research proposed that waste bins were randomly distributed. The quality of communal container collection was assessed by collecting data on the number of overflows from containers over two months -the wet and dry seasons. The wet season data was collected in July, when the wet season is at its peak, while the dry season data was collected in January when the dry season is at the apex. The wet season data were collected at noon, while the dry season data were collected at 17.00 h GMT.

The Ethics Board of the Department of Environment and Sustainability Science, University for Development Studies, approved the research protocols. All the ethical guidelines for conducting such studies were duly followed. Participants' consent was sought before the data collection. The purpose of the research was explained, and all participants voluntarily participated. They were assured of confidentiality and that the information obtained from the study will be communicated in a summary format without identifying individual participants. Therefore, all information gathered from individual participants during the study was anonymized.

## 5 Results

The fieldwork revealed two major city waste collection systems: household waste bins (HWBs) and communal container collection (CCC).

### 5.1 Spatial distribution of household waste bins (HWBs)

The HWBs are practised at the household level, where waste management institutions collect household waste on an agreed-upon basis (regular collection and service charges borne by the client). Figure 2 shows the spatial distribution of household waste bins in Wa. The distribution of HWBs was clustered.

The clustering of HWBs in Wa was because of issues with the accessibility of clients and lower fuel consumption. A key informant further explained why the HWBs are clustered:

> *"Where the waste bins are clustered, trucks have lower fuel consumption in servicing more bins than areas where bins were scattered".*

In corroborating this view, a manager of one of the waste management companies added that the efficiency of waste collection is enhanced when one is servicing several bins in an operational area than when fewer/ sparsely spaced bins are served. The use of waste bins for solid waste collection was concentrated in medium and high-class residential areas that were more easily accessible than peripheral communities. The lack of waste bins in communities with limited vehicular access encouraged indiscriminate dumping. Even with the claim of vehicular access influencing the location of bins, it was observed that some communities with HWBs had HWBs overflowing with waste, indicating irregular services. The spatial distribution of HWBs in Tamale was also clustered around Kukuo, Dohini, Vitim and other communities easily accessible by vehicular movement (Fig. 3).

The critical location factor influencing the distribution of HWBs was customers' ability to pay for services provided. A waste management expert from one of the companies emphasized that cost-effective waste collection systems consider

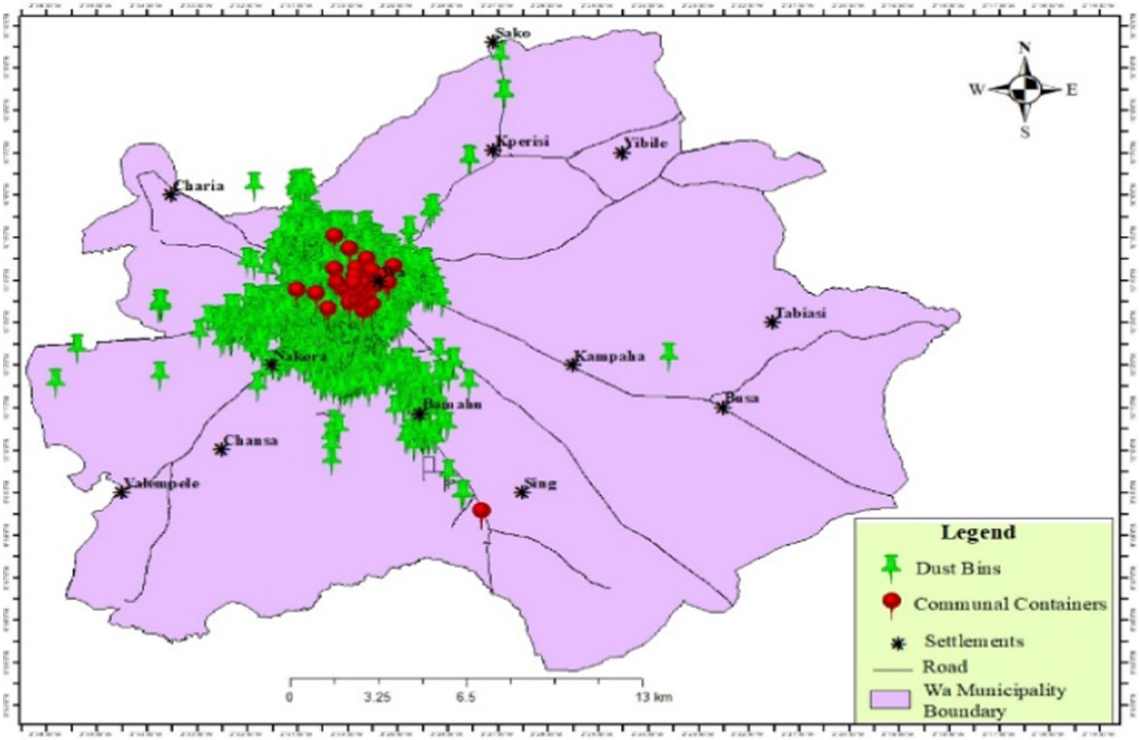


**Fig. 2** Spatial distribution of household waste bins in Wa

distance travelled, fuel consumed, the quantity of waste produced, and, more importantly, the ability of customers to pay whendecisions are being taken.

