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CASE STUDY

Resource recovery potential of the Kumasi landfill waste

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Abstract
Landfill mining is an innovative way to minimize environmental pollution, secure land and airspace, and recover secondary raw materials from landfills. The study examined the characteristics of landfilled waste at the Kumasi landfill and its potential for resource recovery. Samples were collected based on the deposition age and characterized in the laboratory. Characteristics determined were composition, volatile solids, moisture content, and heavy metal concentrations. The results indicated that the most significant recoverable resources were Decomposed Organic Materials (organic waste mixed with sand and papers) and combustibles (plastics, wood, and textile), constituting 44 % and 36 % by weight, respectively. The composition of the landfill waste was found to be influenced by the components of waste initially disposed at the landfill and its subsequent age of deposition. The metal content concentration was, however, independent of the age of deposition. The results indicate that a landfill mining project at the Kumasi landfill will make available about 89 % of the landfill volume and airspace for reuse. However, the DOMs recovered may not be suitable for application as compost on agricultural soils due to the high zinc concentrations unless applied to zinc-deficient soils. It may, however, be used as construction material in earthworks and as cover materials at landfill sites. The combustible component can be combusted to generate heat for producing hot water for hospitals, hotels, and old-age care facilities.

Keywords: Landfill, Resource Recovery, Age of Deposition, Landfill Mining, Combustibles, Decomposed Organic Materials

Introduction

In most developing countries, such as Ghana, the preferred final disposal option for solid waste is an engineered landfill or dumpsite because, compared to other available technologies, they are the cheaper alternative in terms of construction, operation, and maintenance costs. Poorly managed landfills, however, contribute to soil pollution and contamination of groundwater resources. Although environmental issues associated with poorly managed landfills are a significant concern, the need for more space to dispose of the growing quantities of Municipal Solid Waste (MSW) generated once existing landfills/ dumpsites are full remains the most pressing challenge faced by most urban cities because of the extensive land resource required (Awasthi *et al*., 2017).

In Ghana's urban and peri-urban areas, landfills and dumpsites quickly fill up due to the country's high population growth rate of about 2 % per annum. At this rate, in no time, additional waste disposal space will be required, but due to the growing urbanization of these urban and peri-urban cities, land resources near cities needed for city expansion will be deemed too valuable to be utilized as landfills (Dahiya, 2015; Shin, 2014). The other option of siting landfills/dumpsites very far from the cities where land will be readily available will increase transportation distance and make haulage of MSW to the landfill very expensive and uneconomical. In preventing this, it is critical to invest in and encourage reduction, reuse, and recycling, as well as to recognize existing landfills and dumpsites as possible secondary resource storage locations and to make the required efforts to recover these resources (Greedy, 2016).

The resource recovery process from landfills is known as landfill mining. It is an innovative strategy to recycle landfill waste into resources and make the land and airspace available for reuse (Cossu and Williams, 2015; Svensson *et al*., 2010). For any potential landfill mining project to be successful, there is a need for studies on existing landfills to identify their resource recovery potential. It is vital to determine the characteristics of the deposited waste, such as composition, calorific value, heavy metal concentration, moisture content, and fixed and volatile solids, to establish the specific extractable resource and their end-use (Franke *et al*., 2010; Hermann *et al*., 2014; Hogland and Marques, 2010). Previous studies have classified waste composition from landfills into categories based on the extractable components for resources and their specific end-use. These include high calorific fraction (plastics, paper, wood, and textiles), fine material (soil), decomposed organic matter, metals, unrecoverable materials, and inorganic materials such as stones, construction waste, and glass (Franke *et al*., 2010; Gaitanarou *et al*., 2015; Jones *et al*., 2013; Krook *et al*., 2012; Svensson *et al*., 2010).

To assess the potential for resource recovery of the Kumasi landfill, this study was conducted to determine the deposited landfill waste's characteristics and establish the specific recoverable resource and possible use. Kumasi landfill is one of the few engineered landfills operated in Ghana and is situated in a fast-growing city with a rapid increase in waste generation. The results from this study will provide information on the possible resource recovery potential of landfills and dumpsites in Ghana and other countries with similar waste characteristics.

