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Comparative Study of the Leachability of Heavy Metals from Sewage Sludge, Sawdust and Organic Fraction of Municipal Solid Waste

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Authors' contributions

This work was carried out in collaboration between all authors. Author CCN conceived, designed and supervised the research, Author CBA wrote the manuscript. Authors CO and C. Okafor performed the laboratory experiment and sample collection. All authors read and approved the final manuscript.

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ABSTRACT

The comparative study of the leachability of sewage sludge, sawdust and organic fraction of municipal solid (OFMSW) waste was conducted at different rainfall intensities. First, the natural moisture content of the three categories of waste were obtained. Samples of the wastes were air-dried and then subjected to heavy metal tests to determine the initial and overall heavy metal content. Sewage sludge, sawdust and OFMSW were subjected to different rainfall intensities and the concentrations of cadmium (Cd), lead (Pb), chromium (Cr), arsenic (As) and copper (Cu) in the resultant leachates were determined using atomic absorption spectrophotometer. The pH ranges of 6.08 to 6.28, 7.62 to 8.38 and 7.62 to 8.27 were obtained for leachate from saw dust, sewage sludge and OFMSW respectively. The moisture content of sawdust, sewage sludge and OFMSW were 4.58%, 44.4% and 56.06% respectively. Sewage sludge had the highest heavy metal content distributed as follows: Cu (0.4 ppm), As (4.3 ppm), Cr (0.207 ppm), Cd (0.362 ppm) and Pb (2.57 ppm) with arsenic and lead being the highest. There was a good correlation between the

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concentrations of heavy metals in the waste media. The highest correlation was between Cd and Pb (*R =-0.99996).* There was no significant difference in the concentrations of the various heavy metals in the waste media at 95% confidence limit. Copper was the most leachable and sawdust was the most susceptible to copper leaching. On the other hand, cadmium, arsenic and lead exhibited the least leachability, suggesting a measure of affinity between these metals and the wastes.

Keywords: Leachate; rainfall intensities; landfill; contamination; solid waste.

1. INTRODUCTION

Leachate generation and its environmental impact is a global menace because of their potential to contaminate ground water. Leachate from solid waste dumping site is so concentrated that small amounts of leachate can pollute large amounts of ground water rendering it unsuitable for domestic water supply. In addition to potential carcinogens and highly toxic chemicals, municipal waste (MSW) leachate contains a variety of conventional pollutants that can render groundwater unusable or highly undesirable due to tastes and odours. Nigerian cities and towns are currently facing serious environmental problems arising from poor solid waste management. The rate of solid waste generation in Nigeria has increased with rapid urbanization. This has resulted in poor solid-waste management system that portends serious environmental crisis in most Nigerian towns and cities. The residents of Nigerian cities such as Lagos, Onitsha, Aba, Ibadan, Kano, and Enugu, dump refuse indiscriminately along the streets, roads, open spaces, market places, frontages of residential buildings and drainage systems. This results in unsightly mountains of refuse that have become a common feature of Nigeria's urban landscape [1]. [2] posited that there is widespread lack of resources and technical and administrative capacity to properly implement sound mechanisms for wastes management in Nigeria. Consequently, most urban residents have adopted different unscientific and unconventional methods of disposing their waste. They burn, bury or dispose their waste haphazardly [3]. It should therefore be noted that, if waste is poorly managed, it becomes a danger to health, a threat to the environment, a nuisance, a coding factor in civic morals, and possibly a major social problem.