The spatial distribution of HWBs in Bolgatanga was less clustered than in Wa and Tamale (Fig. 4). This was associated with Bolgatanga having more accessible routes than the other cities. Despite this, the spatial distribution of HBS in Bolgatanga was influenced by the same locational factors—cost, accessibility, and economic factors as in the case of Wa and Tamale.

As reported in the literature [17], it was generally observed in this study that the HWBs collection system was intrinsically linked to the ability of residents to pay. Consequently, the distribution of household waste bins was limited to medium and high-class residential areas with the means to pay for that service and better access routes.

### 5.2 Spatial distribution of communal containers (CC)

The communal container collection (CCC) system is operated under the Sanitation Improvement Package (SIP) programme. The SIP is a Public–Private Partnership (PPP) agreement between the private sector and the Municipal Authority for solid waste collection with communal containers. According to the MSWR [19], SIP is Ghana's largest, most extensive, and most crucial solid waste collection contract. Over 70% of municipal solid waste collection is done through the communal collection. It is a signed contract between a single private sector company and a Municipal Authority with defined terms, roles, and responsibilities, typically for four years. Under this arrangement, the private sector provides and manages an agreed number of collection vehicles and containers for a quarterly service fee from the District Assembly Common Fund (DACF).

This study revealed that container random and economic location in municipalities is often challenging under the CCC system. Communal containers (CCs) are unfairly distributed due to many factors, including local politics, space availability, and community acceptance or rejection considerations. Distribution of CCs is mostly concentrated in the Central Business Districts (CBDs) of the selected cities where markets, lorry parks and poorly planned residential areas are common. Apart from the over-concentration of CCs in CBDs, it was also observed that many of these CCs had litter around them. The extent of indiscriminate littering around CCs is shown in Table 2.

