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Assessing the Fertilizer Utilization Potential of Municipal Solid Waste in Akosombo, Ghana

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Authors' contributions

This work was carried out in collaboration between all authors. Authors SJC, RK, SBD designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript and managed literature searches. Authors WA and ABD analyzed samples and helped in literature searches. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

Currently waste managers are unable to keep pace with the waste generation rate hence shank of solid waste are uncollected in both dumping sites and open spaces. The study was conducted to assess the fertilizer utilisation potential of solid waste generated in Akosombo Township. Samples of solid waste were collected from market, slaughter house, dustbins, drains, truck and dumping site during a dry and wet month for analysis. The samples were weighed and segregated into organic and inorganic components. The organic component was thoroughly mixed, shredded and sieved for laboratory analysis. Proximate and ultimate analyses were conducted to obtain the chemical characteristics of the solid waste. The study recorded an average organic material of 70%, making the municipal solid waste suitable for composting because of the presence of high percentage of biodegradable organic matter. The C/N ratio obtained ranged between 11-29: 1 making the solid waste generated suitable for bio-chemical conversions. The study revealed that fertilizer utilisation potentials from solid waste at Akosombo looks promising as most C/N ratio obtained fall within the respective range of 25:1 to 30:1 suitable for fertilizer production. Based on the findings of this study it is recommended that plants that can use solid waste for fertilizer production should be provided to harness the potentials of solid waste.

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1. INTRODUCTION

The accelerated growth of population coupled with urbanization and increasing economic activities has made the menace of solid waste noticeable in the capital cities of Ghana. The urban areas in Accra produce about 760,000 tons of municipal solid waste (MSW) per year or approximately 2000 metric tons per day [1]. According to the EPA report, by 2025, this figure is expected to increase to 1.8 million tons per year, or 4000 metric tons per day. These are estimates and the real values are probably more than these quantities. According to Government of Ghana and Ministry of Local Government and Rural Development [2] Accra Metropolitan Assembly spends about two billion cedis per month (about $227,000) on only waste collection and about 12 billion cedis per year on urban solid waste management. This amount does not however cater for about 30 percent of solid waste in the metropolis [1]. Wastes that we discard and suffer the consequences of improper management are of course partly huge energy and fertilizer sources that can greatly support energy demands of the growing population. Urban waste disposal is a serious challenge in all cities in the developing world and its accumulation is an additional health hazard [3]. Design and optimization of solid waste management technologies and practices that aim at maximizing the yield of valuable products from waste, as well as minimising the environmental effects have had little or no consideration in the Africa region [4]. The enormous increase in the quantum and diversity of waste materials generated by human activity and their potentially harmful effects on the general environment and public health have led to an increasing awareness about an urgent need to adopt scientific methods for safe disposal of waste. Waste generation rates are affected by socio-economic development, degree of industrialization and climate [5].

Globally, so much effort is being channelled towards developing processing technologies to release the resource and economic value of residual wastes as population grows. The effectiveness of solid waste management is of great importance for people's health and environmental protection [6]. Litter is an important factor in environmental pollution caused by excessive consumption in big populations with increased birth rates, resulting in the generation of millions of tons of organic waste, mainly from household waste [7,8]. The implementation of a treatment for the proper management of organic waste is of great importance, because of the benefits that will help to improve human activities like agriculture and the mitigation of negative impacts on the ground, preventing the wear and loss of the production capacity, that leads to the generation of infertile soils with problems of recruitment of both water and nutrients, and therefore, the loss of the organic layer which is indispensable to sustain plant life [9]. Municipal refuse in majority of developing countries contains more than 40% organic materials, which can be converted to useful material or energy by waste transformation processes [10].

