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Characteristics and management of landfill solid waste in Kumasi, Ghana

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ABSTRACT

The design and performance analysis of landfill systems require information on the characteristics of landfill waste as well as the operational activities at the landfill site. There is however limited information on the characteristics of landfill waste in Ghana. This study examined the waste characteristics and the operational management at the Oti landfill in Kumasi, Ghana. For the waste characterization, samples from different areas and depths of the landfill, representing different ages of deposition were used. Truck time studies, as well as spreading and compaction of offloaded waste at the landfill was also studied. A logarithmic relationship was found between average unit weight and age of deposition. The high content of plastics (up to 58%) in the waste stream calls for recycling to prolong the life span of the landfill. The findings on the waste composition also has implications for landfill mining in the future. The unit weight of the compacted waste ranged from 4.28 kN m^{-3} to 16.64 kN m^{-3} depending on the depth and age of waste deposition. The average compacted unit weight of 11.87 kN m^{-3} was higher than the estimated 8.83 kN m^{-3} used for the design of the landfill. The total volume of the void space available at the landfill will therefore be able to receive waste more than the estimated 15-year period. The compaction studies revealed that the compaction of waste was adequate, and that the number of compactor passes was directly proportional to the amount of waste offloaded.

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Introduction

Engineered sanitary landfills as final disposal sites for municipal solid waste is the environmentally acceptable waste disposal method to prevent environmental pollution. The development of an engineered sanitary landfill, is however, without doubt very capital intensive. It is therefore imperative that proper landfill performance analysis is done to ensure optimal use of available landfill facilities to increase its operational life. Such landfill performance analysis require knowledge and understanding of the characteristics of landfill waste as well as the operational activities at the landfill site. Dixon and Jones [4] indicated that evaluating the engineering properties of landfill waste, though very difficult due to the variety of materials present, is very essential in landfill design and assessment. The unit weight of the landfill waste, for example, is

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Table 1
Landfill void space estimation under UESPI.

Phase	Cells	Utilization years	Void space required (at 0.9 tons per m^3)	Cumulative total void space (m^3)
1	1, 2, 3, 4	2004–2008	1,301,960	1,301,960
2	5, 6, 7	2009–2013	1,440,210	2,742,170
3	8, 9	2014–2018	1,845,286	4,587,456

Source: Africon and Conterra Companies [1].

an important information required for the design and performance analysis of landfill systems [4,23]. It is affected by the composition of waste, compaction effort, waste layer thickness, the depth of burial, degree of decomposition and climatic factors [4,9,15,22]. The unit weight remains a difficult parameter to estimate and a major source of uncertainty in landfill design and performance analyses [23].

Although several studies [4,5,7,10,12,19,21,22] have been conducted to investigate the geotechnical properties (such as unit weight, compression index, void ratio, hydraulic conductivity, degree of saturation, etc.) and leachate pollutants and methane emission [13,24] of landfill waste, very little information on the characteristics of landfill waste in Ghana exist. Most of the studies on waste in Ghana has focused on the solid waste characteristics and management in the cities [2,3,11,14,16,20], and not at the landfill site itself.

As noted by Feng et al. [5], geotechnical properties of landfill waste can differ substantially from one region to another due to different waste compositions, climate conditions, operational styles, etc. It is imperative to understand the characteristics of landfill waste especially the compacted unit weight at landfill sites in Ghana so that design and performance analysis of landfill systems can be properly undertaken. This study was therefore conducted to investigate the waste characteristics and management activities at the Oti landfill in Kumasi, Ghana, and the effect on the lifespan of the landfill. This landfill is one of the very few engineered landfills being operated in Ghana and it is in a fast-growing city with the resultant increase in waste generation.