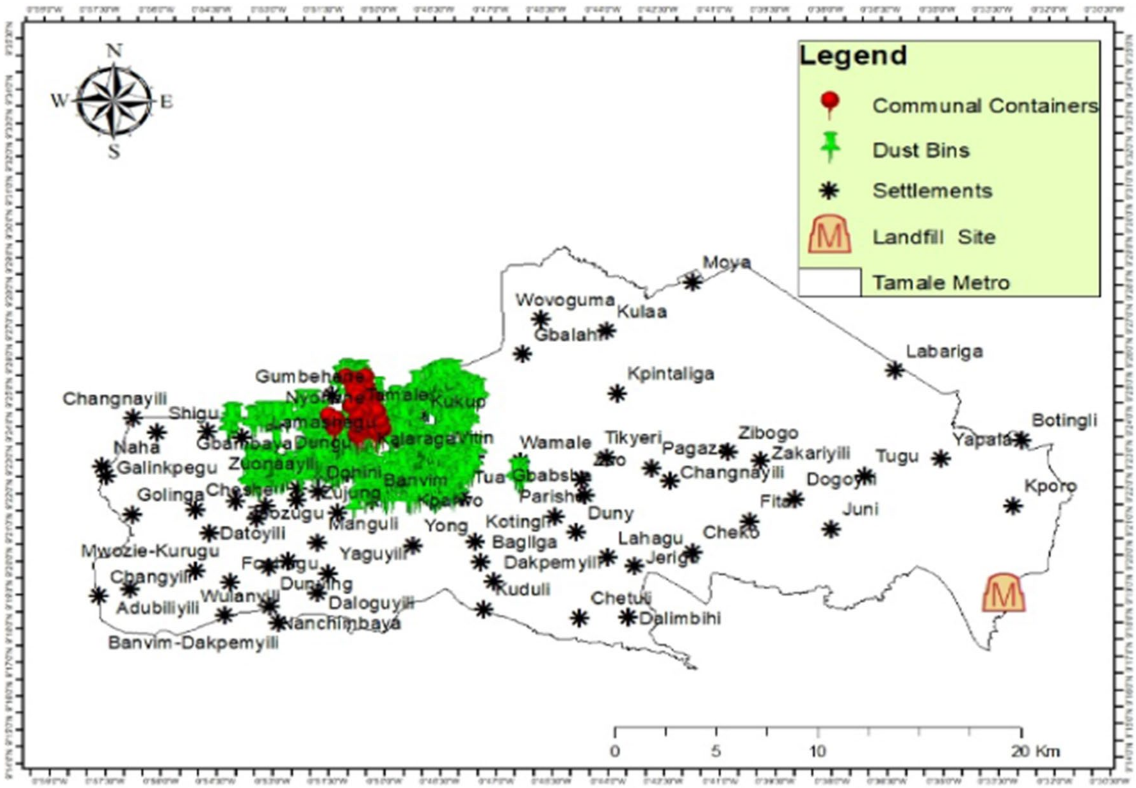


**Fig. 3** Spatial distribution of household waste bins in Tamale

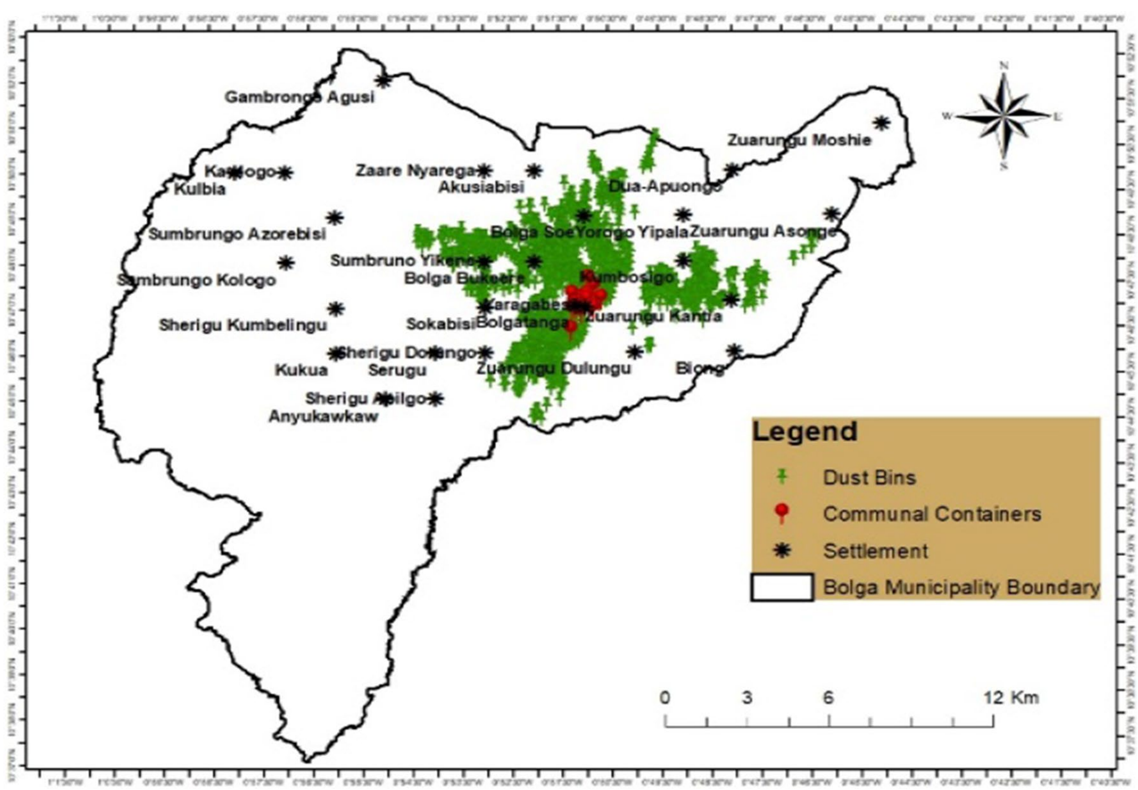


**Fig. 4** Spatial distribution of household waste bins in Tamale

Littering of container sites and burning of refuse in containers in the dry season posed public health and fire risk to the surrounding residents. The source of the fire in containers came from hot ashes poured into the container by residents (these are usually from charcoal or firewood).

There were variations in the quality of communal collection services in the study areas. Twenty-one sites [21] during the wet and fourteen [14] during the dry seasons were not regularly serviced (Table 2). This resulted in the spillage of refuse at container sites. In giving the reasons that account for the differences in efficiency in lifting containers between wet and dry seasons, a key informant in Bolgatanga stated:

*"There are some challenges experienced in the wet season. Challenges such as vehicles getting stacked due to bad roads and difficulty in dumping due to damaged disposal site environments, negatively affecting the servicing of containers in the wet season".*

Littering of container sites was mainly caused by irregular lifting and the poor attitudes of residents. In an interview with a container site attendant, he indicated that:

*"The container is not lifted regularly, but that is not the only cause of the dirty nature of the site. Even if the container is empty, residents dump it on the ground. Every day I clean this site. By the next day, the place is dirty again. Sometimes children are sent here to dump refuse, but they end up dumping it on the ground because they are not tall enough to reach the top of the container. When I am around, I help. But when I am not, they throw the waste on the floor near the container."*

Apart from the CBD, the limited number and accessibility of CCs in the peripheral communities resulted in indiscriminate waste dumping. A key informant at Charia, a peripheral community in the Wa municipality, explained how the frequent request for more community containers had not been heeded to:

*"We have always advocated for waste containers in this community, but to no avail; since residents do not have them, they dump waste behind their houses".*

The spatial distribution analysis of the municipalities' CCs is summarized in Tables 3, 4 and 5.

As explained by the environmental system research institute (ESRI) (n.d.) and Fuseini et al. [38], the nearest neighbour index is the ratio of the observed mean distance to the expected mean distance. In a random distribution, the expected distance is the average distance between neighbouring points (ESRI, n.d). This was the basis for calculating the average nearest neighbour index, expected and actual distances in Tables 3, 4 and 5. From the normal distribution curve in Fig. 5 and a nearest neighbour ratio of 1.14, a z-score of 1.10, and a p-value of 0.27, it was concluded that the communal containers in Bolgatanga were randomly distributed.