Physical, chemical, and biological processes interact simultaneously to bring about the overall decomposition of the wastes. One of the by-products of all these mechanisms is chemically laden leachates [4]. The mechanisms by which contaminants are leached out of the waste in a disposal site (landfill open dump etc) involves: (i) primary leaching - dissolution of soluble salts or soluble organic material that exists is considered in primary leaching; (ii) biodegradation - much of the original organic material in the site has low solubility but the biodegradation of these materials tends to produce more soluble end products such as simple organic acids and alcohols; and (iii) chemical reduction - a disposal site quickly becomes anaerobic, thus becoming a chemical reducing environment where ferric salts will be reduced to ferrous salts. Gravity causes leachates to move through the landfill, to the bottom and sides, and through the underlying soil until it reaches the groundwater zone or aquifer. As leachates move down the subsurface, they mix with groundwater held in the soil spaces and this mixture moves along the groundwater's flow path as a plume of contaminated groundwater. This subsequent movement of the leachate into the surrounding soil, groundwater or surface water could lead to severe pollution problems. Fig. 1 shows a pictorial representation of leachate production.

The knowledge of the quantity and composition of leachates usually gives an insight into appropriate, effective and sustainable treatment approach. Some studies documented the physical, chemical and trace metals characteristics of leachates from repository of municipal solid wastes in different sites. Integrated samples of leachates can be collected during wet and dry periods and analyzed for pH, suspended solids (SS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammonia, nitrate, phosphate, sulphate and trace metals among others [5]. Table 1 gives typical values of leachates from a landfill.

Specific leachate variability is due to variations in the composition of the refuse and its depth and permeability, landfill method, landfilling age, collection system as well as the climatologic

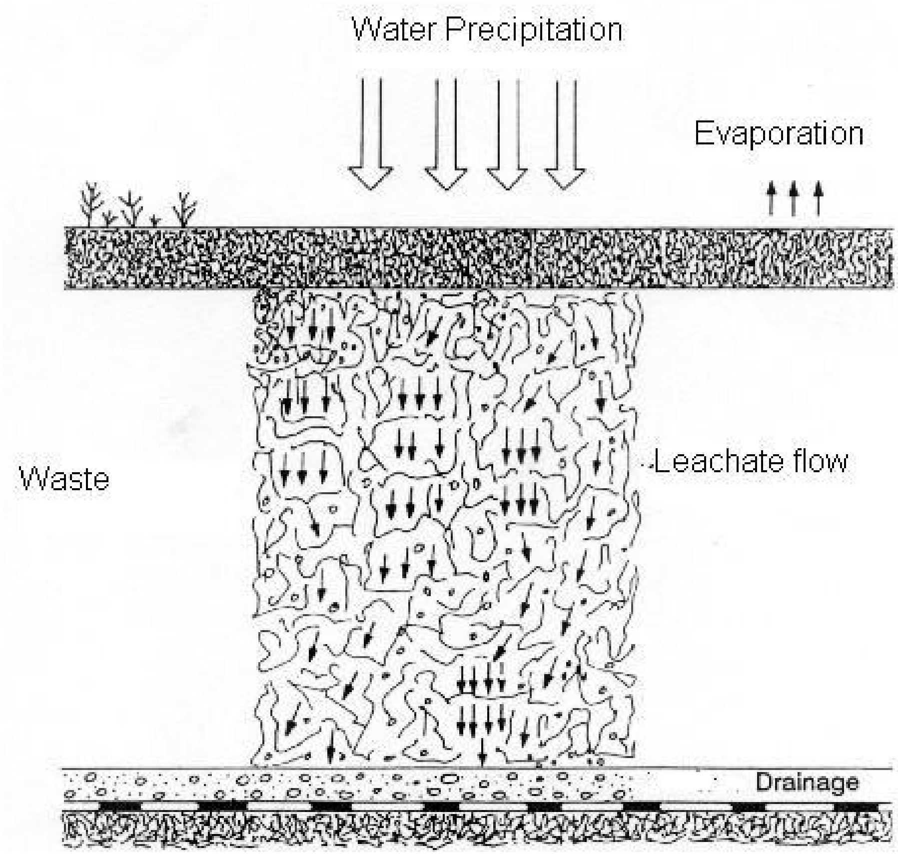

Fig. 1. Leachate formation and percolation in a landfill body [6]