The paper establishes the variation in composition and unit weight of the landfill waste with depth and age of deposition. In terms of operation and management activities the research focused on truck time studies, and the spreading and compaction of offloaded waste at the landfill site. This study is very important because it provides information required for the proper design, development and sustainability of landfill facilities in Ghana and other countries with similar waste characteristics. Specifically, it provides a better estimate of the unit weight with depth and age of deposition that can be used in landfill designs in Ghana and other African countries.

Current status of the Oti landfill

Study area and design of the landfill

The study was conducted at the sanitary landfill called the Oti Landfill in Kumasi, Ghana. Kumasi is the second largest city in Ghana and has an estimated population of 1.73 million inhabitants from the 2010 Population and Housing Census in Ghana [6]. The landfill covers a land area of 40 hectares with 60% of the overall site area expected to be filled during the working life of the landfill. The landfill cells were designed to be developed in three phases (Table 1). The layout of the cells arrangement of the landfill is shown in Fig. 1. The design concept was to fill the site in phases so that areas can be completed and returned to vegetated state as soon as possible after filling has been completed and capped. The first 4 cells constituting Phase 1 was completed under Urban Environmental Sanitation Project Phase One (UESP I) and commissioned for use in January 2004 and estimated to be filled with waste in five years. The fifth cell was constructed under Urban Environmental Sanitation Project Phase Two (UESP II) in 2012 to provide airspace for waste disposal pending fund availability for the development of the full scale of Phase 2.

The cells for each phase were arranged to correspond to the volume required for at least a 5 years filling cycle per the phase and layered filling pattern adopted. The four cells constructed under Phase 1 was almost filled up at the time of study. The fifth cell constructed in 2012 was in use at the time of the study. The landfill was originally designed to accommodate the full waste stream to be deposited for 15 years design life starting from 2004. It was estimated that a total of some 3.53 million tonnes of waste would be deposited over the 15 years design life. Using an in-situ landfill density of 900 kg m^{-3} and a volumetric cover to waste ratio of 1:6, it was estimated that the total airspace required would be 4.6 million m^3. Based on the landfill height of 27 m, land space of the cells and waste generation volume, the total volume of the void space available was estimated as 4.58 million m^3, which is forecasted to be sufficient to meet the needs of Kumasi for 15 years.

Operation of the landfill

The landfill facility consists of a weighing bridge (not operational at the time of study) and guard house, an office building, waste cells, septage treatment ponds system, and workshop/yard. The septage treatment ponds are for treating the leachate from the landfill in addition to faecal sludge from the city. The septage ponds are located at the lowest elevation