**Table 2** State of communal containers sites in the three cities

| Study area | Number of container sites | Wet season July<br>Number of littered sites | Dry season January<br>Number of littered sites | Number of containers with burning activities in them |
|---|---|---|---|---|
| Tamale | | | | |
| Residential | 43 | 10 | 7 | 10 |
| Commercial | 15 | 3 | 2 | 3 |
| Sub-total | **58** | **13** | **9** | **13** |
| Wa | | | | |
| Residential | 27 | 4 | 3 | 5 |
| Commercial | 13 | 1 | 0 | 0 |
| Sub-total | **30** | **5** | **3** | **6** |
| Bolgatanga | | | | |
| Residential | 16 | 3 | 2 | 6 |
| Commercial | 6 | 0 | 0 | 1 |
| Sub-total | **22** | **3** | **2** | **7** |
| Total | **110** | **21** | **14** | **26** |

The bold values are the sub-totals and Totals

**Table 3** Average nearest neighbour distance and ratio for Bolgatanga

| Observed mean distance: | 191.99 meters |
|---|---|
| Expected mean distance: | 168.47 meters |
| Nearest neighbour ratio: | 1.14 |
| Z-score: | 1.10 |
| P-value: | 0.27 |

**Table 4** Average nearest neighbour distance and ratio for Tamale

| Observed mean distance | 108.31meter |
|---|---|
| Expected mean distance | 223.71meters |
| NN ratio | 0.48 |
| z-score | − 6.77 |
| p-value | 0.00 |

**Table 5** Average nearest neighbour distance and ratio for Wa

| Observed mean distance: | 191.99 meters |
|---|---|
| Expected mean distance: | 168.47 meters |
| Nearest neighbour ratio: | 1.14 |
| Z-score: | 1.10 |
| P-value: | 0.27 |

From this distribution, the observed mean distance was 191.99 m, and the expected mean distance was 168.47 m (Table 3). This result implies that keeping all other factors constant, residents must travel 191.99 m to the nearest containers to dump their waste. The z-score indicates a 1.10 m deviation above the mean distance, with the p-value indicating that communal containers in the Bolgatanga municipality are randomly dispersed. Also, given the z-score of 1.10 (Table 3), the distribution pattern could be considered random. Regarding the distribution of CCs in Tamale, the nearest neighbour analysis with the normal distribution curve (Fig. 6) showed a clustered pattern of the communal containers at the CBD (Fig. 6). This observation was in line with the findings of (38), who stated that communal collection points were few and restricted to the city centre.

From Table 4, the observed mean distance between the communal containers in Tamale was 108.31 m, and the expected mean distance was 223.71 m. The nearest neighbour ratio, the z-score, and the p-value computed are presented in Table 4. The value of the nearest neighbour in Tamale implied a clustered pattern of the distribution of communal containers **(**Fig. 6**).** The z-score of 6.77 m represents a deviation below the mean centre of the distribution. At the same time, the p-value indicates a less than 1% likelihood that this clustered pattern of communal containers within the CBD of Tamale could result from random chance. This distribution pattern is influenced by the high volume of waste generation in commercial areas and city centres.

With the distribution of communal containers (CCs) in the Wa municipality, the nearest neighbour analysis results indicated that the CCs were randomly distributed in the area. This is depicted by the normal probability graph (Fig. 7).

Table 5 summarises the average nearest neighbour analysis of the CCs distribution in Wa. The observed mean distance of the distribution was 631.02 m, with an expected mean distance of 587.80 m and a nearest-neighbour ratio of 1.07 m. This ratio indicated that the distribution of communal containers was random. The z-score implied a 0.80 m deviation above the mean centre. The p-value of 0.43 justified that the null hypothesis was valid. Given the z-score of 0.80, the pattern did not appear significantly different from random.

