Chapter

Sustainable Pathway for Closing Solid Waste Data Gaps: Implications for Modernization Strategies and Resilient Cities in Developing Countries

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Abstract

This chapter addresses three peculiar challenges in the solid waste management system of developing countries, namely: the chronic lack of reliable data for planning purposes, the absence of participatory engagement strategies in data gathering for wider ownership and usage, and the lack of monitoring of the climate change burden of existing waste disposal practices. A team of researchers has collaborated with system managers and a responsible philanthropic organization to engage key stakeholders to address these gaps in a sustainable manner. The strategy deployed has been to work in a participatory and evidenced-based frame to solicit support, enhance capacities, empower each other to understand the problems and find for ourselves the practical routes by which solid waste data gaps can be closed in the greater Accra region of Ghana. Stakeholders have participated in a comprehensive waste audit and landfill emission monitoring exercise to develop a baseline, and have used local resources and ideas to recommend steps to sustain reliable data flows and the development of a climate action plan for purposes of modernization. The methodological processes and research outcomes suggest that structural collaboration between researchers and system stakeholders is necessary to break the vicious circle of chronic data gaps and substitute virtuous circles of reliable data for planning purposes.

Keywords: reliable data, participatory processes, municipal solid waste, waste composition, calorific value, greenhouse gases, Ghana, developing countries

1. Introduction

Reliable solid waste (SW) data and information are essential to sustainable waste management systems [1]. It supports decision-makers and professional solid waste management (SWM) staff to build their knowledge-base to effectively plan and develop strategies for modernization [2, 3]. Its usefulness has been recognized in the developed and industrialized worlds, making it a prerequisite and a routine to almost all planning processes [4]. Of the many data sets required in SWM, baseline data on generation rates, composition analysis, and other chemical and mechanical properties are considered vital to the planning of collection and transportation systems, to the choice of treatment and disposal technologies, and the design of municipal solid waste (MSW) recycling and valorization pathways [5, 6].

But despite their significance and usefulness, there exist a chronic lack (or absence) of waste characteristics data in most lower-middle income cities of developing countries, depriving managing authorities the basis to assess their systems and further develop interventions and action plans for modernization [7].

Where some form of MSW data exist, their reliability is affected by many factors such as the collection methodology, the baseline from which they were extrapolated, the number of years since they were collected, and the purpose and circumstances to which they were collected. More often than not, the limited available MSW data has been the product of external consultants (working under time pressure for donors) who have extrapolated from non-validated global or regional data sets. Such data sets are mostly gathered in relation to planning a facility, and are likely to be overestimated to capture the maximum amount of donor funding for the project. Despite the fact that such data are not always readily accessible within the SWM system, stakeholders rarely embrace its usage.

Conventional top-down ways of creating baseline information have also not helped to address this issue, in part because they are most often derived from a paradigm for engineering-based SWM, in which assuring that most waste reaches engineered disposal is most often the main goal of waste system upgrading in many a developing country city. For planning for disposal, generally the gross capacity of the sink (landfill) is important, and so the tendency in most solid waste (SW) plans is to take any available data and update it to make sure that the facility that is built has more than sufficient capacity [3].

Such a strategy has not always been successful even in its own right, and when it comes to planning integrated and sustainable waste management (ISWM), it provides too little basis for assessing the performance of the system, to allow for the participatory formulation of interventions to fix what is failing, and strengthen what is working.

Whilst disposal on land is the most inevitable MSW treatment option after collection in most developing countries, its burden to climate change is seldom assessed, preventing system handlers the opportunity of developing climate change mitigation policies, such as the separation of waste at source and the diversion of recyclables from disposal [8].

The contribution of this chapter is to address these data challenges by engaging academic researchers, solid waste managers, the informal waste sector, and other relevant stakeholders in a participatory process to comprehensively quantify and characterize the solid waste of households, institutions and markets in the greater Accra region of Ghana, and monitor the Greenhouse gas (GHG) emissions from existing SW disposal landfills. Being the first of its kind, the objective has been to strengthen local capacities in data collection and promote participatory research-based decision-making towards SWM system modernization in Ghana. Ideally the result of participatory engagement will work to create knowledge, awareness, transparency, self- and collective-correction, and ownership of results in addition to empowering stakeholders to use same to develop locally responsive interventions and action plans for system improvement.

2. Overview of the solid waste data challenge in developing countries

The publications "What a Waste 2.0, Africa Waste Management Outlook (AWMO) and Solid Waste Management in the World's Cities," encapsulate the MSW data challenge of Sub-Saharan African countries and the developing world [7, 9, 10]. The challenge is exacerbated by the absence of a common framework for comprehensive data capture in especially Sub-Saharan Africa. The AWMO identifies the gravity of this data challenge and articulates it in the statement: One of the limitations of the AWMO is the lack of reliable, comprehensive and up-to-date data for Africa, which is a constraint to effective waste management on the continent. This lack of comprehensive data is further compounded by the different approaches to data collection [7].

This concern is followed by a question to which this chapter seeks to associate with and attempts to find a solution to, namely: "If this issue (lack of data) has been recognized for the past two decades, why have adequate measures not been put in place to ensure the generation and reporting of reliable, comprehensive waste data for Africa?"

Experience from the community of practice and the scholarly literature shows that the generation of reliable data is dependent on a mixture of factors, namely:

- stakeholders realization that reliable data is vital to the planning and development of a well-functioning and sustainable municipal solid waste management (MSWM) system

- availability of the human resource capacity required to generate the data

- commitment of system managers and decision-makers to source the necessary funds for generation of the data

But almost by design, most waste management departments in developing countries are constrained with the required human resource capacity and technical knowledge to support the collection of reliable data [11]. Whilst there may be a growing awareness of the importance of reliable data to planning and system sustainability, the competing need and high cost of waste collection and disposal prevents system handlers from allocating already limited funds for capacity building and data collection [12]. Failure in MSWM governance, characterized by the lack of monitoring stakeholder performance and the continuous refusal to recognize the contribution of informal sector actors, especially in most Sub-Saharan African cities further denies the system of any operational-related MSW data.

The reality on the ground has been the use of consultants working on donor financed projects to collect data, which most often are undertaken without the participation of the local system handlers. Where they are involved in the process, their roles are limited to objects of investigation and validation of information, affecting ownership and eventual usage of such data for planning purposes.

If developing countries would be able to formulate sustainable MSWM plans to modernize their systems, a new approach that create the enabling environment to allow local authorities and system handlers to participate in the planning, collection, analysis and validation of all waste-related data needs to be adopted [13]. The new normal will have to equip those in charge with the necessary know-how and hands on practices to support them generate, replicate and update their own data, and use same for system assessment, intervention development, implementation and the formulation of action plans for system modernization [14].

Interestingly, all the three publications that comprehensively discuss the data challenge in developing country cities embrace participatory engagement strategies as vital to the closing of such data gaps. Participatory action research processes offer researchers and stakeholders the opportunity to build alliances with the commitment and desire to understand, investigate and design solutions to the very problems that affect their systems [13, 15].