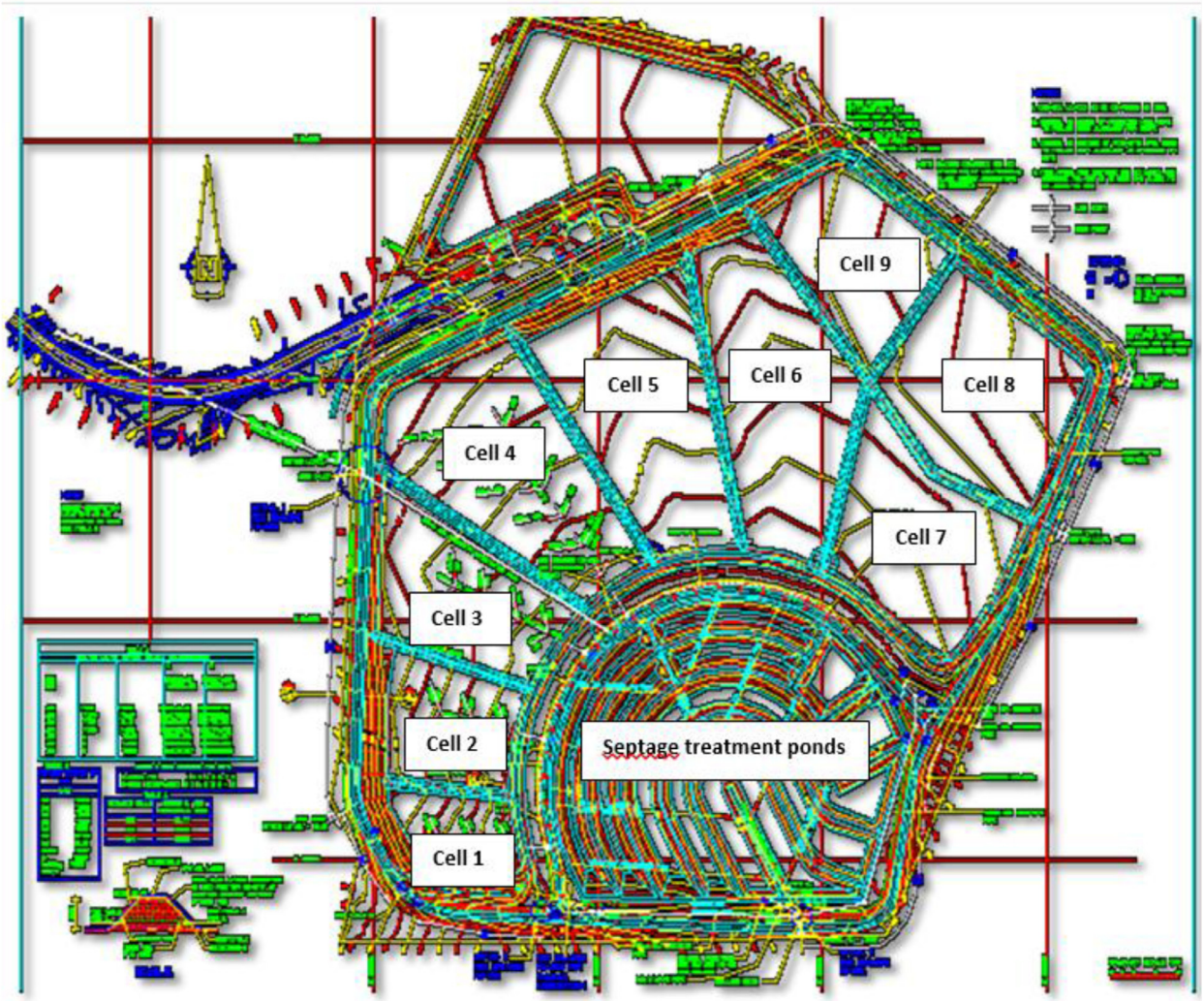

Fig. 1. Layout of Oti landfill showing the cells arrangements. *Source*: Africon and Conterra Companies [1].

of the site. The facility is currently managed by a private company under a management contract and supervision of the Kumasi Metropolitan Assembly.

The landfill operates every day of the week from 6 am to 6 pm with a lunch break between 1 pm and 2 pm for the personnel. On a normal operational day, the landfill is closed to waste delivery trucks at 5pm and the remaining hour is used to tidy up the site. The period for accepting waste is extended when accumulation of waste occurs at the transfer stations or communal collection sites. Night operations are not part of the normal working schedule but when waste is piled up in the metropolis, provision is made to operate at night. The facility is locked at the close of operation and a security man at site takes care of the place.

Tasks carried out in the morning prior to the arrival of waste trucks at the landfill site include: maintenance of compactor equipment, fuelling, preparation of working face of the unloading areas, and cleaning of roads. The equipment used at the site include landfill compactor, dozer, tipper truck, water cart, road grader, excavator, and a utility vehicle. The landfill employs 25 personnel who work at the site daily. The weight of the waste and the names of the locations where the waste is collected are supposed to be recorded at the control room, but this is not done. The landfill does not accept hazardous or pathological waste. Solid waste deposited is compacted using a dozer and a compactor. As is the case in many developing countries, informal waste picking is carried out by people who scavenge through the waste looking for scrap metal, plastic bottles or anything they can salvage to sell. Oduro-Kwarteng and van Dijk [14] revealed that the solid waste collected in Ghana is disposed of at the landfill without recycling to reduce the amount of waste sent to the landfill. The low recycling rate and the little diversion of waste from the Oti landfill shorten the life span of the landfill, despite the increasing scarcity and difficulty in acquiring land for sanitary landfill development [20].