The Organic Fraction of Municipal Solid Waste (OFMSW) has by far the highest moisture content of any constituent in MSW, but the moisture is rapidly transferred to absorbent materials such as newspapers as soon as contact is made. OFMSW also tends to be well mixed in waste and therefore it is difficult to find identifiable bits of OFMSW in mixed refuse other than the large pieces. Garbage is even better distributed in municipal solid waste if the waste is shredded. Anaerobic digestion and composting are broad-spectrum transformation processes, where the specific organisms responsible for the bioconversion of waste into useful products, particularly energy and fertilizer [11]. Lack of resources and ability to plan and implement sewage systems, liquid and solid waste management and other sanitation issues are difficult to manage in developing countries, where houses often are built before sewage systems and other infrastructural necessities. The problem of waste in Ghana is also a direct result of a growing urban population, the changing patterns of production and consumption, the inherently more urbanized life-style and industrialization [6]. Composting is described as an economically viable method compared with other processes and also effective in contributing to the reduction in the amount of material that should be taken to the landfill [12]. Dulac [13] pointed out that the high organic content of the waste streams of developing countries is ideal for composting, but municipal services operators do not have enough and adequate information and even though they may be familiar with the application of composting in agriculture, it is not considered as a way to solve their urban wastes problems. Bogner et al. [14] indicate that labour-intensive processes are more appropriate and sustainable for those countries than highly mechanized technological alternatives at large-scale operations.

In Africa there are few formal systems for material recovery instituted by public agencies or the private sector. Recovery of materials, including source separation and recycling is carried out mainly by the informal sector. This activity is centered on materials of economic and/or social value; plastic bags, bottles, paper, cardboard and cans are reused before entering the waste chain. A few materials are converted into new products for local use; some examples are the smelting of aluminum cans and scrap metals into household utensils, and paper and plastic residues into products for tourists [15].

In Akosombo, citizens dispose of tons of waste per year. Currently, solid waste in the town is disposed by dumping at a site located at the edge of the town. Dumping of waste is the oldest and the most widely used form of waste disposal method in Africa and other developing countries. Ghana as a developing country is faced with the problems of waste disposal and waste management. This has called for an immediate sustainable waste management process which can benefits the society. The garbage fraction of refuse varies with geographical locations and seasons. Dietary habits, affect its compositions and quantity, as does the standard of living. The solid waste matter is a structural problem that requires great investments. The use of organic matter for fertilizer from Municipal Solid Waste (MSW) will improve the environment through the proper waste management, preservation of water bodies, poverty reduction and creation of sustainable development. The main objective of this study was to assess the fertilizer utilisation potential of solid waste generated in Akosombo Township.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted in Akosombo (Plate 2) in the Asuogyaman District in the Eastern region, Ghana (Plate 1) where the country's largest hydropower station is found. Located 100 kilometers north east of the national capital, Accra, the township of Akosombo spreads through valleys and hilltops, covering an area of over twenty-six square kilometers. Akosombo is the home of a predominantly migrant population of about 15,000 from all parts of Ghana and beyond. It is mainly made up of Volta River Authority (VRA) estates with a population of about 0.22 million. Situated at the south west of the Volta basin, the township lies on latitude 6º16'0.47"N and longitude 0º2'40.75"E [16]. Towering over the township are the rolling hills of the Akwapim and Togo ranges, which converge to form one of the narrowest gorges along the river. The highest temperatures occur during the peak of the dry season between the months of March and April, while the lowest temperatures are recorded in the wet months lasting from May to August. The rainy season holds its own unique attraction, beginning and ending with spectacular tropical storms, characterized by lightning, illuminating the hills in a kaleidoscope of dazzling colour. The Eastern Region harbours the two major hydropower plants in the country, found in Akosombo and Akuse.