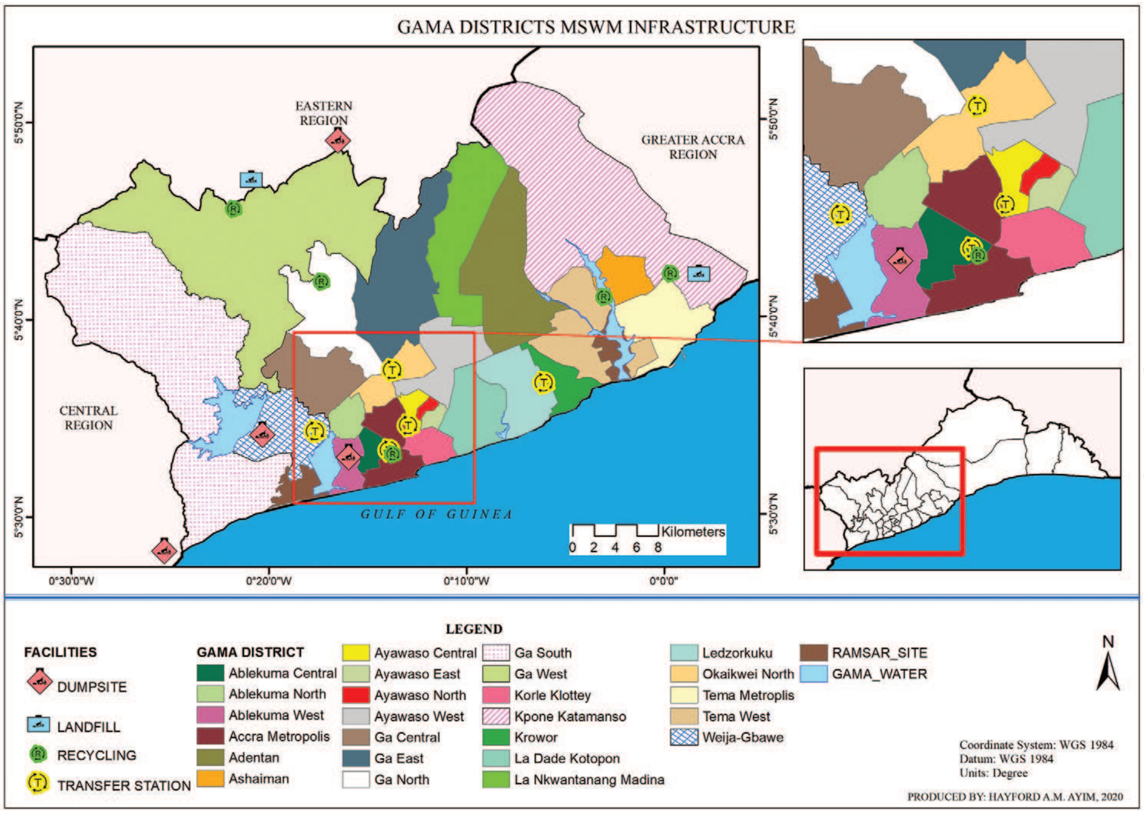

Figure 1.
The greater Accra metropolitan area showing the 25 municipalities, MSWM facilities and the sampled area for analysis. Source: The authors, 2020, Accra, Ghana.

3. The Greater Accra Metropolitan Area

The Greater Accra Metropolitan Area ("the GAMA") comprises 25 municipalities along the South-Eastern Coast of Ghana and covers an area of 1453.53 km^2 (**Figure 1**). The region harbors the capital city, Accra, and the industrial hub, Tema, of the country. The estimated population is 4.63 million with a daily MSW generation rate of 3293 tons [3]. Formal private companies have the concession to collect waste, but poor performance have resulted in the growth of an informal waste collection sector who are significantly filling gaps especially in low-income areas of the region [16]. More than 90% of collected MSW ends up on a system of controlled and uncontrolled landfills, with the informal waste pickers and recyclers contributing to 84% of the reported 8.4% recycling rate [3]. The level of user and provider inclusivity in decision-making, the financial sustainability of the MSWM system, the cohesiveness of the institutions managing the system, and the proactiveness of the legislative and regulatory framework has been reported to be inadequate [17]. Although initially planned for the capital city, Accra, the working group to the research in this chapter selected the GAMA to increase the scope of the assignment and make the outcome more representative of the region.

4. Materials and methods

The research to this chapter has made use of a team of researchers, municipal officials (planners, public health engineers), the informal waste sector (both service- and value-chain actors) and policy institutions to use participatory research action processes to plan and generate comprehensive MSW characterization and landfill emission data for the GAMA. The goal has been to engage public-sector stakeholders as team members to seek their support and build their capacities as part of efforts towards the closing of reliable MSW data gaps within the municipalities. The main activities include the:

- training of stakeholders in MSW data collection processes and GHG monitoring
- determination of the physical (generation rate, composition analysis and bulk density) and selected chemical properties (moisture content, calorific value nutrient analysis and ash content) of the MSW of the region
- monitoring of the GHG (Carbon IV Oxide, Methane and volatile Organic Compounds) directly, and through estimations from the city's final disposal sites to help measure the contribution of the existing MSWM practices to climate change

4.1 Stakeholder mobilization, training and preliminary planning processes

The planning processes to the collection of data began with the mobilization of eight relevant stakeholders to support the characterization exercise (**Table 1**). The objective was to stimulate the potential for wider contribution, ownership, acceptance and eventual usage of the data and the outcomes of the processes. A second objective was to equip the staff within the municipalities with the technical and non-technical know-how to enable them replicate the processes and use same for further planning of their MSWM system [14]. The authors, themselves stakeholder's and researchers worked with managers from the Waste Management Department (WMD) of the Accra Metropolitan Assembly (AMA) as a focal planning and coordinating team. The following activities were agreed upon for implementation as part of the initial meetings between the stakeholders, namely the:

- development of a training manual on MSW characterization and landfill gas monitoring for use in the training of municipal staff
- selection of the municipalities and determination of the scope of analysis
- consultation of private MSW service companies for support on venue and personnel for the solid waste analysis
- scope of the quantification and characterization analysis
- development of the various forms for data capture
- identification of laboratories for chemical analysis of MSW samples
- agreement to outsource the GHG monitoring to a willing and capable consultant
- consideration of the available budget, its sufficiency and the development of a plan to solicit further support from local stakeholders where necessary

4.2 Sample size, scope, distribution of receptacles and collection of demographic data

The MSW for the exercise was collected randomly from households within 10 (out of 25) municipalities, traders within the three largest markets in the GAMA,

No.	Stakeholder (no. of representatives)	Role
1	Accra Metropolitan Assembly (13)	Coordination, support, field work and data collection
2	Ga North Municipality (3)	Mapping, field work participation and observation
3	Ablekuma North Municipality (2)	Field work participation, observation & distribution of receptacles
4	Okaikwei North Municipality (2)	Field work participation and observation
5	Ayawaso West Municipality (2)	
6	Ayawaso East Municipality (2)	
7	Ayawaso Central Municipality (2)	
8	Ashiedu Keteke Municipality (1)	
9	Ablekuma West (1)	
10	Ministry of Sanitation and Water Resources (3)	Field work observation
11	Environmental Protection Agency (1)	
12	Regional Coordinating Council (2)	Field work observation and sampling for laboratory analysis
13	Jekora Ventures Limited (14)*	Coordination, support, field work and data collection
14	Informal MSW collectors (10)	
15	Informal MSW pickers (5)	
16	Nation Builders Corps (NABCO) (10)	
17	National Service Persons (4)	
18	Foreign Intern, Netherlands (1)	
19	University of Cape Coast (3)	
20	Nemas Consult Limited (2)**	Landfill Gas Monitoring
21	Kwame Nkrumah University of Science and Technology (3)**	Laboratory Analysis, Wet and Dry Season
22	University of Ghana (2)**	Laboratory Analysis, Wet Season
23	C40 Cities	Funding

**A private waste management company that provided venue and personnel.*
***These stakeholders did not partake in the day to day activities. We sought their services for landfill gas monitoring and laboratory analysis.*

Table 1.
Stakeholders and their roles within the MSW characterization exercise in the GAMA.

and workers within 15 institutions (**Figure 2**). Twenty households were randomly selected in each of the 10 municipalities (grouped into three income divides) for the analysis (**Figure 2**). A total of 3150 samples of different weights and sizes (2000 samples from households, 700 from markets and 450 from institutions) were analyzed for 10 days during the wet season (August 2019). The process was repeated for the dry season (December 2019). The minimum computed household sample size of approximately 400 [18] was increased almost fivefold to 2000 to allow for a large margin of representation. This decision was taken with the knowledge of having stakeholder's support and the financial resilience to contain the increase.