Table 2
Description of constituents of each component used for waste characterization.

Waste component	Description of constituents
Plastic	Plastic bags, poly ethylene, black bags, plastic bottles.
Organic/inert residue	Food particles, humus, wood, plant organics, and inert material
Textile	Fabric, hair, sanitary pads
Paper	Paper scraps, newspaper, cardboard, bags, wrapping paper
Metal	Cans, foils, tins
Glass	Bottles, broken glassware, coloured glass

It was revealed from the study that there was no daily covering of waste as recommended in the operations manual provided by Africon and Conterra Companies [1] who designed the landfill. From interaction with the landfill manager, it was noted that the waste used to be covered daily when the landfill started operating and decreased to weekly. Currently, it is only covered occasionally.

Materials and methods

Sampling and waste characterization

The ages of the deposited waste at the landfill was estimated based on the operational time of filling the cells. Different points on the landfill site representing different ages of waste deposition were therefore selected for composition and unit weight determination. The ages of deposited waste which were accessible were four months, one year, two years and four years. At each selected point, samples were taken by excavating the in-situ landfill solid waste materials at depths of 0.38 m, 0.76 m, 1.14 m and 1.52 m. This was the maximum depth we could access due to the nature of the waste and the type of equipment used for the excavation.

For each of the depths, the total excavated samples were bagged, sealed, labelled and sent to the lab for weighing and characterization. The composition of the samples obtained from the landfill waste was classified into plastic, organic/inert residue, textile, paper, metal and glass. The proportion of each of the components of the landfill waste was determined by weighing each component separately. A description of the constituents considered for each of the components used for the waste characterization is provided in Table 2.

Determination of unit weight of landfill waste

The unit weight of the landfill waste was determined from “undisturbed” samples obtained using a metallic cylindrical pipe of diameter 150 mm and length 380 mm with a sharp edge. The same points and depths used for the waste characterization was considered for the unit weight determination. At the point and depth of investigation, the soil cover, if available, was first removed and the pipe was driven into the landfill waste with a hammer until the pipe was driven fully into the waste. The driven pipe and its content were removed by excavating around it. The content in the pipe was emptied into a plastic bag, sealed, labelled and sent to the lab for weighing and moisture content determination.

Truck time and compaction studies

The various trucks tipping waste at the landfill site were noted and each of the truck types identified was given a special code. Time studies were then conducted from morning till evening (8 am–3 pm) to observe the arrival, unloading and departure times of each truck type. The number of each truck type arriving at the landfill site every hour was counted, and their waiting and at-site times were estimated from the time studies. The waiting time refers to the time between arrival of waste truck and offloading of waste at the landfill whiles the at-site time refers to the time between arrival and departure of waste truck at the site. The unloading time refers to the time between when the truck is admitted to the unloading area and when it leaves the unloading area. The peak hour at the landfill site was also determined from the time studies. The operation of the landfill involving the spreading and compaction of offloaded waste at the working face of the landfill was also studied.

Results and discussion

Landfill waste composition

The results of the composition of the landfill waste are presented in Fig. 2. The results show the putrescible organics decreased over time due to decomposition. The fraction of decomposed putrescible organics decreased from 47% after four months, to 33% after four years of deposition. In a study conducted by Rockson et al. [17], in which fresh solid waste brought to the landfill site was characterized, the results indicated that putrescible organic waste constituted the highest fraction of