One of the challenges with this study is that the initial composition of waste deposited at the various ages of deposition is unknown, and the assumption that the waste may be of the same composition may not be valid due to changes in households' waste generation habits over time. Therefore, further studies may be needed considering the composition of the initial waste brought to the landfill.

Materials and Method

Study area

The study took place at the Kumasi landfill in Kumasi, Ghana. The facility is on 100 acres of land and consists of an engineered landfill for Municipal Solid Waste (MSW) disposal and a liquid waste treatment plant, as illustrated in Figure 1. Owusu -Nimo *et al.* (2019) provides a detailed description of the design and operation of the landfill. As of 2017, the landfill had seven cells in total. Cells 1-4 were full and capped, while cell 5 was in use, with the remaining two cells (6 and 7) yet to be used.

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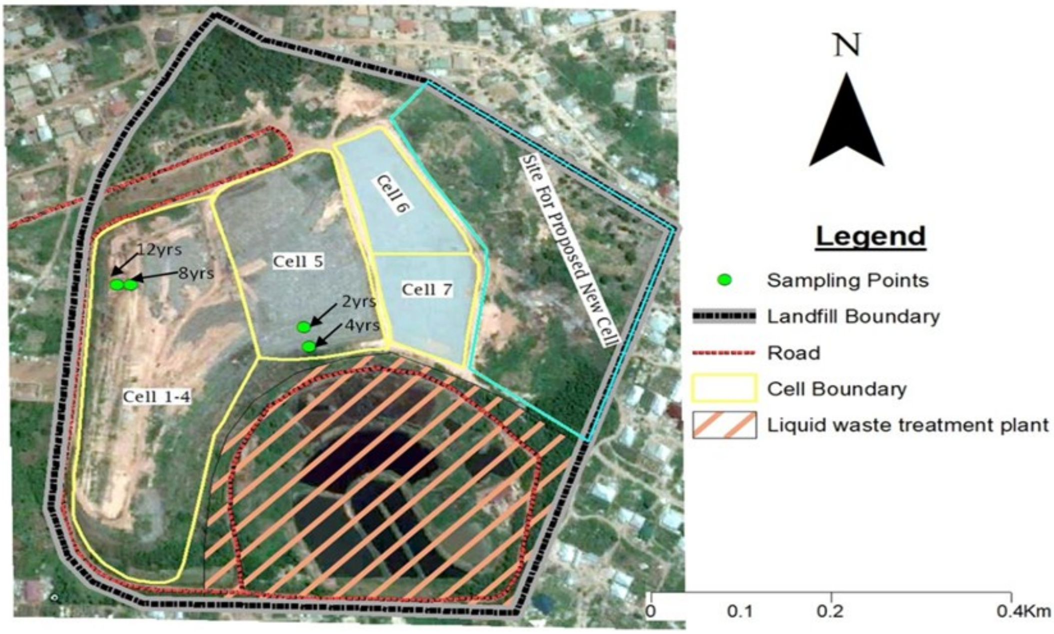

Figure 1 Layout of Kumasi landfill and location of sampling points

Sampling

Four sampling points were selected (Figure 1) for the study based on the age of deposition (2, 4, 8, and 12 years). The coordinates of the selected sampling points are provided in Table 1. The age of deposition of the landfill waste was determined from landfill waste disposal data. For the older waste (8 and 12 years), the intermediate cover material was removed before the waste was sampled. At each sampling location, five samples were collected within a depth of 800mm to obtain representative samples for the specific deposition age. A pickaxe and shovel were utilized at each sampling location to excavate and loosen the compacted waste in an area of about 0.5m^2 and within the depth of interest.

Each sample was then bagged, labelled, weighed, and transported to the laboratory for characterization studies. Twenty samples were taken from the four sampling locations and analyzed.