A 45 member team of service persons, Nation Builders Corps (NABCO) representatives, informal solid waste collectors, municipal officers and the coordinating team sought the consent of the various households, institutions and markets and

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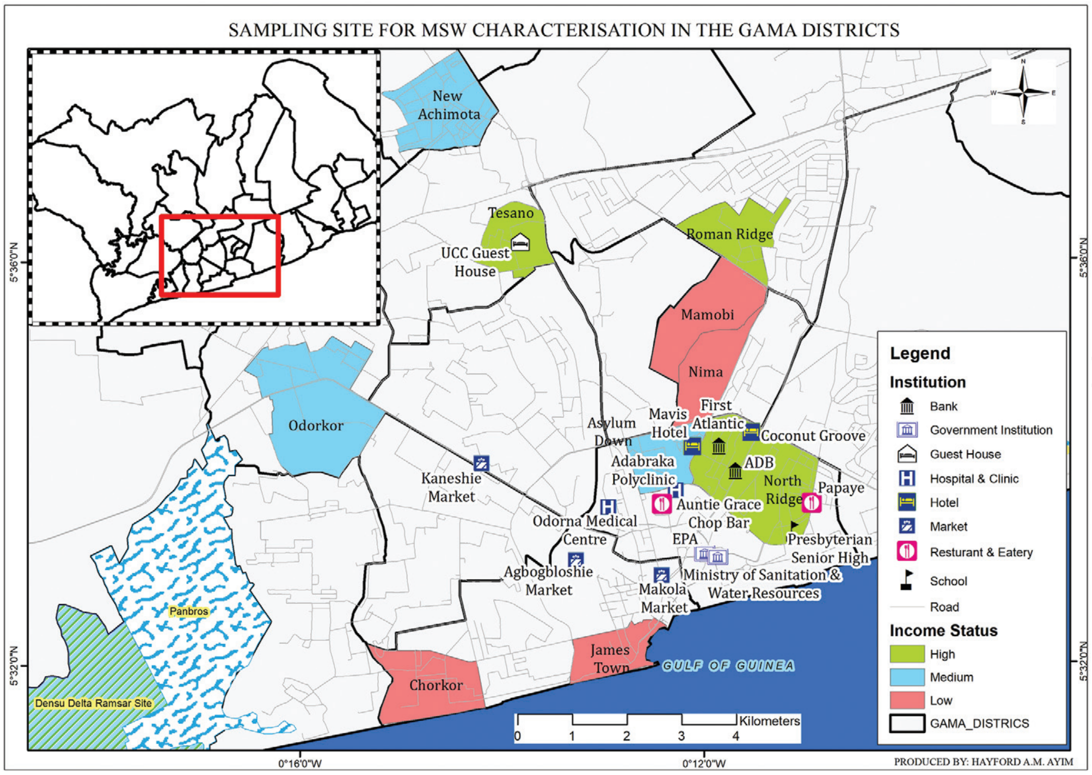

Figure 2.
The 10 municipalities, 3 main markets and the 15 institutions sampled for the MSW characterization exercise within the GAMA of Ghana. Source: The authors, 2020, Accra, Ghana.

Figure 3.
The receptacles used for the collection of MSW from households, markets and institutions respectively. Source: The authors, 2020, Accra, Ghana. Legend: AMA: Accra metropolitan assembly.

distributed labeled and AMA embossed polyethylene bags of volumes 30 ml, 240 ml and sacks (150 ml) respectively for the daily storage of their waste. The printing of the AMA's logo on the receptacles (**Figure 3**) was to promote trust and also to add value and a high level of importance to the exercise.

The demographic data (name, house number, household size etc.) of the various participants were taken in the process of distribution of the receptacles and each participant was introduced to the informal solid waste collector tasked to collect the stored MSW every morning from the participants. Each participant was expected to use one receptacle per day but records were taken each day to justify the provision of more receptacles to participants/institutions/traders who needed more than one a day. A total of 6316 (30 ml) polyethylene bags, 3000 sacks and 400 (240 ml) polyethylene receptacles were distributed for sample collection during the wet and dry seasons.

Participants were provided with telephone numbers and were encouraged to ask questions about the process when the need arose. They were advised to opt out of the process if they felt to do so.

A period of four days was left between the end of distribution of the receptacles and the collection of the first set of samples for analysis in both seasons. In between the four days:

- the site for analysis was prepared
- tarpaulin on which the sorting of MSW was to be undertaken was procured and laid
- canopies, tables and chairs to provide shade and convenience to the workers were installed
- manual and digital scales for weights measurement were installed and calibrated
- plastic containers of different volumes were labeled and weighed
- special sampling bags for the laboratory aspect of the analysis were procured

The same period served the purpose for rehearsals to the characterization team on the expected daily routines including the distribution of procured coveralls and other personal protective equipment (PPEs). The demographic data collected from the households were also analyzed and verified through telephone calls to the households during the period. Selected representatives were tasked within the last two days before collection of samples to remind all participants of the date of collection of samples.

4.3 Collection of MSW from participants for analysis

Tricycle operators from the informal waste sector collected the MSW from the various households, markets and institutions across the 10 municipalities. Collected samples were sent each day to the site for the various characterization analysis. Samples of MSW received on the field were taken on the 6th, 7th, 9th and 10th days in both seasons to the laboratory for various nutrient and heat value analysis.

4.3.1 Determination of generation rate

Samples received were weighed on an OHAUS Defender 3000 Digital Bench Scale (model D31P150BX) of maximum capacity 150 kg and readability of 0.02 kg and recorded against the identities of the various households, market participants and institutions. The various quantities were divided by the corresponding household sizes and the weighted average daily quantities per capita per day was computed.

4.3.2 Determination of MSW composition

A total of 35 participants, informal waste pickers and collectors were divided into four teams for the segregation of the weighed MSW samples into various fractions. Segregated fractions were placed into labeled containers, weighed and recorded. The coordination team supervised and also recorded all daily measurements/weights, initially on paper and later onto the field laptop. Each day's measurements were recorded unto the laptop to prevent backlog of entries and also to identify and address any possible challenges in the daily data recording process. Recorded data was later analyzed using Microsoft Excel. All samples for the composition analysis were based on the recommendation of ASTM D5231-92 [19].