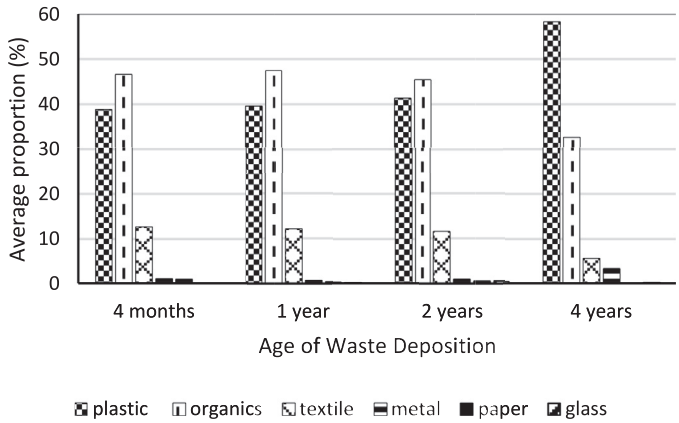

Fig. 2. Composition of deposited waste in the landfill.

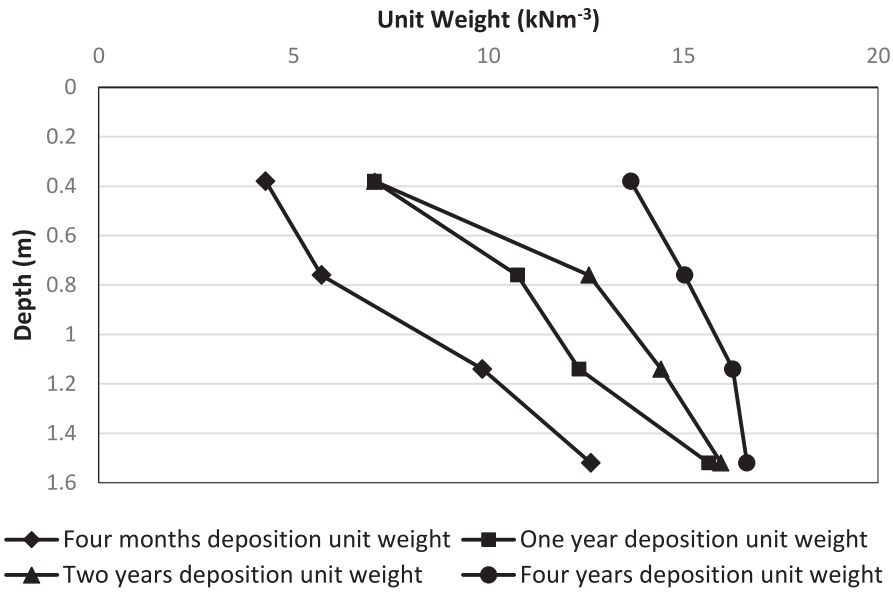

Fig. 3. Variation of unit weight with depth and age of waste deposition.

the waste (40.32%) whiles the inert fraction of waste which consists of sand, fine organics and ash on average was 20.9% of the waste. The difference in the organic and the inert obtained by Rockson et al. [17] and this study may be due to the decomposition of the food waste and activities of scavengers at the site.

As the putrescible organics decay with time, the proportion of plastic waste increases since plastics do not decompose and thus their proportion of the total waste increases with time. The composition of plastic was thus found to increase from 39% for four months old deposition to 58% after four years of deposition. After complete decomposition the waste body will be mainly plastics and inert materials which has implications for landfill mining.

The results of the composition of the landfill waste showed that the metal and glass waste accounted for just about 5% of the total waste. This small amount of inorganic waste in the landfill can be attributed to the activities of scavengers. The scavengers at the landfill site pick the metals (soft drink cans, tin containers, lids), glassware and electrical waste from the municipal solid waste brought to the landfill. The inorganics usually left are the broken glass bottles and those not desired by the scavengers.