Plate 1. Map of Ghana

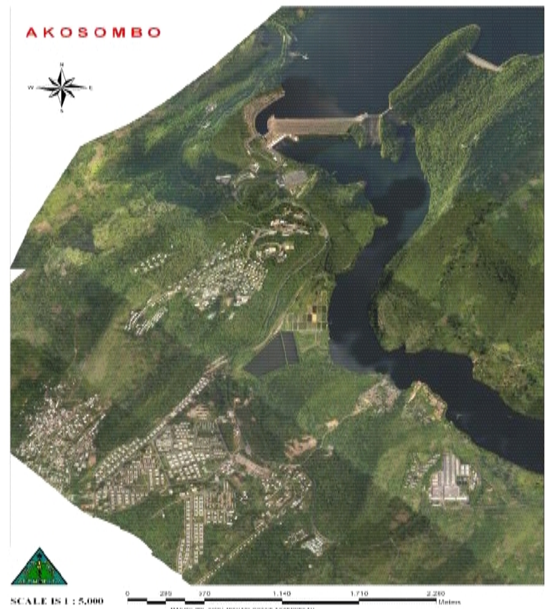

Plate 2. A layout of Akosombo Township

2.2 Sample Collection and Analysis

Solid waste characterization methods used was in accordance with US EPA [17] and Shukla et al. [18]. Random sampling was used to collect samples directly from six waste temporal and final disposal sites; dumping site (Plate 3), trucks, dustbins, market, slaughter house and drains for the characterization of Municipal Solid Waste (MSW). Seasonal conditions were considered as Akosombo has two main seasons: wet and dry seasons. A total of twelve (12) samples were collected from the township within the months of December, 2012 (dry month) and May, 2013 (Wet month). The target size of the sample weight for this research was about 10 kg throughout the two sampling months. The solid waste samples were collected into polythene bags and labelled. Interviews were conducted to obtain information on how the waste at home and office were handled at the source and the type of waste they generate in relation to their life style (culture), food type consumed and perception towards waste.

The samples were transported to the Ghana Atomic Energy Commission laboratory, Accra and stored in a fridge at 4ºC. Determination of solid waste material composition was done by way of physical segregation (manual sorting) and observation of collected solid wastes components. Each bag of waste was weighed and then its contents emptied, sorted and weighed again (Plate 4). The weight of the collected solid waste samples was measured and percentage (%) composition was categorized into ten major groups. The organic components was thoroughly mixed, shredded and sieved to a quality size of < 2 mm for the laboratory analysis.

2.3 Proximate and Ultimate Analysis

This was done in accordance with Banks [19] who conducted proximate analysis by looking at moisture, volatile matter, ash and carbon. Moisture content was determined by drying well mixed samples in an oven at 105ºC for 24 hours and expressed as a percentage of total weight. The volatile solids content of organic matter was determined on the dried sample taken for the moisture content test by measuring loss on ignition at 550ºC for 3 hours using a muffle furnace. The ultimate analysis provides the major elemental composition (C, H, O, N and S) contained in the sample, reported on a dry and ash-free basis. Compositions were experimentally determined using head space analysis and calourmetric method. Carbon, hydrogen and nitrogen were determined by burning the sample in oxygen (at about 1000ºC) in a closed system and quantitatively measuring the combustion products.

The carbon includes organic carbon as well as carbon from the mineral carbonates. The hydrogen includes organic hydrogen as well as any hydrogen from the moisture of the dried sample and mineral hydrates. Sulphur is determined by burning the sample in oxygen at a minimum temperature of 1350ºC in a closed system and quantitatively measuring the sulphur oxides formed. Oxygen is determined by the difference between 100 and the sum of the percentages of C, H, N and S. All these measurement and procedures are standardised in accordance with American Society for Testing and Materials (ASTM) approach. The ash was determined by the weight of residue after open burning in the crucible. The C: N ratios for the different waste subsamples were calculated to find out whether variation in waste composition had any effect on such waste stream factors.

Plate 3. Dumping site at Akosombo

Plate 4. Sorting process

3. RESULTS AND DISCUSSION

3.1 Composition of Solid Waste in Akosombo Township

The study revealed that food waste, paper and card and plastic and rubber waste are of higher proportion in terms of composition from the sorted solid waste from the study area (Table 1). The solid wastes generated from all the sampling sites are heterogeneous in nature. The high proportion of food, garden trimming, animal droppings and wood waste is due to the fact that Ghana's economy largely depends on agricultural products for export and domestic consumption. The understanding of the composition of solid waste generated in the Akosombo will indicate the management methods and the kind of technology that will be used to harness the economic value of waste. The waste generated from Akosombo shows typical characteristics of solid waste (Table 1).

Solid waste consists of many different materials, some are combustible and some are not, some can be recycled and some cannot. Solid waste is composed of combustibles and non-combustible materials. The combustible materials include paper, plastics, yard debris, food waste, wood, textiles, disposable diapers and other organics. Non-combustibles also include glass, metal, bones, leather and aluminium [20]. A major source of putrescible waste is food preparation and consumption. As such, its nature varies with lifestyle, standard of living and seasonality of foods. Fermentable wastes are typified by crop and market debris [21]. It is clear that MSW is a complex and heterogeneous mixture, whose composition is made up of different chemical structures and physical properties [22].