4.3.3 Determination of bulk density

The bulk densities of both comingled and biodegradable MSW within the samples from the various economic divides were determined by filling a plastic bucket container of known volume with waste and then weighing the loaded container. The bulk density was then computed by dividing the net weight of waste by the volume and expressing the unit in kg/m^3. Three bulk density measurements were carried out each and every other day on samples from each municipality to allow for the computation of means.

4.3.4 Determination of moisture content

The moisture content was determined by bulk drying the laboratory samples in an oven at 105°C ± 5°C for a 24-hour period until a constant weight was achieved. The ratio of the weight loss of the sample to the initial weight of the sample was computed and multiplied by 100% as depicted in Eq. (1).

$$M = \frac{M_w - M_d}{M_w} \times 100\% \quad (1)$$

where M = Moisture Content, M_w = Weight of wet sample received and M_d = Net weight of waste sample after oven drying.

4.3.5 Determination of calorific value

The gross calorific value was determined using the PARR 6400 Bomb Calorimeter. A known weight (0.5 g) of the representative samples (prepared after pulverizing the combustible portions of the dried sample) was picked and combusted in the bomb calorimeter. The equipment provides the user the opportunity to input the weight to be combusted. The equipment calculates the calorific value by an internal program and displays the dry-based higher calorific value (HCV). A reference material (Benzoic Acid) whose calorific value is known was used to ascertain the proper functioning of the bomb calorimeter before the samples were analyzed. The calorific value of the benzoic acid was within the recommended range (26.454 MJ/Kg ± 0.50 MJ/Kg). The lower heating value (LHV) was then computed from the HCV.

4.3.6 Nutrient analysis

The following methods were used in the determination of the various nutrients within the samples

- Walkley-Black wet oxidation method for the determination of Carbon (C)
- Kjeldahl method for Nitrogen (N)
- Titrimetric method for Hydrogen (H)
- Spectrophotometric method for Sulfur (S)
- Flame Photometery for Potassium

Phosphorus was determined using methods recommended by Motsara and Roy [20].

4.3.7 Determination of ash content

5 g ± 0.1 g of dried waste was accurately weighed with a precision of 0.0001 g and placed into a crucible that had been dried to a constant weight at 815 ± 5°C.

The crucible and its content was then placed into a muffle furnace. The furnace was heated slowly to 300°C within 30 mins. Heating was continued until 815 ± 5°C. The crucible was scorched for 3 hours at this temperature. The scorching was stopped and the crucible taken out of the furnace after the temperature had dropped to about 300°C. The crucible was then placed on asbestos wire gauze, covered and cooled for 5 minutes in a drier and weighed at room temperature after cooling. The crucible was scorched again for 20 mins and weighed at room temperature after cooling until the difference in value of the two measurements was less than 0.0005 g. The Ash content was computed using Eq. (2).

$$Ash\ Content = \frac{Weight\ of\ Ash}{Mass\ of\ Sample} \times 100\% \tag{2}$$

5. Results and discussion of the MSW characterization exercise

5.1 Generation rate

The analysis in the GAMA points to an average MSW generation rate of 0.70 kg per capita per day and 0.83 kg capita per day for households and institutions respectively. Markets recorded an average of 1.32 kg per shop per day. The result for households is closer to the averages (0.72 kg) and (0.71 kg) respectively in earlier solid waste characterization studies for metropolitan cities of Ghana [17, 21], but above the average 0.54 kg estimate for developing countries [9]. Whilst average per capita generation rates within low-income areas is 0.51 kg, that of their high-income counterparts is 0.91 kg; confirming already known trends in which the affluent in society is reported to generate more MSW than their urban poor counterparts [5].

The waste generation trend within each income divide is provided in (**Figure 4**). There are reasonable deviations about the MSW generation means in low- and middle-income areas but not in high-income areas. The significantly high generation rates for the first and sixth days in high-income areas are possible contributory

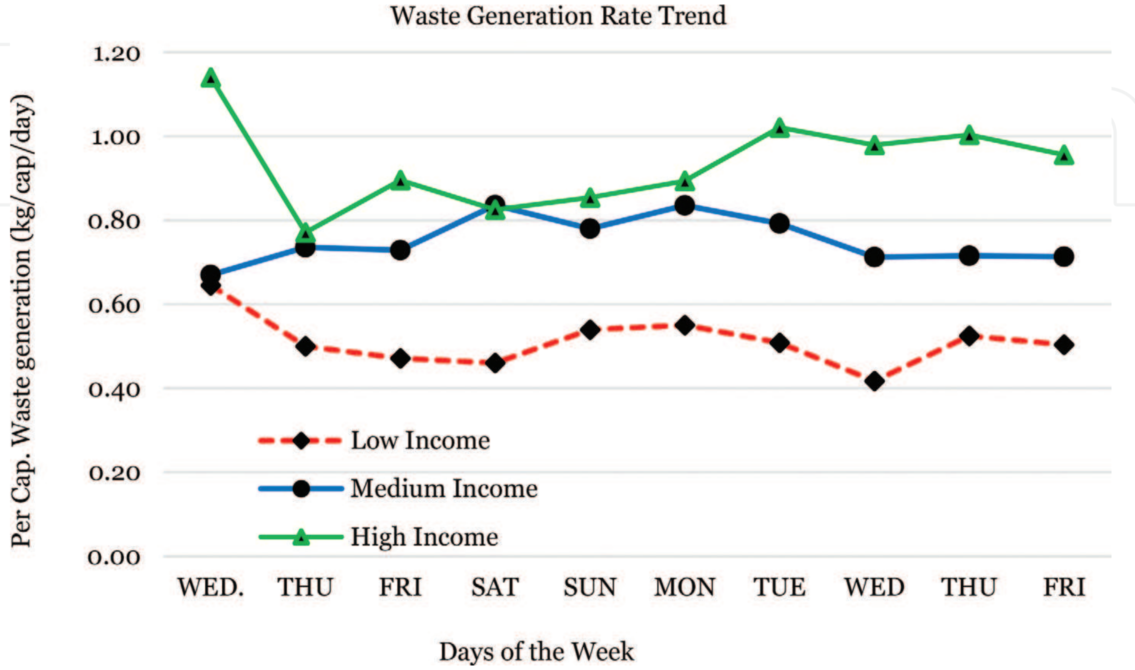

Figure 4.
Household MSW generation trends within three income divides in the GAMA.

factors. Whilst the generation rate per capita per day for the first-day is considered an outlier (likely due to the suspicion that the first day MSW received for analysis might not be a true reflection of the previous day's waste). The relatively high generation rate per capita on the sixth day (Monday) is likely a result of real generation rates from the weekend. Most middle- and high-income dwellers generate more waste during the weekends than the other days since they might mostly be at work; away from home during the weekdays.

There is a negative correlation between generation rate and household size (**Figure 5**) which is also indicative of earlier research findings in which smaller household sizes, mostly in single family dwellings within sparsely dense and affluent areas generate more MSW per capita per day than their poor urban counterparts in multifamily dwellings (locally known as compound houses) within densely populated areas [5].

5.2 Composition analysis

The three most significant components within households MSW are organics, a combination of food waste and garden waste (53.84%), plastics (16.05%) and inorganics (12.89%). Inorganics referred to here are virtually silts and ash swept from dirt floors and fetched from coal pots respectively in low income areas of the region [17]. The seasonal variation in composition is shown in (**Figure 6**). The high organic component is indicative of similar reports in developing countries that points to a large percentage of biodegradables in the household MSW [7].