conditions of the region [7, 8]. [9] in their study on sanitary landfills in Norway and in the U.S.A. observed that iron (Fe) concentration was high in all the leachates. The concentrations of chromium, nickel, copper, cadmium and lead were low. Young or new landfill is highly influenced by the acid fermentation stage of anaerobic decomposition resulting in the presence of free volatile fatty acids. Leachate thus generated is deemed to be well suited for biological treatment. In contrast, leachate from old landfills are influenced by the methane fermentation stages of anaerobic decompositions yielding primary recalcitrant humic and fulvic compound which are more amenable to physical or chemical treatments [10]. Humic and fulvic acid which are categorized as humic substance (HS) are relatively higher in old landfill. HS are a naturally occurring mixture of organic compounds which play an important role in both pollutant chemistry and the biogeochemistry of natural waters and soils. The physical appearance of leachate when it emerges from a typical landfill site is a strongly odoured black, yellow or orange coloured cloudy liquid. The smell is acidic and offensive and may be very pervasive because of hydrogen, nitrogen and sulfur rich organic species such as mercaptans and methane. During the decomposition of solid waste, leachate produced is characterized by a temperature rise and rapid fall of the pH. The metal ions which are relatively insoluble at neutral pH dissolve in the developing leachate as the pH falls. Leachate also reacts with materials that are not themselves prone to decomposition such as fire ash, cement based building materials and gypsum based materials, changing the chemical compositions. The reaction of leachate with gypsum can generate large volume of hydrogen sulphide.

Leachates contain a host of toxic and carcinogenic chemicals, which may cause harm to both humans and the environment. Leachate-contaminated groundwater can adversely affect industrial and agricultural activities that depend on well water. For certain industries, contaminated water may affect product quality, decrease equipment lifetime, or require pretreatment of the water supply, all of which cause additional financial expenditures. The use of contaminated water for irrigation can decrease soil productivity, contaminate crops, and move possibly toxic pollutants up the food chain as animals and humans consume crops grown in an area irrigated with contaminated water [11].

Table 1. Typical composition of landfill leachate (values in mg/l unless otherwise stated)

Parameter	Range
pH	4.5-9
Spec. Cond. (μS cm−1)	2500-35000
Total Solids	2000-60000
Organic Matter	
Total Organic Carbon (TOC)	30-29000
Biological Oxygen Demand (BOD5)	20-57000
Chemical Oxygen Demand (COD)	140-152000
BODS/COD (ratio)	0.02-0.30
Organic nitrogen	14-2500
Inorganic Macrocomponents	
Total phosphorous	0.1-23
Chloride	150-4500
Sulphate	8-7750
Hydrogen bicarbonate	610-7320
Sodium	70-7700
Potassium	50-3700
Ammonium- N	50-2200
Calcium	10-7200
Magnesium	30-15000
Iron	3-5500
Manganese	0.03-1400
Silica	4-70a
Heavy Metals	
Arsenic	0.01-1
Cadmium	0.0001-0.4
Chromium	0.02-1.5
Cobalt	0.005-1.5
Copper	0.005-10
Lead	0.001-5
Mercury	0.00005-0.16
Nickel	0.015-3
Zinc	0.03-1000

The objective of this research was to investigate the leachability of lead (Pb), chromium (Cr), copper (Cu) Arsenic (As), and cadmium (Cd) from sawdust, sewage sludge and OFMSW under varying rainfall intensities.

2. METHODOLOGY

Sewage sludge was collected from a treatment plant at the University of Nigeria Nsukka, and saw dust was collected at the Nsukka Timber Market while OFMSW was collected from the Staff Quarters of the University of Nigeria, Nsukka. All samples were collected same day and transported to the laboratory for immediate leachate extraction and analysis. Fig. 2 shows the samples collected for the experiment.

2.1 Leachate Extraction

The leachate extraction columns were constructed with a PVC pipe of 1 meter length, standing on a metal tripod support for easy collection of leachates. The upper ends of the columns were open while the lower parts were covered with a semi permeable membrane so that only liquid solution was allowed to pass through (see Fig. 3a). A plastic container was placed directly under the PVC column and the lower portion of the PVC columns were wrapped with impermeable polythene material to prevent water from the simulator from entering directly into the plastic collector. This ensured that only water entering the column was collected by the collector. Fig. 3b shows the leachate coulmns positioned under the rainfall simulator.