Table 1. Physical composition of solid waste generated at Akosombo

Waste source	Dumping site	Dustbin	Truck	Slaughter house	Drains	Markets
% Food waste	20	30	15	-	5	20
% Paper and card	15	10	12	-	15	10
% Textiles	8	5	10	-	5	10
% Plastics & Rubber	25	20	20	-	25	30
% Garden trimmings	10	15	10	-	20	2
% Animal droppings and dirts	6	10	5	100	18	5
% Wood	5	-	10	-	-	5
% Glass	4	4	5	-	-	4
% Metals and cans	5	5	10	-	5	5
% Miscellaneous other waste	2	1	3	-	7	9

The study recorded organic matter content that ranged between 60 to 100 percent with the highest value recorded from slaughterhouse in both seasons while the least was recorded from truck samples in dry season (Table 2). The study established that the type of solid waste generated in the study area has organic material of about 70% on the average. Hence, the municipal solid waste is suitable for composting because of the presence of high percentage of biodegradable organic matter. The average organic matter composition recorded in this study is higher than those recorded in some cities in African (Table 3). The study recorded organic matter in percentages higher than that obtained by Wikner [6], who conducted three consecutive tests and recorded the organic material (biodegradable, plastics etc.) that ranged between 40% to 60% of the total solid waste of the Unsorted Municipal Solid Waste (UMSW) used for experiment at Kumasi. The study generally recorded organic matter values that are consistent with the earlier estimation by Carboo and Fobil [23].

The greatest composition of solid waste in Accra the capital of Ghana consists of easily degradable components termed “organic material”, which have been predicted to be 80%-90% by weight of the total waste generated. The materials typically found in the waste streams of the metropolis include organic materials, paper cardboards, plastics and inert materials [23]. The physical and chemical forms of these materials are heterogeneous in phase. Hence, the need to design a relevant and effective waste management programme by putting together waste treatment technologies for energy recovery and organic fertilizer production. Inorganic matter ranged from 0% to 40% with the highest recorded from track samples in wet season while the least was recorded in slaughter house samples in both seasons (Table 2). Volatile matter ranged between 30.5% and 87.5% with the highest recorded from dustbin in dry season while the least was recorded in drains samples in wet season (Table 2).

Table 2. Percentages of the various composition of solid waste in the Akosombo township

Sample source	Season	% Organic component	% inorganic component	% moisture	% volatile matter	% ash
Dumping site	Wet	70.6	29.4	53.32	74.1	17.02
	Dry	65	35	26.72	75.9	19
Dustbin	Wet	75	25	26.2	85.8	1.07
	Dry	68	38	52.4	87.5	1.2
Truck	Wet	60	40	73.71	86	1.04
	Dry	67	33	43.11	68.5	1.05
Slaughter House	Wet	100	-	24.63	75.4	4.87
	Dry	100	-	28.7	70.5	4.52
Market	Wet	75	25	66.49	52.0	11.12
	Dry	62	38	60.35	70.6	10.85
Drains	Wet	64	36	71.74	30.5	2.34
	Dry	65	32	75.6	42.5	2.21

Table 3. Waste composition of some African countries and their cities

Country/city	Waste production kg/hd/year	Waste composition % organic	References
Louga / Senegal	110–250	50	Collivignarelli et al. [24]
Cape Town/South Africa	-	58	Spies et al. [25]
Manila/Philippines	146	45	Diaz et al. [26]
Dares Salaam/Tanzania	-	62.5	Otieno and Taiwo [15]

3.2 Chemical Composition of Waste Generated in Akosombo

The percentage compositions of C, H, O, N and S for solid waste obtained from the study area are presented in Table 4. The study recorded carbon (C) percentage that ranged from 42.26% to 65% with the lowest value recorded in samples from drains and the highest value in samples from slaughter house (Table 4). Hydrogen (H) percentage ranged between 4.62%

to 8.15% with the lowest recorded in samples from truck and highest from slaughter house (Table 4). Nitrogen (N) percentage ranged between 1.52% to 4.43% with the lowest value recorded in samples from drains and highest in market samples (Table 4). Sulphur percentage ranged from 0.01% to 0.47% with the lowest recorded in samples from slaughter house and highest from market (Table 4). Oxygen (O) percentage ranged between 20.02% to 46% with the lowest recorded from dumping site and highest from drains (Table 4). Ash percentage ranged between 1.04% to 17.03% with the lowest recorded in samples from truck and highest from dumping site (Table 4). Comparative assessment of the various elements from the different sample sources of the unsorted organic fraction samples from the Akosombo Township (Fig. 2).