System managers and other stakeholders will need to look for a locally responsive intervention to not only reduce the biodegradable content of the MSW of the municipalities, but also to find sustainable handling and treatment options to reduce its climate change burden on the environment. There is however significant variation in the MSW composition of institutions. Whilst there is relatively higher percentage of plastics within the MSW of government agencies, hospitals and schools, the MSW of restaurants/eateries, hotels and banks are rather dominated by organic wastes. Expectedly, schools generate the highest of paper waste followed by government institutions and banks. The MSW from markets is highly composed of organics (56.27%) followed by plastics (13.59%), textiles (13.17%) and paper (8.75%).

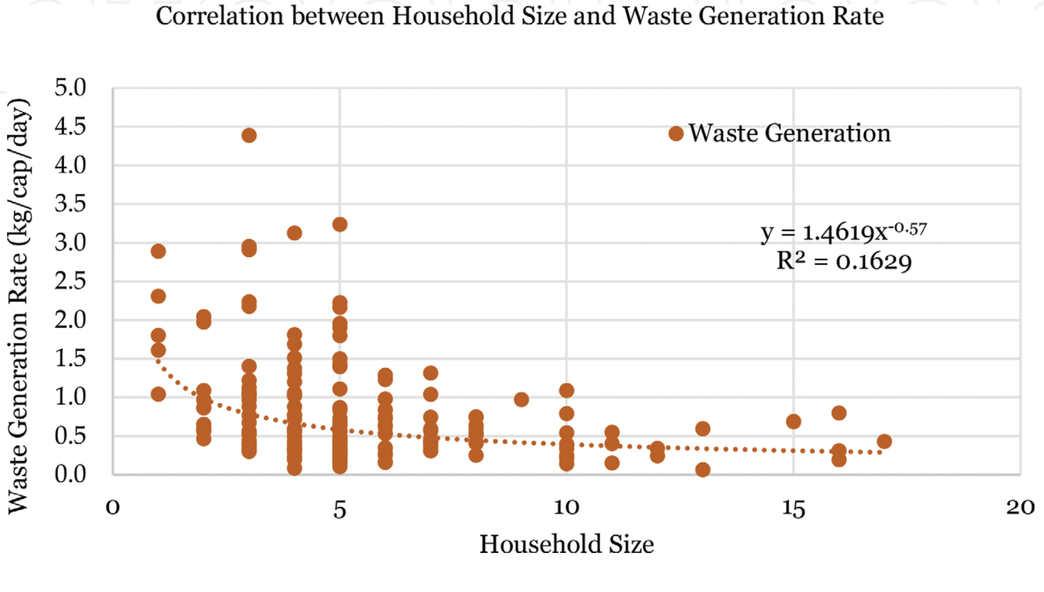

Figure 5.
MSW generation rates as a function of household size within the GAMA.

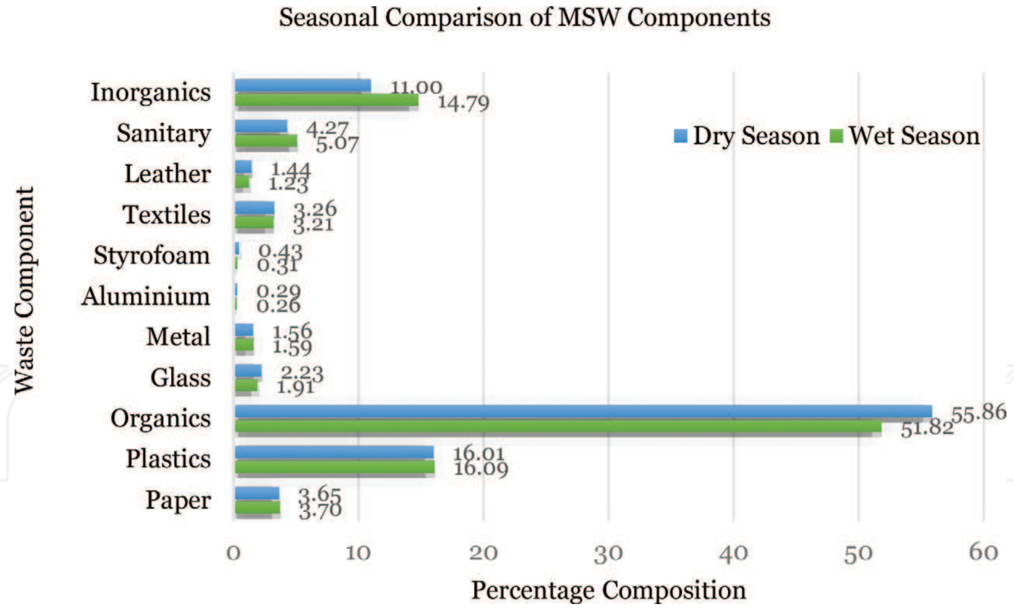

Figure 6.
Seasonal comparison of household MSW composition within the GAMA.

5.3 Bulk density and moisture content

The bulk density of MSW plays a major role in the determination of the lifespan of landfills, an inevitable disposal option for most developing countries. The average bulk densities for food waste (517. 73 kg/m^3) and mixed waste (331.39 kg/m^3) are typical of the MSW of developing countries. These relatively high densities are mostly due to the high moisture content of the MSW, which more often than not is open to precipitation before collection [10]. The average moisture content is 50%, which is highly unlikely to support the adoption of waste to energy (e.g. incineration) as a treatment option within the municipalities.

5.4 Calorific value of the MSW of the GAMA

The calorific value of the MSW was determined by two approaches: through model prediction based on the composition and water content of the MSW [22] and also by the bomb calorimetric method. The model prediction provides information on the net calorific value is also known as the lower calorific value (LCV); while the bomb calorimetric method provides the gross calorific value (higher calorific value, HCV), which is then converted to LCV for informed decision-making. The LCV is a technical criterion for the incineration of solid wastes. The LCV must on average be at least 7 MJ/kg and must not fall below 6 MJ/kg in any season if a particular waste stream is to be considered for incineration [22].

The estimated LCV of the MSW of the GAMA, based on the waste composition computation and water content of Eq. (3) is 6.74 MJ/kg (**Table 2**). The estimated LCV for the wet and dry season analysis are 6.47 MJ/kg and 7.01 MJ/Kg respectively.

$$LCV = 40\,(A + B + C + D) + 90E - 46W \tag{3}$$

Where A, B, C, D, E and W represents the wet weight composition (%) of the MSW of the GAMA as shown in (**Table 2**).

The results of the Bomb calorimetric method (**Table 3**) has been converted to the net calorific value using Eq. (4) [23, 24].

Variable	Parameters	Wet season	Dry season	Ave. GAMA
A	Paper	3.74	3.65	3.70
B	Textile	3.21	3.26	3.24
C	Wood and Leaves	16.44	15.42	15.93
D	Food waste	36.11	41.07	38.59
E	Plastic and Rubber	16.29	16.01	16.15
W	Water	49.97	50.03	50.00
LCV (kcal/kg)	4.18E-03	1547.48	1675.52	1611.90
LCV (MJ/kg)		**6.47**	**7.01**	**6.74**

Table 2.
Estimated lower calorific value based on the wet MSW composition values of the GAMA.