Table 1 Coordinates of sampling locations

Sampling Point ID	Deposition Age (Years)	Latitude (N)	Longitude (W)
S1	2	6˚ 37′ 31.4″	1˚ 35′ 31.00″
S2	4	6˚ 37′ 30.90″	1˚ 35′ 30.80″
S3	8	6˚ 37′ 32.84″	1˚ 35′ 38.28″
S4	12	6˚ 37′ 32.90″	1˚ 35′ 38.80″

Laboratory testing and analysis

Each sample's composition, volatile solids, moisture content, and heavy metal concentration were determined.

Composition

The waste samples were manually separated into the following components: wood, plastics, textiles, leather, glass, metals, organic waste mixed with sand and paper, and unwanted/ unidentifiable waste (classified as re-disposables). After sorting each sample into various components, the weight of each component (W) was determined. For each sampling location (i.e., age of deposition), the weight of each component for all five samples was added together to obtain the component's cumulative weight (W_t) for that sampling location. This was divided by the total weight of all five solid waste samples (W_T) collected at the sampling location expressed as a percentage as given in Equation (1).

Some of the waste components were further grouped into broader categories to reflect possible resources available for recovery (Yi, 2019). The broader categories were Combustibles (plastics, wood, and textile) and Decomposed Organic Materials (organic waste mixed with sand and papers), referred to as DOMs. The components grouped as combustibles were high-calorific materials that can be used as an energy source.

$$C = \frac{W_t}{W_T} X\ 100 \quad (1)$$

Moisture content and volatile solids

The volatile solids and the moisture content of the DOMs were determined. For the volatile solids, the methodology described by the US EPA of igniting the sample at 550°C was used. 50g of DOMs were oven-dried for at least 12 hours at 103^{o}C to 105^{o}C. The residue was cooled and weighed, and the moisture content was determined. The sample was then combusted at 550 ^{o}C to burn away the volatile solids. This was done for the samples collected at the four (4) sampling points. The moisture content of the DOMs was determined using Equation 2.

$$\text{Moisture Content} = \frac{Wet\ Sample weight - Dry\ sample weight}{Wet\ sample\ weight} X\ 100 \quad (2)$$

Heavy metals concentration

Heavy metal concentrations in the DOMs were determined using the atomic absorption spectrophotometer. The heavy metals tested for were Zinc (Zn), Cadmium (Cd), Copper (Cu), and Lead (Pb) because they are considered potentially toxic elements in municipal solid waste compost. After sorting and grinding into fine fractions, DOM samples were air-dried. A gram was digested using 10ml of diacid containing nitric and chloric acid. The digested sample was diluted with 50ml distilled water and filtered into sampling bottles for heavy metals concentration analysis. Each sample collected at the four sampling locations was analyzed for its heavy metal concentration.

Results and Discussion

Composition of excavated landfill waste

The landfill waste, irrespective of the age of deposition, was found to be averagely composed of 44 % DOMs (organic waste mixed with sand), 29 % plastics, 11 % redisposables, 4 % wood, 4 % metals, 3 % leather, 3 % textile, and 2 % glass as shown in Figure 2. The results show that if any landfill mining activity is carried out at the Kumasi landfill, most of the recoverable waste resources will be the DOMs and the combustibles (Plastics, Wood, and Textiles). There will, however, be a need to put back about 11 % of the waste categorized as redisposables because we may not find a use for such waste.

When the composition of waste was considered in terms of the age of deposition, more combustibles were found in the recently deposited waste (less than four years) than in older waste (more than eight years), as shown in Figure 3. As indicated in Table 2, more plastics contributed to this high percentage of combustibles for all deposition ages. However, the composition of plastics in the waste stream decreases with the age of deposition. The observed decrease in the percentage of combustibles with the age of deposition can be due to the reduced plastic content of the landfilled waste. The decreased plastic content with the age of deposition may be attributed to either waste decomposition or more plastics in the initial composition of recent waste landfilled, as Pecorini and Iannelli (2020) suggested. Analyzing the data in Figure 3 and Table 2, however, indicates that an increase in the initial plastic composition of the waste brought to the landfill is the reason for the decrease in combustibles with an increase in the age of deposition. Again, analyzing the data, it is observed that plastic waste generation rates increased by about 7 % between the deposition periods of 12 years and 8 years and remained fairly the same afterward. This may result from the increased desire for plastic-generating waste items by households.