It is observed that the waste can be composted and used as a fertilizer and/or biologically treated (anaerobic digestion or aerobic digestion) to produce biogas in vessels. The study obtained carbon to nitrogen (C/N) ratio that ranged between 11:1 to 29:1 with most values falling within the optimum range for waste to undergo steady biodegradation. According to Shukla et al. [18] the recommended value for such conversion should range between 25 and 30. Previous work by Kiely [27] shows that at the optimum C/N ratio of 30, there is adequate nitrogen for cell synthesis and carbon for energy source. At C/N ratio of about 25 on the average, the waste is biodegradable and ideal for composting and bio-chemical conversion. However, composting process and compost quality can be boosted by adding inoculating agent like cow manure, poultry manure, yard waste among others in the municipal solid waste.

Table 4. The percentages of carbon, hydrogen, oxygen, nitrogen, sulphur and ash in different constituents of the waste collected during the wet month

Sample sources	% Carbon, C	% Hydrogen, H	% Nitrogen, N	% Sulphur, S	% Oxygen, O	% Ash
Dumping site	45.3	7.85	1.72	0.43	20.02	17.03
Dustbin	54.43	6.24	1.90	0.46	32	1.07
Truck	45.45	4.62	1.87	0.16	45.6	1.04
Slaughter house	65	8.15	2.43	0.01	20.64	4.87
Drains	42.26	6.58	1.52	0.14	46	7.12
Market	49.94	5.86	4.43	0.47	38	2.3
Total						39.42

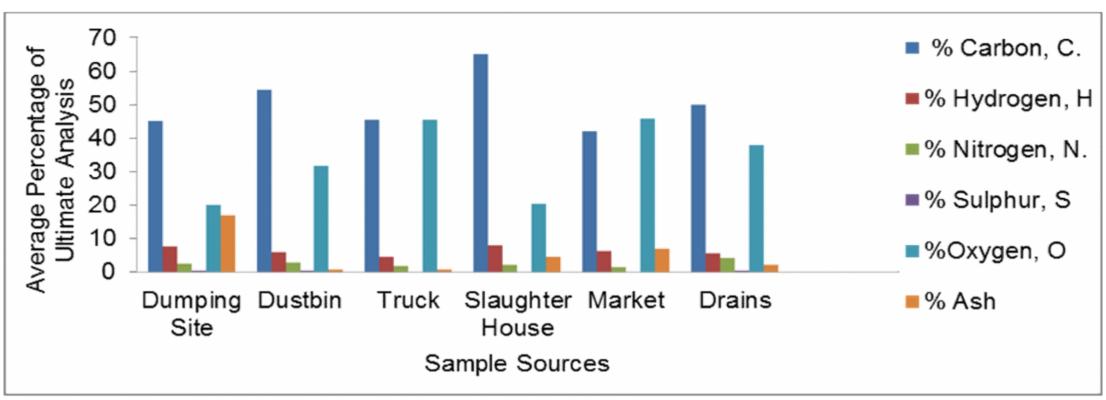

Fig. 2. Comparative assessment of the various elements of the unsorted organic fraction samples

4. CONCLUSION

The study revealed that food waste, paper and card, and plastic and rubber waste are of higher proportion in terms of composition from the sorted solid waste from the study area. The solid wastes generated from all the sampling sites are heterogeneous in nature. The high proportion of food, garden trimming, animal droppings and wood waste is due to the fact that Ghana's economy largely depends on agricultural products for export and domestic consumption. The study recorded organic matter content that ranged between 60 to 100 percent. The study revealed that the type of solid waste generated in the study area has organic material of about 70% on the average. Hence, the municipal solid waste is suitable for composting because of the presence of high percentage of biodegradable organic matter. The C/N ratio obtained from most sample sites is suitable for bio-chemical conversions. The solid wastes generated in the study area have substantial organic matter that can be converted to fertilizer to boost agricultural production and also reduce government expenditure on fertilizer subsidy. Based on the findings of this study it is therefore recommended that plant that can use solid waste for fertilizer production should be provided to harness the potentials of waste.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interests regarding the publication of this paper.

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