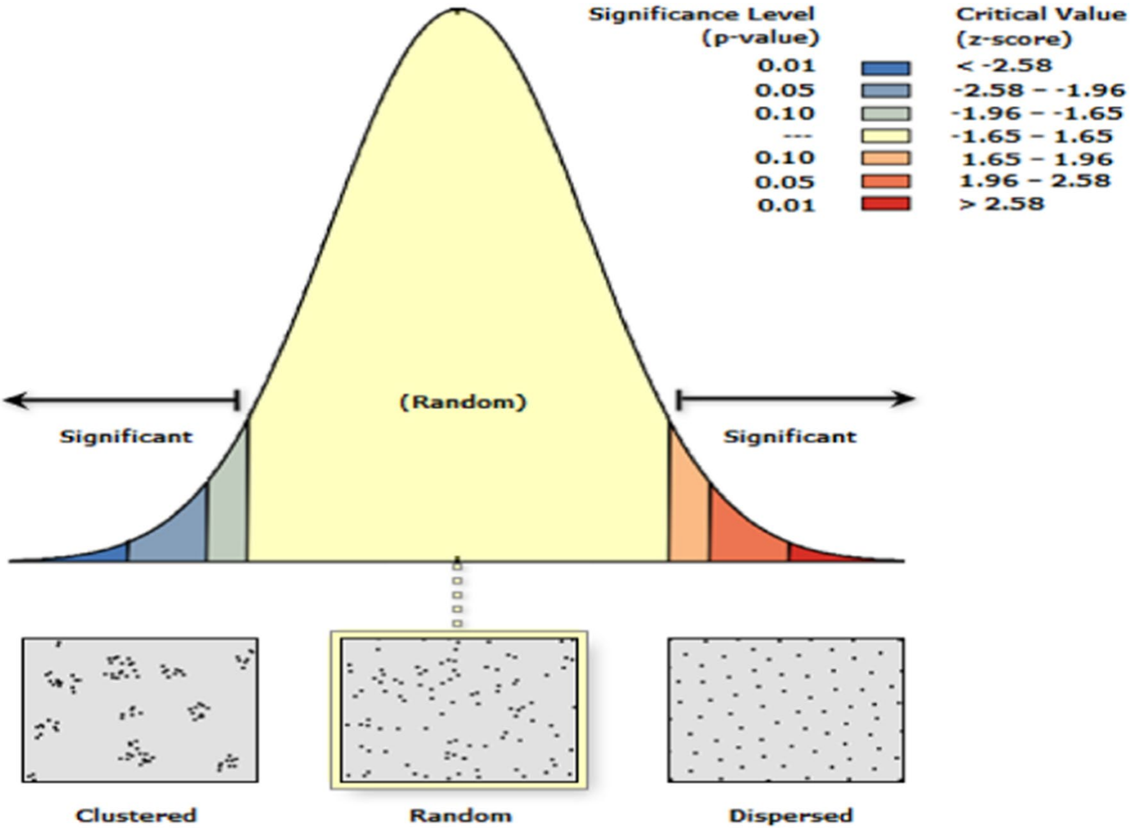


**Fig. 5** Probability normal distribution curve of Bolgatanga central collection

### 5.3 Physical quality indicators of waste collection

The physical quality indicators of the waste collection were assessed based on the percentage of waste collection in the various cities regarding the available waste collection system. Generally, the percentage collection through the CCC system ranged between 36.8 and 49.2%. The number of households with access to door-to-door waste collection services was below 12.6% for all cities (Table 6). The number of households who used standard waste bins (waste bins with wheels and covers) ranged between 7.6 and 12.6%, falling within the low benchmark of 0–49%. The results in Table 6 showed that the collection efficiency ranged between 47.4 and 57.1%. This was consistent with the collection rate of 55% for Africa, as reported by the World Bank in 2018. Tamale had a higher collection rate of 80.8% than the other study areas. This could be due to their higher urban service coverage as the literature shows that, on average, more resources are usually allocated to urbanized areas than their rural counterparts [14, 18, 19]. In response to a question on waste collection, a director of one of the waste management departments indicated that:

*"The Ministry of Local Government and Rural Development (MLGRD) allocates more resources to cities due to high waste generation. Collection, therefore, tends to be higher there than less urbanized MMDAs".*

The ratios of waste management workers to the population were 1:32, 1:19 and 1:26 for Wa, Tamale and Bolgatanga (Table 6). This ratio was high and above the recommended ratio of 1:10. The implication is that workers are overwhelmed by the volume of work and tend to be ineffective. In response to the low number of staff, one regional environmental health officer (REHO) explained:

*"The number of staff in the Department of environmental health in the Wa municipal assembly and other district assemblies is woefully inadequate. This situation and inadequate resources make it difficult for officers to perform".*

The study further showed that the inability of the waste management companies to hire more workers was due to limited funding. It was found that the revenue generation rate of the five waste collection companies had been