It was also found that the DOMs increase with the age of deposition, with a more significant increase observed from 8 to 12 years of waste deposition. However, if the quantities of redisposables are added to the DOMs, the percentage composition of DOMs will remain fairly the same till the 8-year age of deposition and then increases for the 12-year age of deposition, similar to the trend found for the plastics, albeit inverse. Redisposable materials are waste materials that had crumbled due to machine compaction and could not be identified, and pieces of paper/cardboard that had been soaked with leachate.

Finally, the low percentage compositions of metals, glass, and leather, which remained almost the same for all ages of

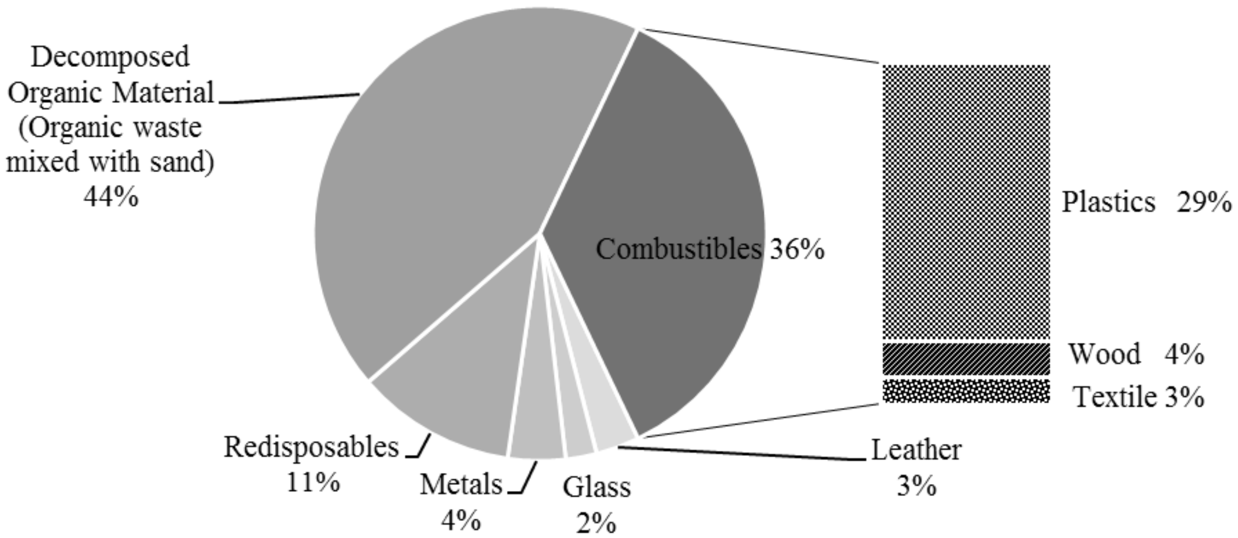

Figure 2 Composition of excavated landfilled waste at the Kumasi landfill site

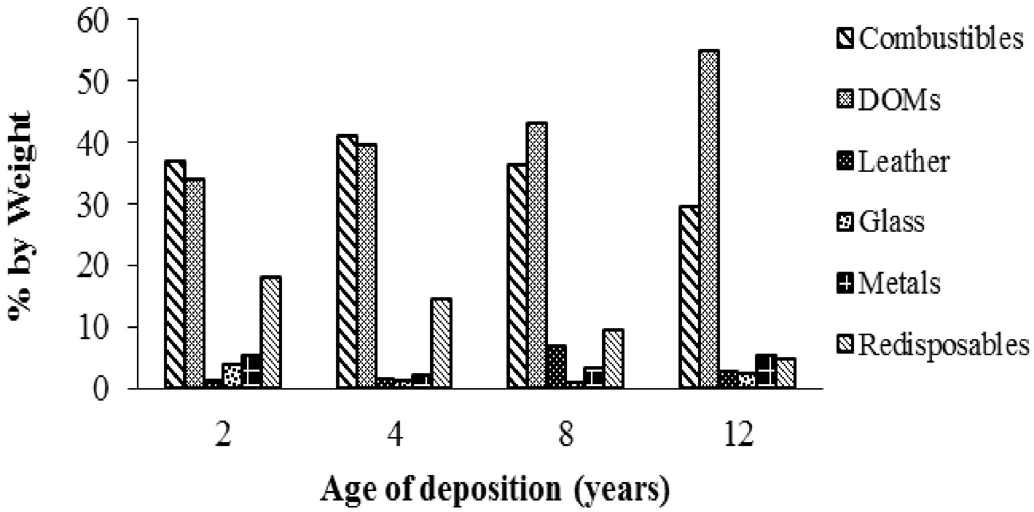

Figure 3 Composition of landfill waste for **different ages of deposition of waste**

deposition, can be attributed to the activities of scavengers as described in the studies carried out by Owusu-Nimo et al. (2019) at the Kumasi Landfill. It was observed from the study that metal and glass waste accounted for just about 5% of the total waste due to the activities of scavengers.

Characteristics of DOMs

The potential use of DOMs indicated from previous studies includes landfill cover material, construction material, waste to energy, and soil media for non-edible cropping (Hull *et al*., 2005; Jani *et al*., 2017; Quaghebeur *et al*., 2013; Zhao *et al*., 2007). Out of these examples, the precise end-use is determined by the characteristics of DOMs, such as nutrient content, volatile solids, heavy metal concentration, and calorific value, which must all meet quality standards/guideline values. The characteristics of the DOMs from the Kumasi landfill are, therefore, essential in determining its possible use.

Table 2 Percentage composition of combustibles for different ages of deposition of waste

Deposition Age (Years)	Components (%)			
	Plastics	Textile	Wood	Total Combustibles
2	32.4	1.2	3.5	37.1
4	31.9	5.7	3.4	41.1
8	30.0	2.2	4.0	36.2
12	23.1	4.3	2.3	29.7

Moisture and volatile solids content of DOMs