Variation of unit weight with age and depth

The unit weight of landfill waste was found to vary with depth and age of deposition (Fig. 3). It increased from as low as 4.28 kN m^{-3} for a four-month old waste (at a depth of 0.38 m) to as high as 13.6 kN m^{-3} for a four years old waste (at the same depth of 0.38 m). For about the same age of landfill waste, the unit weight was found to increase with depth. The waste at the upper part of the landfill had lower unit weights because of the absence of overburden pressure. The unit

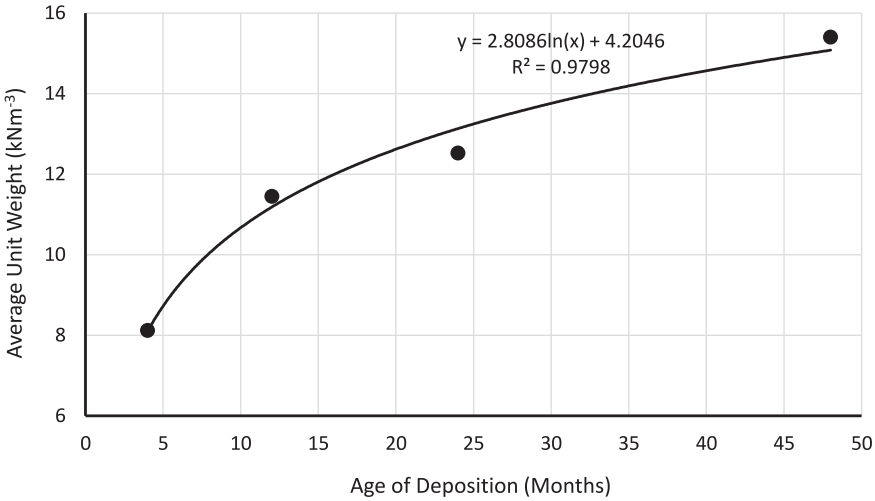

Fig. 4. Variation of average unit weight with age of waste deposition.

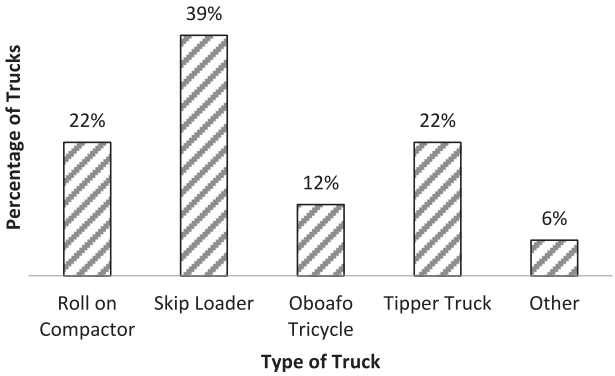

Fig. 5. Percentages of truck types delivering waste to the landfill site.

weight however increased with depth due to increase in the overburden pressure, and this was consistent with finding of Zekkos et al. [22]. Coupled with overburden pressure, the rate of decomposition at the underlying layers was higher than on the upper layers. Decomposition creates voids within the waste material which leads to compressibility because of the overburden pressure and results in higher unit weights with depth. Compaction of waste on site was also a contributing factor to the high unit weight at greater depths. A logarithmic relationship (Fig. 4) with a coefficient of determination (R^2) of 0.98 was found between the average unit weight and age of deposition. This relationship suggests that the unit weight of landfill waste increases rapidly at the early stages of deposition till a period and then the rate of increase in unit weight decreases.

Truck time studies

The truck types identified to deliver waste to the landfill site include roll on compactors, skip loaders, tipper trucks, and motorized (oboafo) tricycle. Other vehicles such as poultry van and agricultural tractors were classified as 'other'. Fig. 5 shows the percentage of truck types delivering waste to the landfill site daily. The skip loader was the truck type that mostly delivers waste to the site.

Although a total number of 69 trucks were counted during the study hours of 8 am–3 pm, the supervisor at the site indicated that an average of 120 trips of waste is deposited at the landfill site each day. The number of trucks arriving at the site every hour is shown in Fig. 6. The peak hour for arrival of waste trucks was between 8:30 and 9:30 am with an average of 15 trucks.