	Community	Mean HCV, (MJ/Kg)	Water (%)	Hydrogen (%)	Wet base HCV, (KJ/Kg)	Mean calorific value LCV, (MJ/Kg)	
Wet Season	Jamestown	19.15	48.20	8.74	9919.70	7.75	**7.71**
	Odorkor	20.58	41.90	7.35	11,956.98	10.00	
	Tesano	21.25	51.70	6.90	10,263.75	8.27	
	New Achimota	20.90	50.00	8.70	10,450.00	8.27	
	Roman Ridge	17.96	60.00	8.18	7184.00	5.00	
	Nima/Mamobi	17.64	48.50	8.29	9084.60	6.96	
Dry Season	New Achimota	16.25	45.70	8.80	8823.75	6.66	**6.71**
	Odorkor	19.08	52.80	9.80	9005.76	6.70	
	North Ridge	16.61	56.80	8.68	7175.52	4.97	
	Tesano	19.04	45.20	6.96	10,433.92	8.49	
Average calorific value (MJ/Kg)						**7.31**	

Table 3.
Bomb calorimetry heating values for the MSW of the GAMA.

$$LCV = \frac{HCV * 1000 * (100 - M)}{100} - 24(\mathrm{M} + 9 * \mathrm{H} * \frac{(100 - M)}{100} \quad (4)$$

Where LCV, HCV, H and M represents net calorific value, gross calorific value, hydrogen (%) and moisture content (%) respectively of the MSW of the city.

The average net calorific value (LCV) of the city's MSW is 7.31 MJ/Kg. The LCV for the wet and dry season analysis are 7.71 MJ/kg and 6.71 MJ/Kg respectively (**Table 3**). The results from both methods present LCVs which are close to 7 MJ/Kg, required in literature for probable consideration of incineration as a treatment choice for the MSW towards the recovery of energy.

5.5 Ultimate analysis of the MSW of the GAMA

The ultimate analysis of MSW involves the breakdown of the MSW into its elemental components. It plays an important role in the determination of the energy recovery potential of the waste as well as its application to support agricultural

SN		Community	% C	% H	% S	% N	% P	% K	% Ash	C:P	C: N
1	**Wet Season**	New Achimota	24.9	8.7	0.7	1.4	0.4	0.7	18.1	58.9	18.1
2		Roman Ridge	22.6	8.2	0.7	1.3	0.2	2.1	25.0	120.1	17.4
3		Nima/Mamobi	18.9	8.3	0.6	1.1	0.2	1.5	28.0	112.1	17.0
4		Odorkor	27.0	7.4	0.5	1.2	0.2	1.0	17.6	121.1	22.4
5		Jamestown	29.1	8.7	0.6	1.2	0.2	0.7	8.8	169.6	24.6
6		Tesano	26.6	6.9	0.6	1.8	0.2	2.5	20.8	154.9	14.6
7	**Dry Season**	New Achimota	27.9	8.8	0.7	1.4	0.2	1.0	19.6	144.1	20.7
8		Odorkor	27.5	9.8	0.6	1.4	0.1	1.3	21.2	194.2	20.4
9		Kaneshie Market 1	28.9	10.1	0.7	1.7	0.2	1.3	15.7	165.7	17.4
10		Kaneshie Market 2	28.3	7.4	0.4	1.4	0.2	0.6	7.6	145.9	21.0
11		North Ridge	28.1	8.7	0.4	2.2	0.7	1.3	15.2	42.7	12.8
12		Tesano	32.1	7.0	0.6	1.5	0.2	2.1	12.7	162.2	21.5

Table 4.
Ultimate nutrient analysis of the MSW of the GAMA.

needs. Composting is increasingly being considered as a favorable SWM strategy in most developing countries where larger portions of the waste are biodegradable. The Carbon to Nitrogen (C: N) and Carbon to Phosphorus (C: P) ratios are essential parameters for the sustainable valorization of MSW. Carbon to Nitrogen ratios of 25:1 and 30:1 of raw MSW is recommended by literature [6] for achieving maximum efficiency in composting and anaerobic digestion processes. Carbon to Phosphorus (C: P) ratio, on the other hand, has received little attention in literature even though it can be a limiting factor. A C: P ratio of 120:1 to 240:1 is necessary when the C: N ratio is 30:1.

The C: N ratio of the MSW of the GAMA ranges from 12.8:1 (North Ridge) to 24.6:1 (Jamestown) as shown in **Table 4**. The low C: N ratio means that material with high Carbon content such as wood and saw dust must be added to the waste to support composting and anaerobic digestion treatment technologies as part of the city's MSWM strategy. With the exception of the results from New Achimota and Nima/Mamobi in the wet season and North Ridge in the dry season (**Table 4**), the C:P ratio for the city's waste falls within the recommended range in literature.

6. Greenhouse gas monitoring and estimations within the GAMA

This section presents the methods and results of the GHG emissions from the waste sector (specifically, the MSW disposal practices) within the GAMA. Two methods were used: field measurement using the Aeroqual series 500 (A-S500) portable gas sensor method and indirect estimation using the auto-populated Microsoft Excel tool of the City Inventory Reporting Information System (CIRIS).

6.1 Field monitoring of the greenhouse gases

The concentration levels of the gases Methane (CH_4), Carbon IV Oxide (CO_2) and volatile organic compounds (VOCs) were monitored directly for four continuous days each during the wet and dry seasons, using an A-S500 potable gas meter instrument. The A-S500 portable gas sensor meter is a highly-rated device that enables accurate real time monitoring of common indoor and outdoor air pollutants

Figure 7.
The A-S500 portable gas instrument with sensors being mounted on the Nsumia landfill and a control site for GHG measurements.

and gas emissions, all in an ultra-portable air quality monitor [25]. The Instrument (**Figure 7**) consists of a monitor base and a gas sensor head of the respective gas under investigation. A particular gas was measured, when the sensor head of the gas was connected to the monitor base. The Nsumia landfill and one control site located about 500 meters away from the landfill was selected to monitor the various gases. The Global Positioning System (GPS) locations were, 5° 46′ 59.1″ N, 0° 21′ 14.1″W for the landfill site and 5° 46′ 53.5″N, 0° 21′ 03.1″W for the control site.

The instrument once fitted with a particular sensor head is also activated to measure ambient temperature (T) and relative humidity (RH) by inserting the TRH sensor into the PS/2 connector at the base of the monitor. Connection of the required sensor head to the monitor was done prior to the turning on of the equipment before measurement. The monitor was switched on and allowed to warm up for 3 minutes to "burn off" any contaminants trapped in the sensor prior to monitoring. The gas concentrations logged by the instrument were automatically saved in high capacity internal flash memory built within the instrument. The results of the measurement were then transferred to a laptop for analysis and reports were created using the A-S500 V6.5 Software.

The following sensor heads were used for the determination of the various gases

- Gas Sensitive Semiconductor (GSS) for CH_4 gas
- Non-Dispersive Infrared (NDIR) for CO_2 gas
- Photoionization Detector for VOCs

For the sake of brevity, the time series of the measured CH_4 and CO_2 gases, for both the wet and the dry seasons are displayed in (**Figure 8**).

6.2 Greenhouse gas computation using the city inventory reporting information system

Methane (CH_4) and biogenic Carbon IV Oxide ($CO_{2(b)}$) are the two GHGs considered in this section since they predominate the GHG from solid waste degradation and decomposition. The landfill data used in the estimation of GHGs was sourced from a recent research output in Ghana [26].