The moisture content of the DOMs of the landfill waste ranged from 23 % to 40.5 %. The older waste (8 and 12 years) had lower moisture content than the recently deposited waste (2 and 4 years). The amount of moisture present in DOMs is a crucial parameter for the selection of appropriate processing technology for landfill mining since it can affect processing efficiencies such as sorting with either sieving, density separation, or sensor -based methods (Parrodi *et al*., 2018a; *Hull et al*., 2005). Also, DOMs with less moisture content and less organic matter content could be a good source of cover material if the particle size distribution is determined to be within the standard. Using cover material with high to medium permeability material (compost/DOMs) than with low permeability clay material means that the degradation process of landfilled waste could be significantly faster. This is because permeable landfill cover material may enhance the aerobic biological degradation of some organic components, which degrade faster in aerobic than anaerobic conditions (Parrodi *et al*., 2018a).

The volatile solids of the DOMs ranged between 15 % to 24 %, as shown in Figure 4, and generally decreased with increasing age of deposition. Volatile solids give an estimation of organic matter yet to be biodegraded. As such, the older the waste, the more organic matter biodegradation has already occurred.

Heavy metal concentration

In assessing heavy metals concentration in landfill waste, the focus is on DOM fractions due to their high specific surface area for interaction which leads to higher levels of bioaccumulation of these heavy metals compared to the other components of the waste (Parrodi *et al*., 2018a; Parrodi *et al*., 2018b). The bioaccumulation of the heavy metals in the DOMs can be hazardous to soil properties, microorganisms, plant growth, and human and plant health. Thus, determining the heavy metals and other pollutants concentrations in the DOMs is crucial to identifying the ability to reuse this fraction for agriculture purposes or as construction material. The heavy metal concentration levels in the DOMs are a fundamental quality check parameter, mainly when the recovered waste is utilized as a compost material.