The municipal solid waste was shredded into pieces and mixed thoroughly to ensure homogeneity. Each sample was packed into a pre-labelled PVC column and the three columns were placed under a rainfall simulator at an intensity of 18.04 mm/hr. The plastic collectors were also labeled. With the rainfall simulator at minimum height, rainfall was simulated until leachate started coming out, and the rainfall was stopped only when enough leachate was collected. The time of simulation of rainfall to the time of enough leachate collection was recorded with the stop watch and the leachate samples were taken to the laboratory immediately for pH test and heavy metals test. The heavy metals tested are lead (Pb), chromium (Cr), copper (Cu) Arsenic (As), and cadmium (Cd). The procedure was repeated with rainfall intensities of 19.6 mm/hr, 21.4 mm/hr and 22.88 mm/hr. Finally, sun-dried samples of saw dust, sewage sludge, and OFMSW were digested and also tested for heavy metals.

2.2 Laboratory Analysis

Analyses of leachate samples for physico-chemical (e.g. pH) and elemental characteristics were carried out as prescribed by American Methods for Examination of Water and Wastewater. The three wastes were subjected to moisture content determination before extraction of the leachates.

Fig. 2. showing the three (3) collected samples (source: authors' fieldwork)

Fig. 3 (a). Constructed leachate extraction columns; (b) simulating rain on the leachate extraction column (source: authors' fieldwork)

The weights of the empty labeled moisture cans were weighed using an electronic beam balance. Small quantities of the three samples were put in the three labeled pre-weighed moisture content cans. The moisture cans with the samples inside were weighed and then put in an oven at 105°C and allowed to dry for 24 hours after which the weight of moisture can with the samples inside was weighed and recorded again. Heavy metals (Cd, Cr, Cu, Pb, and As) concentrations of leachates were analyzed using a Buck Scientific VGP 320 atomic absorption spectrophotometer (AAS). The pH of the samples was determined by simply dipping pH meter into each sample and the values read off immediately and recorded.

3. RESULTS AND DISCUSSION

Table 2 shows that the rate of movement of water through each type of waste is a function of the physical properties of the waste. It can be clearly seen that sewage sludge is the most resistant to the movement of water followed by sawdust and then OFMSW. This can be attributed to the varying degrees of void in the wastes as well a surface area. Besides, before the passage of water is allowed, the waste must first reach saturation. OFMSW allowed more infiltration of water than the other two kinds of waste. Sewage sludge has higher water retention capacity than sawdust and OFMSW and was therefore more reluctant to let go of water. However, free passage of water does not necessarily translate into higher leachability because pollutants can only be leached by percolating water if the pollutants are freely available. Availability of pollutants for leaching is heavily dependent on whether the pollutant is chemically or endogenously bound to solid waste and the level of biodegradation of the parent material. It is important to note that these wastes had undergone different levels of biodegradation and the degree of leaching was dependent on the level of degradation. While the sewage sludge had undergone substantial biodegradation, the OFMSW and sawdust had undergone virtually little degradation. Biodegradation releases endogenic heavy metals from organic waste, thereby producing a more concentrated and polluted stream of leachate.

The pH ranges of 6.08 to 6.28, 7.62 to 8.38 and 7.62 to 8.27 (Fig. 4a) for leachate from saw dust, sewage sludge, and OFMSW respectively were obtained from the samples, with values falling within 6.0 – 9.0 FEPA limit for wastewater [12]. However, slightly lower values of (6.78 - 6.93) were reported by [13] in Tunisia. While slightly higher values of 7.74 - 7.91 and 8.17 were reported by [14] in Taiwan and [5] in Ibadan, respectively. Lower to higher values (5.10 – 8.60) have been reported for landfill leachates in United State of America and Germany [15]. Generally, the pH of a stabilized leachate is higher than that of a young leachate [16]. Leachate is generally found to have pH between 4.5 and 9 [17]. [18] reported that the pH of leachate increased with time due to the decrease of the concentration of the partially ionized free volatile fatty acids. pH enhances solubility of metals in leachate, thus elevating their concentration and possibly their toxicity to organisms within their area of influence. The low alkaline nature of the leachates is attributable to the presence of calcium and magnesium bicarbonate. Alkalinity in wastewater helps to resist changes in pH caused by the presence of acidic materials in domestic waste. Generally, the pH values of the leachates obtained from this study decreased with increase in rainfall intensity.