6.2.1 Method of estimation

The Methane Commitment Method within the CIRIS Excel tool was used to calculate the GHGs originating from solid waste disposed of in the GAMA.

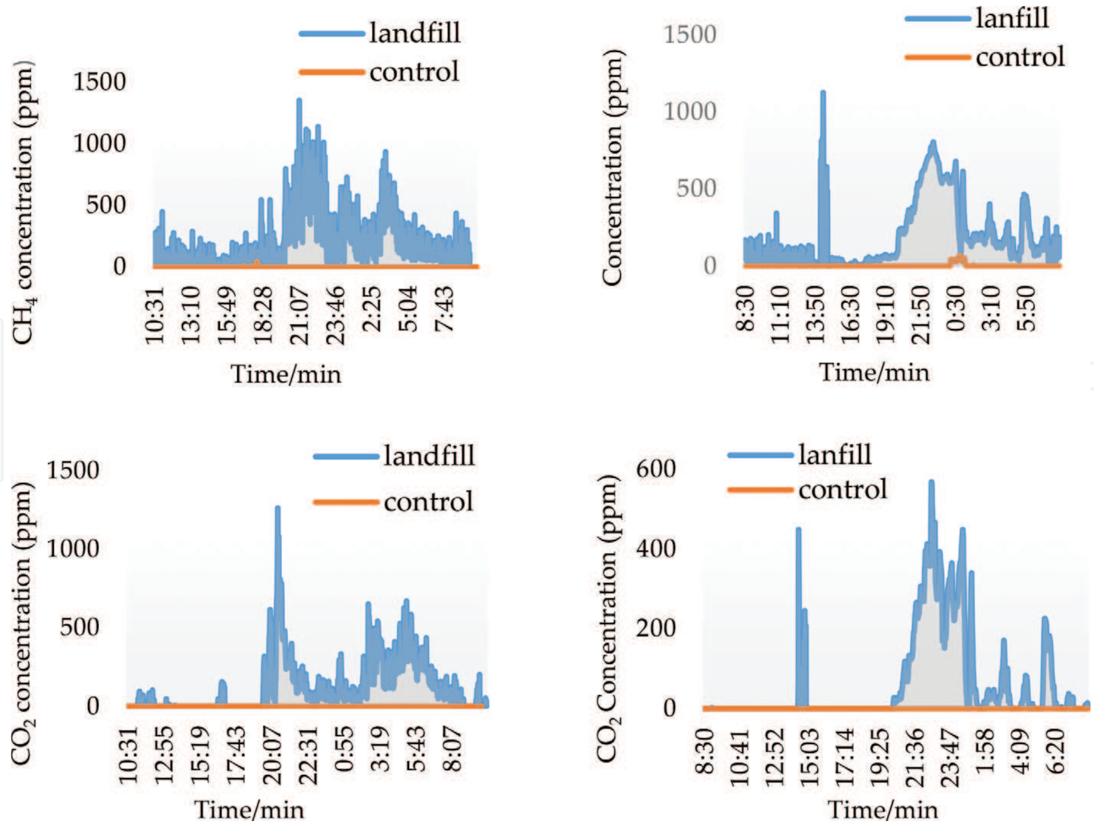

Figure 8.
Time series of hourly averaged CH_4 and CO_2 from measurements made by the Aeroqual CH_4 and CO_2 gas monitors during the wet and dry seasons.

The CIRIS make use of landfill disposal data of the year of inventory, the city's background information, the city's global warming assessment report, the city's waste composition data, and the city's landfill depth and management criteria as inputs for GHG estimation.

The GHG emissions computations are based on the total emissions from the two main repositories for the MSW of the GAMA (**Figure 1**). Both landfills are considered unmanaged and have depths more than 5 metres. The consideration of the landfills as unmanaged stems from the fact that daily covering is absent and highly inconsistent, and gases are not collected for controlled release. Although the Kpone landfill, which falls within the boundaries of the GAMA has a network of gas seams for the collection of gases, these seams have virtually been covered in the process of waste deposition into the fill, preventing the smooth release of gases, a situation which led to fire outbreak on the landfill in the second half of 2019. The other landfill (Nsumia) outside the boundaries of the GAMA, however, has no gas collection system.

There is, however, daily records and control of waste tipping on both landfills. The total MSW disposed on these two landfills in the year 2019 was 688,482.65 metric tons; 346,633.17 and 341,849.50 metric tons at Kpone and Nsumia respectively. The composition data (**Table 5**) was used for the computations. The locations of the two landfills (within and outside the city's boundaries) respectively required the use of Scope 1 and Scope 3 of the Excel tool of the CIRIS.

6.2.2 Results of estimation

The total emissions of the various GHGs are presented in tonnage of Carbon IV Oxide equivalence, tCO_2-eq in (**Table 6**). The Methane Commitment Method supports the computation of the total quantity (metric tons) of Methane (CH_4) and biogenic Carbon IV Oxide $CO_{2(b)}$ produced from the disposed waste. These values

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Component	Composition (%)
Food waste	36
Paper/cardboard	4
Wood	1
Textile	3
Garden & park waste	16
Nappies	5
Rubber/leather	1
Plastics	16
Metal	2
Glass	2
Other, inert	14
Total	100

Table 5.
MSW composition averages of the GAMA.

Scope	Disposal site	Waste quantity disposed (tons)	Methane, CH_4 (tons)	Carbon IV oxide, CO_2(b) (tons)	Methane, CH_4 CO_{2-}eq	Carbon dioxide, tCO_{2-}eq
1	Kpone landfill	346,633	14,250	39,187	356,247	39,187
3	Nsumia landfill	341,849	14,053	38,646	351,331	38,646
	Total	688,482	28,303	77,833	707,578	77,833
Total emission in carbon dioxide equivalence, tCO_{2-}eq (Tons)				785,411		

Table 6.
GHG computations from the two main landfills using the CIRIS method.

are then converted to Carbon IV Oxide equivalence, tCO_{2-e} (**Table 6**). The regions two main landfills produced 28,303 tons of CH_4 and 77,833 tons of $CO_{2(b)}$ in 2019. The total emissions for CH_4 have been converted to $tCO_{2\text{-eq}}$.

The total GHGs emissions from Scope 1 compares approximately to the emissions from scope 3 (**Table 6**). The management criteria, the MSW quantities and composition disposed of at the two main landfills remain almost equal. A total 395,434 $tCO_{2\text{-eq}}$ of GHGs are emitted from the solid waste generated and disposed on the Kpone landfill in 2019. The corresponding emission realized on the Nsumia landfill site was 389,977 $tCO_{2\text{-eq}}$. These together put the total GHG emissions arising from the MSW of the GAMA in 2019 to 785,411 tCO_2e. Methane (CH_4) accounts for 90% of the GHGs emissions with $CO_{2(b)}$ contribution as 10%. The quantity of GHGs emissions from solid waste disposal is highly influenced by the depth and the management of the landfill. A limitation of this approach at estimating GHG emissions is the possible likelihood of overestimation resulting from the assumption that all the computed methane was generated in the year of computation.

7. Implications and recommendations for system modernization

Characterizing MSW of households, markets and institutions in addition to monitoring and estimating greenhouse gas emissions from solid waste disposal practices in a lower-middle-income city of 4.63 million people is both an elaborate and quite expensive venture. It starts well when solid waste managers and local government decision-makers realize and accept that, they lack the requisite baseline data for planning purposes and are committed to bridge such data gaps. These two factors initiate the thought processes of looking for the requisite funding and the relevant stakeholders to support the participatory gathering of relevant data.