The mean concentrations of Zn, Cd, Cu, and Pb in the DOMs for the different deposition ages are given in Figure 5 (a-d). Concentrations for some of the heavy metals in the figure are below the detection limits of the equipment used. The maximum permissible limit by World Health Organization (WHO) for soil samples for each heavy metal has also been indicated with a horizontal line. These limits are 50 mg/kg, 0.8 mg/kg, 36 mg/kg, and 85 mg/kg for Zn, Cd, Cu, and Pb, respectively (WHO, 1996). The range for the concentrations of the various heavy metals was 194 – 401 mg/kg, 0.6 – 1.2 mg/kg, < 0.1 – 98 mg/kg, and < 0.1 – 80 mg/kg for Zn, Cd, Cu, and Pb, respectively.

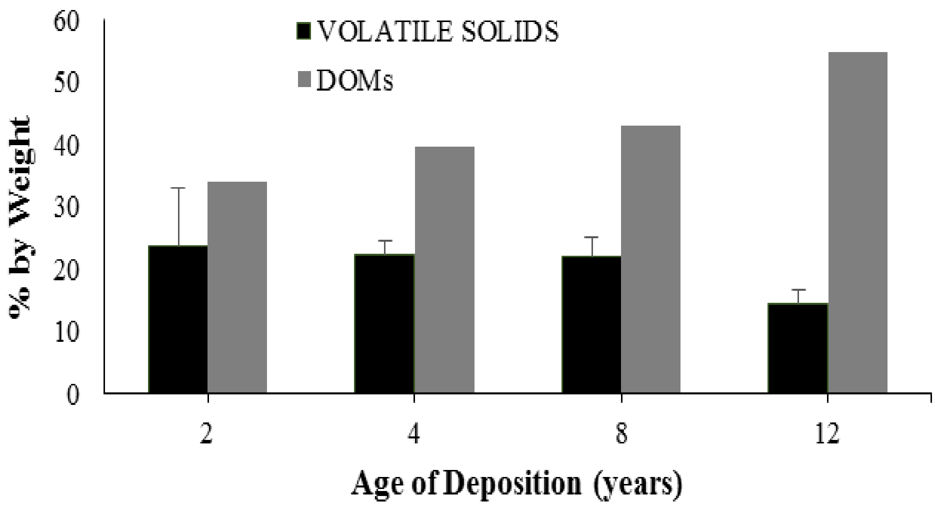

Figure 4 Variation of volatile solids content and proportion of DOMs with the age of deposition of waste

The concentration of Zn was higher than the maximum permissible levels for all the deposition ages. In contrast, that of Pb for all deposition ages was lower than the maximum permitted level. However, Cd and Cu had concentration levels in some deposition ages higher than the maximum permissible level. The concentration of heavy metals for the various ages of deposition shows no specific trends indicating that the level of heavy metals may not be due to the age of deposition but rather the initial composition of the waste. This is corroborated by Somani et al. (2020), who observed a wide variation in heavy metal concentrations in the soil-like material from landfills and attributed it mainly to the compositions of the waste deposited.

The level of heavy metals observed in the waste can therefore be attributed to the initial composition of waste deposited, which has the potential of releasing heavy metals into the waste stream. Plastics, paper, kitchen waste, ash, and other household products are the primary sources of Cu and Zn in MSW (Parrodi *et al*., 2018a; Hogland and Marques, 2010). Other sources of heavy metals include metal waste such as utensils, cans, and tins, electrical waste (cables and batteries), and petroleum and petrochemical products such as paints.