Fig. 4b shows that sawdust had the least moisture content of 4.58% while those of sewage sludge and OFMSW were 44.4% and 56.06% respectively. While the water in sewage sludge is a combination of bound water and free water which can be removed subject to dewatering, the water in sawdust and the fresh OFMSW is basically bound water. The presence of moisture aids biodegradation and hence leachate producing potential. Adequate moisture will catalyze the solubilization and hydrolysis of organic matter and subsequent release of pollutants.

Fig. 5 presents the heavy metal concentrations of the sun dried waste samples. It can be seen that sewage sludge has the highest heavy metal content distributed as follows: Cu (0.4 ppm), As (4.3 ppm), Cr (0.207 ppm), Cd (0.362 ppm) and Pb (2.57 ppm) with arsenic and lead being the highest. OFMSW and sawdust were also found to contain substantial level of lead (1.94 ppm) and arsenic (1.94 ppm) respectively. [19] noted that heavy metals in sewage sludge are basically from dietary sources, runoff and industrial effluent. In turn, heavy metals in OFMSW are as a result of land application of heavy metal laden sewage sludge to enhance agricultural productivity. This is a common practice in Nigeria. Heavy metal in sawdust can result from bioaccumulation via plant uptake as well as the application of wood preservatives.

Table 2. Leaching rate of different wastes

Type of Waste	**Saw dust**	**Organic MSW**	**Sewage sludge**	**Saw dust**	**Organic MSW**	**Sewage sludge**	**Saw dust**	**Organic MSW**	**Sewage sludge**	**Saw dust**	**Organic MSW**	**Sewage sludge**
Rainfall Intensity (mm/hr)		**22.8**			**21.4**			**19.6**			**18.04**	
Weight (Kg)	0.87	0.87	0.87	0.87	0.87	0.87	0.428	0.468	0.428	0.5	0.5	0.5
Volume of Leachate (ml)	375	775	10	820	1200	35	420	575	25	530	1160	50
Rainfall duration (mins)	52	52	52	36	36	36	27	27	27	21	21	21
Rate of leachate (ml/Kg/min)	8.289	17.131	0.221	26.181	38.314	1.117	36.345	45.505	2.163	50.476	110.476	4.762