The landfill area was designed to allow free flow of trucks in and out of the facility. The average waiting times and at-site times for the truck types is given in Table 3. In terms of waiting times, tipper truck had the highest average waiting time whiles the uncommon waste delivery trucks classified as other, had the highest unloading and at-site times.

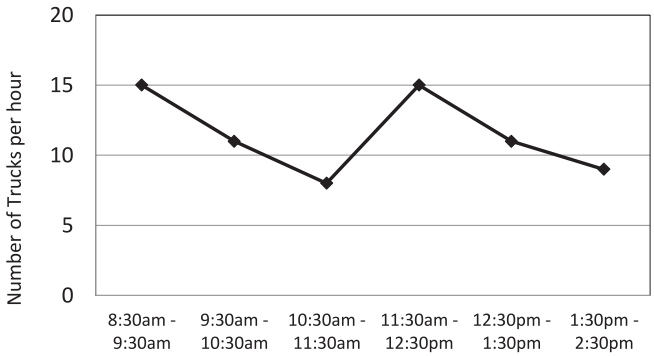

Fig. 6. Number of Trucks per hour arriving at landfill site.

Table 3
The average times of various truck types delivering waste to landfill site.

Truck type	Average waiting time (minutes)	Average unloading time (minutes)	Average at site time (minutes)
Roll on compactor	2.67	3.07	7.07
Skip loader	2.58	2.25	5.52
Motorized tricycle	1.78	3.38	6.75
Tipper truck	3.23	2.92	7.38
Other	0.50	4.25	8.00

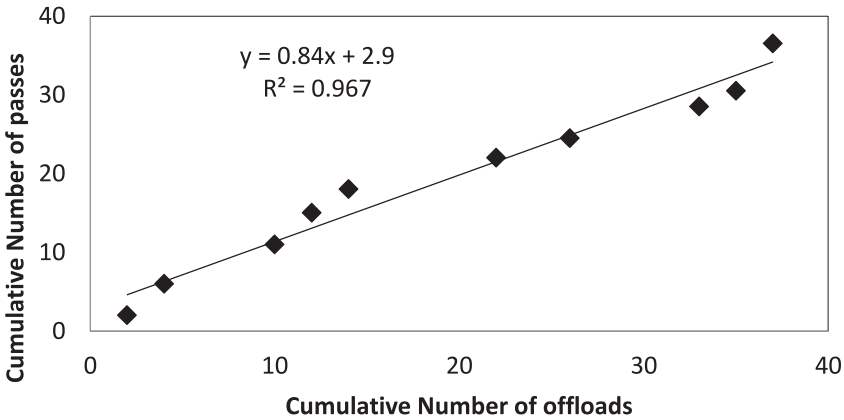

Fig. 7. Cumulative number of passes against cumulative number of offloads.

Landfill waste compaction studies

The waste deposited is usually spread and compacted. From the compaction studies, it was observed that the spreading and compaction of the offloaded waste was not standardized but based on the discretion of the compactor operator. The operator however ensured that too much waste is not accumulated before compacting. The degree of compaction achieved depends on the number of offloads and number of passes. UNEP [18] indicated that an operator can combine different loads of different materials to achieve high compaction densities. A procedure could be combining low-density, dry materials (such as paper or textile waste) with high-density, moist wastes (such as restaurant or market residues). This mixing of waste was not practiced at the Oti landfill site because of several reasons. One of the main reasons is that the waste brought to the site were not identified but were just offloaded at random. Also, most of the waste brought to the site are already mixed up from the transfer station or source.