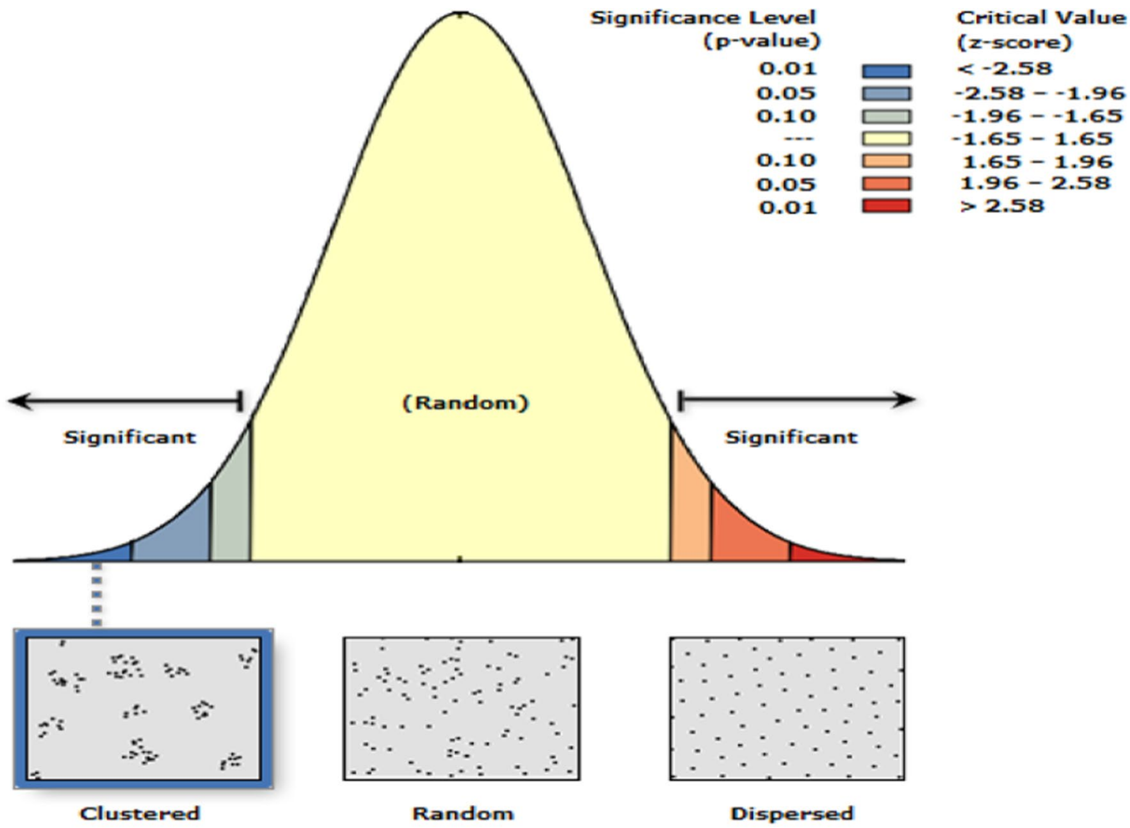


**Fig. 6** Probability normal distribution curve of Tamale central collection

reduced drastically due to non-payment of debt by the government and other user agencies and the refusal of some households to pay agreed fees.

### 5.4 Getting waste out of sight

The safe disposal of waste is fundamental for protecting the environment and ensuring good public health [11]. Like many countries in sub-Saharan Africa, the final disposal site of waste for Bolgatanga and Wa was designated dump sites [19]. Tamale, however, has an engineered landfill. Interactions with some key informants revealed that a landfill as the final disposal facility was preferred because of safety/risk reduction. It was also popular because other methods like reuse, recycling and waste-to-energy are not receiving enough advocacy within the study area. It was observed that the Tamale landfill was fraught with vulnerabilities. For instance, the facility was poorly managed, creating a nuisance in smoke, bad odour, spills, and the source of flies to surrounding communities [18, 19]. The key informant at the Tamale landfill site summed up the state of the landfill as follows:

> *"This disposal site is causing serious health problems to us. Burning in the site engulfs the community with smoke, making breathing difficult. The trucks that pass through the community cause a lot of dust. In the rainy season, we experience a lot of flies coming from the landfill into our homes."*

Wa and Bolgatanga, which lacked engineered landfills, got their municipal authorities dealing with regular complaints, conflicts, and protests because of the continuous operation of dumpsites. One of the municipal environmental health officers opined:

> "D*isposal has been a problem for the assembly for many years now. The Siriyiri dumpsite has been used for several years and closed due to land litigation. The surrounding communities have been agitating for the relocation of the site and have blocked our trucks from dumping on several occasions. This year alone, we have changed three different locations as dumpsites. This is not the best practice. We need to find a permanent solution to this problem. Fortunately, the municipal*

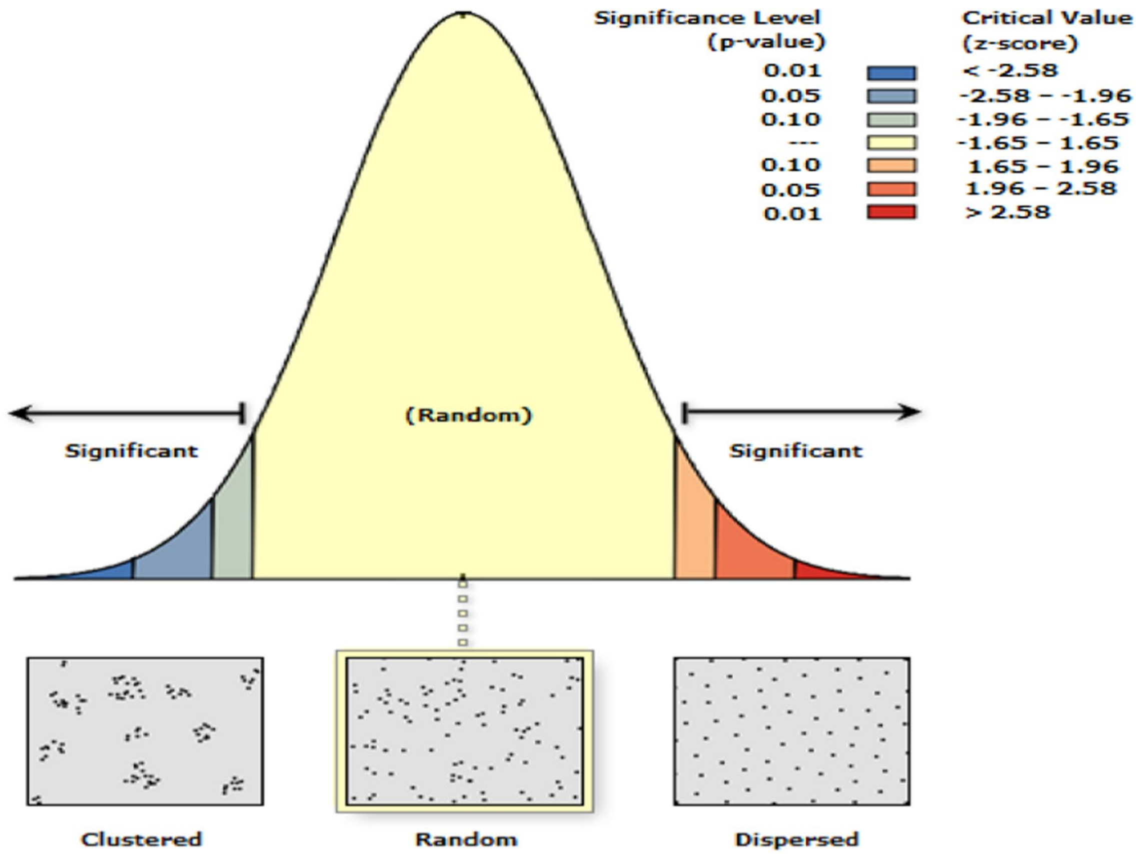


**Fig. 7** Probability normal distribution curve of Wa central collection

*assembly has partnered with Zoomlion Ghana Limited to construct a 200 Mt waste processing plant. Construction is ongoing."*