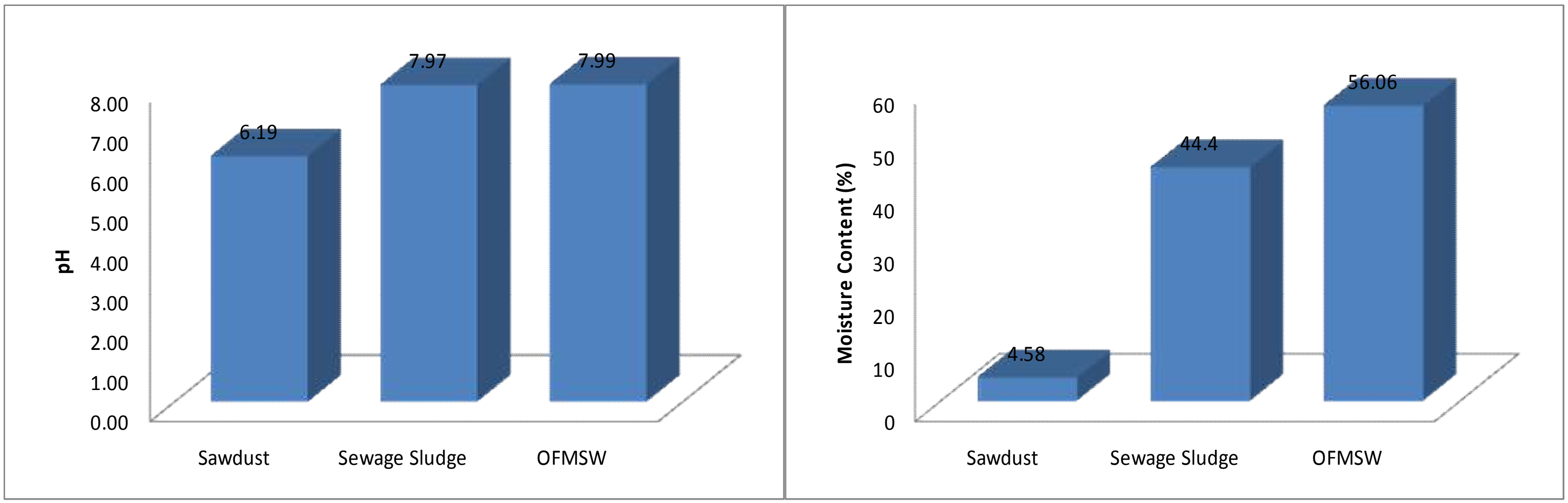

Fig. 4. (a) Average pH values; (b) moisture content of different waste types

Table 3 shows the correlation between heavy metals in the wastes. A very high negative correlation was obtained between Cd and Pb (*R =-0.99996)*, and between As and Cr (*R* = *-0.94*). A two-way analysis of variance was performed on the results of heavy metals concentration in the three waste media. The result presented in Table 4 shows that there was no significant variation in the concentrations of various heavy metals in the waste media at 95% and 90% confidence limits. Besides, there was no significant variation of heavy metals concentration as a result of difference in waste media. However, significant difference in the concentrations of the various heavy metals in the waste media was observed at 85% confidence limit with an *F* value of 2.39 greater that the *F* critical value of 2.27.

3.1 Leachability of Heavy Metals from Waste

3.1.1 Copper

The concentration of copper in the three categories of waste was generally low, measuring between 0.384 ppm to 0.427 ppm for saw dust, 0.216 ppm to 0.368 ppm for sewage sludge, and 0.256 ppm to 0.379 pmm for OFMSW. Leachability of copper measured was higher in saw dust, followed by OFMSW and then sewage sludge. There was a general increase in the concentration of copper leached from all types of waste as simulated rainfall intensity increases. The same trend holds for chromium and arsenic for all types of waste as well as for lead leached from sewage sludge and cadmium leached from OFMSW. The National Academy of Sciences has recommended 2 to 3 mg of copper as a safe and adequate daily intake for adults. Copper has been shown to have a protective effect against cadmium poisoning, and people who do not have enough copper in their diet can be more susceptible to adverse effects from lead. Drinking water with concentrations of 30 ppm or greater can cause vomiting, diarrhea, stomach cramps, and nausea. Large intakes can cause liver or kidney damage, or even death in cases of extreme exposure. Acute exposure via inhalation of copper dusts or fumes can cause a condition called "metal fume fever," characterized by chills, fever, dry throat and aching muscles. Long-term exposure to copper dust in air can irritate the nose, mouth, and eyes, and cause headaches, dizziness, nausea, and diarrhea. Adverse effects on the lungs of animals have been reported at concentrations of 0.1 to 3 ppm in air.