The Implication of Study on Possible Resource Recovery

The results from this study give an idea of the possible resources that can be recovered from mining the Kumasi Landfill. An analysis of the landfill waste composition revealed that the significant resource to be retrieved after mining the landfill is the DOMs. Finding a good use for these recovered DOMs will be critical in relying on landfill mining as a potential resource recovery venture. The possible uses of DOMs include utilization as compost for agricultural purposes, as construction material for earthworks, and as cover material at landfill sites. The DOMs obtained from the Kumasi landfill may not be suitable for application as compost on agricultural soils due to the high zinc concentrations found in the DOMs unless applied to zinc-deficient soils. A high Zn concentration in farming soils has health concerns since it can bioaccumulate along the food chain and cause significant stomach cramps and anemia in humans (Voet *et al*., 2013). Regarding using DOMs as construction material for earthworks, the organic matter in DOMs may cause long-term creep settlement when such DOMS are used in earthworks (Somani *et al*., 2020). The volatile solids in the DOMs indicate that the older the waste, the less the organic matter, with about 15 % of organic matter left in the DOMs after 12 years of deposition. This implies that when the landfill is mined, the older waste can be used as construction material in earthworks since most organics would have been biodegraded. The other most probable use for the DOMs may be utilization as cover materials at landfill sites. Soil materials that would have been procured and used as cover material can then be utilized for other purposes.

For the combustibles, it is observed that more combustibles by weight will be recovered in recently deposited waste (1-4 years), with plastics having the most significant fraction. Combustibles are usually utilized as an energy source, and the amount of energy that can be released depends on their calorific