Sharing his views on the lack of engineered landfill in Bolga, a key informant indicated that:

*"My brother, the problem is that the government does not have the funding to construct an engineering landfill. Unfortunately, the cost is also prohibitive, and the private sector alone cannot shoulder such a responsibility. Unlike the other cities in Ghana, where land scarcity has become the reason for the lack of engineered landfill, the land is not a problem in our case. The problem is cash*", he concluded.

The response of the environmental health officer exemplified the state of waste disposal sites in the Wa and Bolgatanga. These have received negative media attention due to the perceived health and environmental effects. Residents assume they contain high concentrations of toxic compounds, including nitrate, ammonia, solvents, PCBs, and heavy metals. Once these substances reach groundwater, the contamination can be very damaging.

## 5.5 Waste treatment and value addition

The interaction with key personalities involved with waste planning and management in the cities selected for the study indicated that even though plans are far advanced to construct waste treatment infrastructure, their actualization will depend on the funds' availability. No engineered recycling process plant was in the study areas. Waste recovery activities were mainly undertaken by the informal sector/individuals who engaged in this practice as a means of income. The main materials recovered were metals, plastics, manure, and animal feed. The percentage of waste recovered (scrap metals and plastics) ranged from 0.5% in the Wa municipality to 1.3% in the Tamale Metropolis (Table 6). However, it was observed that a private waste management company was constructing waste processing/resource recovery plants. In an interview, a waste management expert at one of the waste management units in Tamale explained:

**Table 6** Status of solid waste management services in the selected communities

| The aspect of physical quality | Indicator | Wa | Tamale | Bolgatanga | Standard/Benchmark |
|---|---|---|---|---|---|
| Collection | % of solid waste collected | 47.4 | 57.1 | 48.9 | Low (0–49%), Low/Medium (50–60%), Medium (70–89%), Medium/High (90–98%) High (99–100%) |
| | % of households that have access to the door-to-door collection | 7.6 | 7.9 | 12.1 | Low (0–49%), Low/Medium (50–60%), Medium (70–89%)Medium/High (90–98%), High (99–100%) |
| | % of waste collected through communal container collection (CCC) | 39.8 | 49.2 | 36.8 | |
| | % of households using the standard waste bin | 7.6 | 7.9 | 12.6 | Low (0–49%), Low/Medium (50–60%), Medium (70–89%) Medium/High (90–98%), High (99–100%) |
| | The ratio of waste management and sanitation workers to the population | 1:32 | 1:19 | 1:26 | 1: 100 |
| Transport | % of enclosed collection vehicles in use | 100 | 100 | 100 | 100% |
| | Availability of Transfer stations | No | No | No | Yes |
| | % of collected waste transported to landfill/controlled dumpsite | 65 | 68 | 67 | Low (0–49%), Low/Medium (50–69%), Medium (70–89%) Medium/High (90–98%), High (99–100%) |
| Treatment | Availability of functional waste processing facility | No | No | No | Yes |
| | % of waste recycled/recovered/treated | 0.5 | 1.3 | 0.7 | Low (0–9%), Low/Medium (10–24%), Medium (25–44%) Medium/High (45–64%), High (65% and above) |
| Disposal | Availability of engineered landfill | No | Yes | No | Yes (engineered landfill available) |
| | % of solid waste safely disposed of in landfill/official disposal site | 25 | 41 | 39 | Low (0–49%), Low/Medium (50–60%), Medium (70–89%) Medium/High (90–98%), High (99–100%) |

Source: Regional Waste Management Operations Reports for Wa, Tamale, and Bolgatanga for 2022 reporting year

*"The Metropolitan Assembly, in partnership with Zoomlion, is constructing a 400 Mt/day solid waste processing plant. This plant will solve the disposal problem and help us recover resources from the waste."*

While there are attempts to construct waste-compost plants, the construction of waste-to-energy (WTE) so far is not an option in the immediate future. The key informant explained why WTE options are not being explored:

*"You know the functionality and sustainability of the WTE system depend on proper auditing of the waste stream in terms of the chemical and physical properties, but currently, such auditing systems are not in place. Again, the particle sizes, moisture levels, calorific and heating values, and daily volume must all be known. Still, for now, such data is not available even at the country level, and so it will be difficult, if not impossible, to have such a project".*

Apart from these reasons, other key informants indicated that in considering WTE technologies, other factors are appropriate sites and economic, environmental, and social impacts. Again, such infrastructure must be informed by an integrated solid waste management plan.