Fig. 7 shows the cumulative number of compactor passes against the cumulative number of offloads in three consecutive hours. The relationship between the cumulative number of passes and the cumulative offloads was found to be linear ($y = 0.84x + 2.9$) with a coefficient of determination (R^2) of 0.97. This indicates that, although the compaction was at the discretion of the operator, the number of passes of the compactor was directly proportional to the amount of waste offloaded. It was observed that the maximum number of compactor passes after a few offloads were six. According to UNEP [18], although additional passes result in higher compaction, the return for the effort diminishes beyond six passes, and an experienced operator knows when additional passes will result in greater compaction. A well compacted landfill can

achieve densities higher than 1000 kg m^{-3} leading to efficient utilisation of airspace. Waste densities less than 700 kg m^{-3} significantly reduce landfill efficiency and increase the risk of landfill fires [8].

It must be noted that, even though the relationship is between number of passes and number of offloads, the operator compacts based on the amount of waste disposed and not the number of offloads. The variability in the relationship developed might be due to the number of offloads not proportional to the amount of waste since the waste trucks were of different sizes.

Implications of findings on Oti landfill

The results of this study have implications for improving the design, operation and possible mining of Oti landfill and other landfills in areas of similar waste characteristics. From the Oti landfill design, cells 1 to 4 were estimated to be filled in 5 years. It however took 9 years (from 2004 to 2012) for it to be filled. The reasons were that:

- The volumetric cover to waste ratio of 1:6 was used in the void space estimation but in practice this was not done due to operational difficulties and limited funds to pay for cover material haulage cost.
- The density of 900 kg m^{-3} used for the design was less than the average compacted density of 1210 kg m^{-3} (11.87 kN m^{-3}) obtained from this study resulting in an under estimation of the design life.

The total volume of the void space available at the landfill will therefore be able to receive waste more than the estimated 15-year period. This information will help in the future economic planning and development of landfills in Ghana. Specifically, using correct unit weight values specific to Ghana and other countries with similar waste characteristics will enable the correct estimation of the space required for landfill over the expected design life. It will also inform landfill managers on how much to levy for waste disposal at the site over its life span.

The findings on the waste composition show that after complete decomposition the waste body will be mainly plastics and inert materials which has implications for landfill mining in the future. Mining of the landfill will make airspace available for landfilling to take advantage of the proximity of the landfill to the city of Kumasi. The decomposed organics and inert could be used for landscaping and land reclamation purposes whiles the plastics could be recycled or incinerated for waste-to-energy. However, further studies need to be carried out on the cost effectiveness of the landfill mining and the uses of the mined products. There is also the potential for waste diversion and recycling of plastics prior to landfilling. This will save landfill space for prolong use of the landfill.

In terms of landfill operation, the consequences of the absence of the daily cover have been flies, rodents and odour nuisance around the site which has health implications. In terms of waste compaction, the absence of the daily cover reduces the inert component of the waste and the compacted density achieved.

Conclusion

Landfill waste characteristics were conducted to examine the waste composition, unit weight and compaction at the Oti landfill in Kumasi. The plastic content with respect to the total landfill waste was found to increase with time and that of putrescible organics decrease with time due to decomposition. The high content of plastic waste in the waste stream calls for recycling of plastics to prolong the life span of the landfill, by making more volume or airspace available. The findings on the waste composition also has implications for landfill mining in the future.

A logarithmic relationship was found between average unit weight of compacted waste and age of deposition. The unit weight of the landfill waste determined ranged from 4.28 kN m^{-3} to 16.64 kN m^{-3} depending on the depth and age of waste deposition. The average unit weight of 11.87 kN m^{-3} was higher than the estimated 8.83 kN m^{-3} used for the design of the landfill. The total volume of the void space available at the landfill will therefore be able to receive waste more than the estimated 15-year period. This information will help in the future economic planning and development of landfills in Ghana.

Finally, the compaction studies revealed that the compaction of waste was adequate, and that the number of compactor passes was directly proportional to the amount of waste offloaded. The absence of daily cover however reduces the compacted density achieved.

Conflict of interests

The authors declare there are no interests to declare and no conflict of interest whatsoever.

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