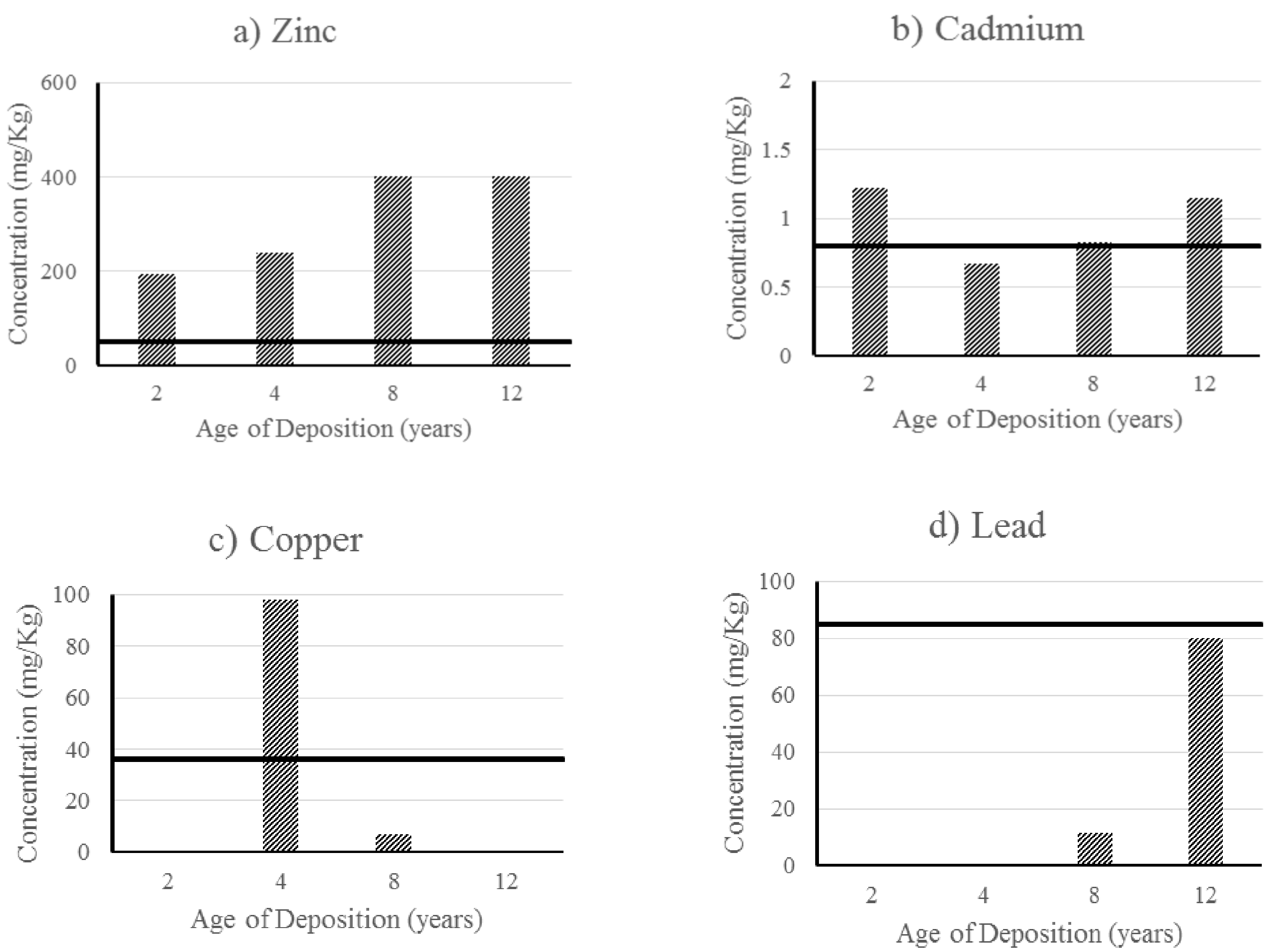

Figure 5 Heavy metal concentrations in DOMs with the age of deposition of waste

value. Although the calorific value of the combustibles was not determined in this study, the components of waste classified as combustibles are high calorific materials according to literature and have the potential to release high quantities of energy in the form of heat (Franke *et al*., 2010; Hogland and Marques, 2010; Jagodzińska *et al*., 2021; Krook *et al*., 2012). This implies that the combustibles can be combusted to generate heat for producing hot water for hospitals, hotels, and old-age care facilities. The study also revealed that the activities of scavengers at the landfill had impacted the quantities of recoverable or recyclables. However, some recoverable metals, glass, and leather can serve as secondary raw materials for industries to recycle into various products.

Finally, when excavated, the waste at the Kumasi landfill site will have about 80 % comprising DOMs (organic waste mixed with sand) and combustibles (plastics, wood, and textile). With only 11 % of the waste identified as redisposables, nearly 89 % of the landfill volume and airspace can be made available for reuse. This estimated available volume may increase further because part of the waste components classified as redisposables in this study will degrade over time and add to the DOMs. This accessible waste disposal volume will significantly help because of the scarcity and associated huge cost of allocating lands for landfilling purposes, not forgetting the cost of developing the landfill. Apart from its environmental friendliness, for a country like Ghana with other pressing needs and limited financial resources, reusing existing landfills from landfill mining will save resources.

Conclusions

The existing Kumasi landfill waste has been characterized to determine its composition based on the age of deposition. The waste comprises 44 % DOMs (organic waste mixed with sand and papers) and 36 % combustible material (plastics, wood, and textile). From the study, the composition of the landfill waste is influenced by the components of waste initially disposed at the landfill and its subsequent age of deposition. The metal content concentration was, however, independent of the age of deposition.

If a landfill mining project is completed at the Kumasi landfill, nearly 89 % of the landfill volume and airspace can be made available for reuse. However, the DOMs recovered may not be suitable for application as compost on agricultural soils due to the high zinc concentrations unless applied to zinc-deficient soils. It may be used as construction material in earthworks (especially for lightly-loaded structures) and cover materials at landfill sites. The combustible component can be combusted to generate heat for producing hot water for hospitals, hotels, and old-age care facilities. Although the age of waste deposition that will result in optimum resource recovery was not studied, the results indicate that 12 years may be the minimum years for waste deposition for optimum resource recovery.

Because the initial composition of the waste at the time of deposition was unknown, the assumption that all the waste had similar composition may not be valid. It is therefore recommended that further studies be conducted to determine the initial composition of the waste brought to the landfill.

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Conflicts of Interest Declarations

The authors declare no interests and conflict of interest whatsoever.

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