Table 3. Correlation between heavy metals in wastes

	Cu	As	Cr	Cd	Pb
Cu	1				
As	-0.68463	1			
Cr	0.389201	-0.93788	1		
Cd	-0.3903	-0.40387	0.696189	1	
Pb	0.398928	0.395263	-0.68942	-0.99996	1

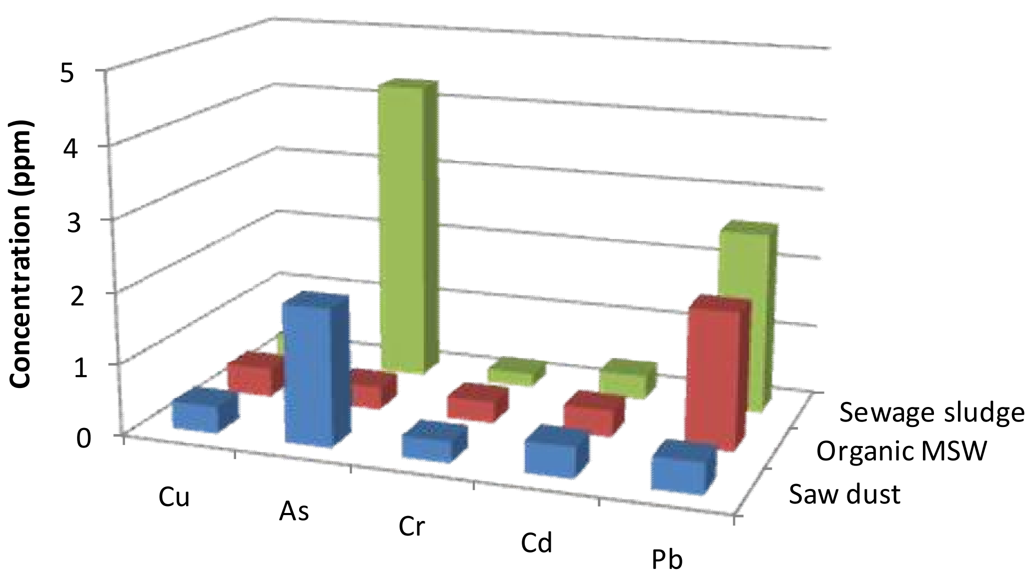

Fig. 5. Total heavy metal content of different waste types

Table 4. Analysis of variance

Source of variation	SS	df	MS	F	P-value	F crit(95%)	F crit(90%)	F crit(85%)
Heavy metals	9.294419	4	2.323605	2.386376	0.137278	3.837853	2.806426	2.273964
Waste	2.561495	2	1.280747	1.315346	0.320711	4.45897	3.113118	2.427427
Error	7.789568	8	0.973696					
Total	19.64548	14						

3.1.2 Lead

Lead (Pb) concentration in leachates was between 0.018 ppm to 0.149 ppm for saw dust, 0.013 ppm to 0.125 ppm for sewage sludge, and 0.017 ppm to 0.127 ppm for OFMSW, for the four rainfall intensities. As expected, the quantity of lead in leachate from sewage sludge increased as rainfall intensity increased. However surprisingly, the reverse was the case for OFMSW and sawdust. The reason for this behavior cannot be explained. Higher values of 0.35 - 0.97 mg/L were reported by [20] in Sweden, while similar values (0.10 mg/L) and less were reported for landfill leachate in Dusseldorf Germany and Taiwan [14]. If significant quality of Pb in leachate is leached into farmland and groundwater, it may cause cytogenetic alteration such as kidney and brain damage or birth defects if ingested through the food chain or drinking water [21]. The U.S. Environmental Protection Agency (EPA) has classified lead as a probable human carcinogen. Zinc can protect against lead toxicity by reversing its enzyme-inhibiting effects, whereas iron deficiency appears to increase the gastrointestinal absorption of lead leading to increased toxicity to the hematopoietic system as well as other effects.