## 6 Discussion

The issue of spatial inequality in the distribution of solid waste management infrastructure in Ghana is not new. Various studies have highlighted spatial inequality, and often the cause is pinned on waste management costs [18]. For instance, analyses from this study show that the door-to-door waste collection in low-income and peri-urban communities was less economical (high operational cost) due to limited access routes to residents. So, it is argued that for equality in the distribution and servicing of waste bins, urban planning (accessible roads) must be improved in all the towns concerned. The limited access to service vehicles in low-income areas militates against the success of the PPP policy on waste management. This policy requires that all communities in the town benefit equally from waste management services. However, the results show that the private companies concentrated on well-planned areas where profitability facilitated by accessible routes was inherently high. This contributed to the variations in service delivery between the affluent and poor neighbourhoods, as observed in the study areas.

The cost-of-service charges were also influenced by the equipment used. The field observation showed that compaction vehicles were used most for door-to-door waste collection in the communities. While using these trucks is convenient, easy, and sanitary, their use could be less profitable in poorly planned urban communities with low waste generation rates and limited access routes. According to Oteng-Ababio [39], compactor vehicles are suitable for solid waste collection in well-planned urban areas with a waste density between 100–150 $kg/m^3$, where the waste can be compacted to 400–500 $kg/m^3$ as an economic load (compaction ratio 4:1–5:1). However, solid waste densities in many cities in Ghana including the study communities are between 250 and 400 $kg/m^3$ and contain abrasive sand and ash [11]. Consequently, using compaction trucks results in high operating costs, and these vehicles can be prone to severe debris damage due to the presence of abrasive materials. Motorized tricycles may be ideal alternatives for waste collection in poorly planned areas.

Regarding the distribution of the CCs (skip bins), the results revealed that the spatial location of skip bins was influenced by accessibility and the volume of waste generated. For these reasons, most communal containers were found in the CBD and highly populated communities. This observation concurs with the findings of Odonkor et al. [40], who stated that communal collection points in the cities of Ghana were often few and restricted to city centres, making them inaccessible to residential households in large urban districts. Moreover, Owusu-Sekyere [41], in a study in the Kumasi Metropolis of Ghana, concluded that CCs distributions were concentrated at where commercial activities were high. Several other studies have reported the skewed distribution of CCs in many different African locations. They conclude that such containers are usually clustered in high-density populated communities with high commercial activities. For instance, Naibbi and Umar [30] reported clustered distribution of waste collection containers at the city centre of Kano, Nigeria. On the other hand, a study in Katsina, Nigeria, discovered severe indiscriminate dumping in the peri-urban areas than in the city centre, but this was due to limited collection containers in the peri-urban areas [29]. All these lapses in the distribution and collection of waste containers are evidence of structural problems with existing solid waste management systems in Africa that needs further studies, analyses, and strategic interventions.

From the interactions with research participants, there was an admission that even though there has been some form of investment and policy decisions to improve waste collection services, the quality of service was not good. There were many instances where waste collected was indiscriminately dumped at ecologically sensitive locations.

The results, for instance, showed that in all the study areas, the collection rate fell short of the benchmark rate of 50–60% (see Table 6). This has therefore called into question the effectiveness and appropriateness of the current waste collection system, which some scholars [11, 12] have described as an importation of policies without recourse to local development trajectories. Such concerns are often underpinned by failures associated with the collection systems that promised sustainability but, in effect, are a pale shadow of themselves.

Another important study finding was the lack of engineered landfill sites in Bolgatanga and Wa. Often, in many cities across the globe, the lack of land and public resentment against landfill has been cited as the reasons for their waning popularity [18, 37]. In the case of the study area, land for such projects was available as the land size far outweighed the population size. The major challenge was the lack of funds to build landfills. The issue of funding constraints facing both national and local government in developing countries have been acknowledged in the literature [2]. Even though there have been several efforts to forge a partnership between the private and the public sector, the outcomes have not been encouraging. Funding solid waste management services is a major issue for city authorities globally [2]. The situation is, however, dire in the developing world. Therefore, the condition in the study areas should not be viewed in isolation. Like many African cities south of the Sahara, Ghana's expenditure on waste management services does not commensurate with collection coverage. Waste collection is low, while investment in waste treatment and final disposal sites remains below acceptable standards.

## 7 Conclusion

This study used the NNI to analyze the spatial distribution of waste collection systems in selected towns in northern Ghana. Household waste bins were generally clustered in high residential areas. The distribution patterns of communal skip bins for the Bolgatanga and Wa municipalities were random, but the distribution of these bins was clustered in Tamale. It was also observed that the distribution of CCs was particularly clustered in the CBDs of the towns. Irregular lifting and inadequate containers resulted in the spillage of refuse and dumping around container sites.

It is recommended that policy approaches intended to foster proper waste management should be tweaked explicitly to recognize that reducing disparity issues are an important step in overcoming some of the shortcomings of sustainable waste management. Changes to the spatial planning strategies and the informal waste management sector recognition can reduce the service gap between high and low-income areas. In summary, we argued that irrespective of the context, sustainable solid waste management is one of the major challenges facing settlements of all sizes, whether mega-cities or small towns. In most statistics, it features among the top five of the most environmentally challenging problems for city authorities. Therefore, it must receive equal attention just as the other human development issues.

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## Declarations

**Competing interests** None declared.

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