Although funding might be obtained (as the city of Accra received some funding from C40 Cities), it might not be enough to conduct a comprehensive exercise. There is therefore the need for collaboration with researchers and other local stakeholders for technical assistance and logistical support towards participatory and inclusive planning processes. In Accra, the WMD of the city had since 2015 shown commitment to work together with researchers in a locally conceived project to develop interventions to modernize the MSWM system [17].

This structural cooperation was essential to the conception, implementation and delivery of the study to this chapter. The coordinating team was able to secure some logistical support (in terms of sorting grounds and human resources to add to the numbers planned and budgeted for) from a local solid waste management company. There is no doubt, the municipalities of developing countries and economies in transition need technical assistance towards capacity building and research to sustain SWM at the local level [27].

The lead researchers and their counterparts from the municipalities of the GAMA made a firm but difficult decision during budget preparation to refuse remuneration commensurate with international best practices for such an assignment. This was necessary to ensure that the available funds could procure the necessary items for the work and pay for field staff.

Participatory action research processes that strengthens the capacity of MSWM system handlers and relevant stakeholders presents a unique opportunity and a greater potential to support cities of developing countries, to not only close their reliable MSWM data gaps, but also use such data to further assess their systems to assist them to strengthen what works and fix what is failing.

The ISWM Wasteaware framework methodology for assessing the performance of MSWM systems of cities presents an open and free-to-use shareware [28] which can be adopted for use across cites of developing countries as a starting point towards the closing of chronic MSWM data gaps [7]. The framework allows for the collection of background information of a city and baseline waste related data similar to what has been presented in this chapter. It further supports the use of a comprehensive set of indicators to measure and benchmark the performance of all cities, irrespective of their Gross National Income (GNI) levels, in both the physical components (collection, treatment and disposal, recycling) and the governance aspects (user and provider inclusivity, financial sustainability, sound institutions and proactive policies) of the MSWM systems.

The team of stakeholders has evaluated the methodological processes and the results of the characterization and GHGs monitoring exercises in the GAMA and has made the following recommendations towards further research and system improvement.

1. The training programme and the participatory action research approach (PAR) has contributed to strengthening capacities of municipal staffs towards data collection and inclusive decision-making which is essential for continuous development of locally responsive interventions based on the baseline data collected. Municipal authorities and system handlers are encouraged to continue in such participatory processes to stabilize gains, sustain data flows and possibly improve the dynamics of good MSW governance within the GAMA.

2. The use of relevant stakeholders (formal and informal service providers), researchers, municipal officials, policy makers, etc. for the MSW characterization exercise and the validation of the data provide a greater potential for data ownership and usage. We recommend the establishment of a working group of relevant stakeholders to continue with the development of interventions and action plans based on the data obtained.

3. The average daily household solid waste generation rate per capita of 0.7 kg, though lower than that of other similar cities in the developing world is of great concern; partly due to the fact that SW generation rates in lower-middle income cities like Accra is projected to increase by more than threefold by 2050 [9], against the background of population growth, urbanization, improved living standards and inadequacies in system service delivery. Decoupling generation rates from economic growth is the way to go, but that is no easy task [29]. A holistic mix of policies that addresses citizen education and awareness, responsible production and consumption, and extended producer responsibility may provide a pathway. We do not have direct answers to the problem of increasing generation rates, but a possible charging of service user fees based on tonnages generated and collected (different from what is currently practiced) can prove to be a successful intervention towards MSW minimisation in the GAMA.

4. The composition data shows that a significant amount of the city's MSW stream is putrescible organics (within household, market and institutional solid waste streams) in addition to increasing plastics. A planned diversion of these components from disposal has the potential to reduce the GHG emission burden of the current MSW handling practices.

5. We recommend further deliberations among the proposed working group towards the development of locally appropriate interventions for organic waste valorization and plastic recycling purposes. This would require an urgent development of an action plan towards diversion from disposal. The action plan may include among others:

    - introduction and piloting of a three-stream separation of biodegradable waste, plastics and all others at source (the point of generation)

    - investments into infrastructure for locally appropriate and low cost composting and anaerobic digestion [30]

    - establishment of bring-back (buy-back) centres to encourage recycling behavior

    - recognition and integration of the informal waste sector (both in the service- and value-chains to play an integral role in the collection and recycling of segregated materials

    - training of municipal staff and system handlers in the processes of recycling, composting and anaerobic digestion

    Introducing a MSW segregation process must precede with a behavioral study of the latent variables (attitudes, personal norms, subjective norms, and perceived behavioral control) and the dynamics that has the greatest potential to influence waste generators intentions towards MSW separation at source. This also means that plans geared towards the use of results based financing mechanisms as an incentive towards an efficient source separation process needs to be explored further for consideration as part of the action plan.

6. The average calorific value (7.31 MJ/kg) of the MSW of the GAMA is in conformity with the recommended threshold for consideration of the use of Waste-to-Energy (WtE) plants for the treatment of the MSW of the GAMA. But we do not recommend the adoption of such treatment (WtE) technologies, since there are many other factors which need to be addressed if WtE treatment technologies are to be adopted by cities of developing countries [31]. Some of the factors worth addressing include but not limited to:

    - the high moisture content (50%) and high biodegradable fraction (54%) of the MSW of the GAMA;

    - the relatively significant amounts of silts and fines (13%) within the waste;

    - existing inefficiencies in service delivery and the absence of an integrated and sustainable MSWM strategy

    - limited financing in the SWM sector of the GAMA

7. The average carbon to nitrogen ratio of the MSW of the GAMA is below recommended averages to support efficient aerobic and anaerobic valorization processes (composting and aerobic digestion). This can be improved upon by the addition of carbon related materials such as saw dust if valorization processes are to be considered as part of the treatment options in the action plan.

8. Soliciting for support from local stakeholders is a necessary undertaking to support the efforts of external funding organizations in such research studies. When planned well, local stakeholders can provide support in many aspects to reduce the budgetary constraints which often prevents system handlers in generating such relevant baseline data.

8. Conclusion

The Chinese Confucian philosopher Xun Kuang is credited to have written the statement paraphrased as: "Tell me and I forget, teach me and I may remember, involve me and I learn." The work in this chapter has demonstrated how participatory engagement strategies can support the planning and closing of reliable data gaps in MSW quantities, composition, chemical proprieties and GHG emission burdens of the municipalities of the GAMA; a recurring challenge for most developing countries. The average household MSW generation rate per capita for the municipalities of the GAMA is 0.7 kg per day. That for institutions is 0.83 kg per day and markets are recorded to generate 1.32 kg per stall per day. The composition of the waste has significant percentage of biodegradable (54%), plastics (16%), silts and fines (13%). Bulk density is 518 kg per cubic metre and the moisture content of the waste is 50%. The average C: N ratio is 19:1 well below the recommended 30:1 for efficient waste valorization processes. The laboratory measured calorific value of 6.74 MJ/kg is comparable to the computed value of 7.31 MJ/kg. The methodological process of gathering the data in addition to the monitored and estimated concentrations of MSWM-related GHG will support system handlers to not only replicate and update data flows but most importantly develop locally responsive interventions to address the mirage of SWM challenges confronting the GAMA and other developing countries.

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No potential conflict of interest was reported by the authors.

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