3.1.3 Arsenic

Arsenic (As) concentration in leachates was between 0.012 ppm to 0.033 ppm for saw dust, 0.068 ppm to 0.127 ppm for sewage sludge, and 0.013 ppm to 0.22 ppm for OFMSW, under the four rainfall intensities. The quantity of arsenic leached out of the three types of wastes was in proportion to the original arsenic content of the wastes and increased as rainfall intensity increased. Fig. 6 indicates that despite the relatively high concentration of arsenic in sewage sludge and sawdust, its concentration in the leachates was low. This indicates that arsenic is generally less leachable than the other metals. The same observation and inference also applies to lead. Arsenic is mostly used as a wood preservative, and in paints, dyes, metals, drugs, soaps, and semi-conductors. Chickens raised for meat, are commonly given the arsenical roxarsone to prevent them from getting parasitic diseases. The concentration of arsenic in the earth's crust ranges from 2 to 5 milligrams per kilogram (mg/kg), or parts per million (ppm). The mean natural soil concentration is 5 mg/kg, and it ranges from about 1 to 40 mg/kg. Levels in drinking water are commonly 2 to 20 parts per billion (ppb). Some organisms (notably in aquatic systems) can accumulate nontoxic, organic forms of arsenic; for example, levels of arsenobetaine in shrimp are often high. However, the typical ratio of the arsenic concentration in plants to that in soil is low, estimated at 0.006 (or 0.6%). Depending on the amount ingested, arsenic can be beneficial (animal studies suggest that low levels of arsenic in the diet are essential) or adverse (high levels can be toxic). The acute lethal dose to humans can be about 2 to 20 mg/kg body weight per day (mg/kg-day). Occupational exposure studies show a correlation between chronic arsenic exposure and lung cancer. Arsenic can also cause reproductive/developmental effects, including spontaneous abortions and reduced birth weights. Epidemiological studies indicate an association between arsenic concentrations in drinking water and increased incidences of skin, liver, kidney, lung, and bladder cancers. Studies also show an association between inhaling arsenic and lung cancer. From these sets of data, the U.S. Environmental Protection Agency (EPA) has classified inorganic arsenic as a known human carcinogen.

3.1.4 Chromium

Of all the three heavy metals, chromium had the lowest concentration in the three waste types. Chromium concentration was between 0.061 ppm to 0.13 ppm for saw dust, 0.043 to 0.102 ppm for sewage sludge, and 0.071 ppm to 0.094 ppm for OFMSW, for the four rainfall intensities. According to Fig. 6, lead and chromium were more easily leached from sawdust than OFMSW and sewage sludge. The leachability of chromium was highest in sawdust, followed by sewage sludge. The leachability of chromium from sawdust doubled for an increase in rainfall intensity from 18.04 mm/hr to 22.8 mm/hr. Because it is an element, chromium does not degrade nor can it be destroyed. The trivalent form of chromium is an essential nutrient in our diet and is needed for many important functions, including lipid, protein, and fat metabolism. Even at levels above those required to maintain health, it exhibits very low toxicity and it is not known to cause cancer. In contrast, hexavalent chromium can be toxic, including causing cancer if it is inhaled; the lethal dose is estimated at about 7-milligrams hexavalent chromium per kilogram (mg/kg) body weight. When inhaled, hexavalent chromium can damage the lining of the nose and throat, and irritate the lungs as well as the gastrointestinal tract. Nasal irritation has been observed following acute exposure at levels less than 0.01 mg/m3. When swallowed, it can upset the stomach and damage the liver and kidneys. Some people have an allergic skin reaction after using material containing chromium.

3.1.5 Cadmium

The leachability of cadmium from sawdust with increase in rainfall intensity did not follow any specific pattern. The leachability of cadmium decreased with increase in rainfall intensity for sewage sludge but increased with rainfall intensity for OFMSW. However, these behaviours cannot be generalized as it has been previously observed that leachability increases with increase in rainfall intensity. The reason for the occasional irregular pattern of leachability with increase in rainfall may be attributed to runoff/spillage of water from the upper end of the column when rainfall intensity exceeded the rate of infiltration. This can cause some of the leached heavy metals to overflow with the water, thus giving a false sense of reduced leachability. Cadmium (Cd) concentration in the leachates was between 0.008 ppm to 0.032 ppm for saw dust, 0.01 ppm to 0.026 ppm for sewage sludge, and 0.01 ppm to 0.023 ppm for OFMSW for the four rainfall intensities (see Fig. 7). Higher values

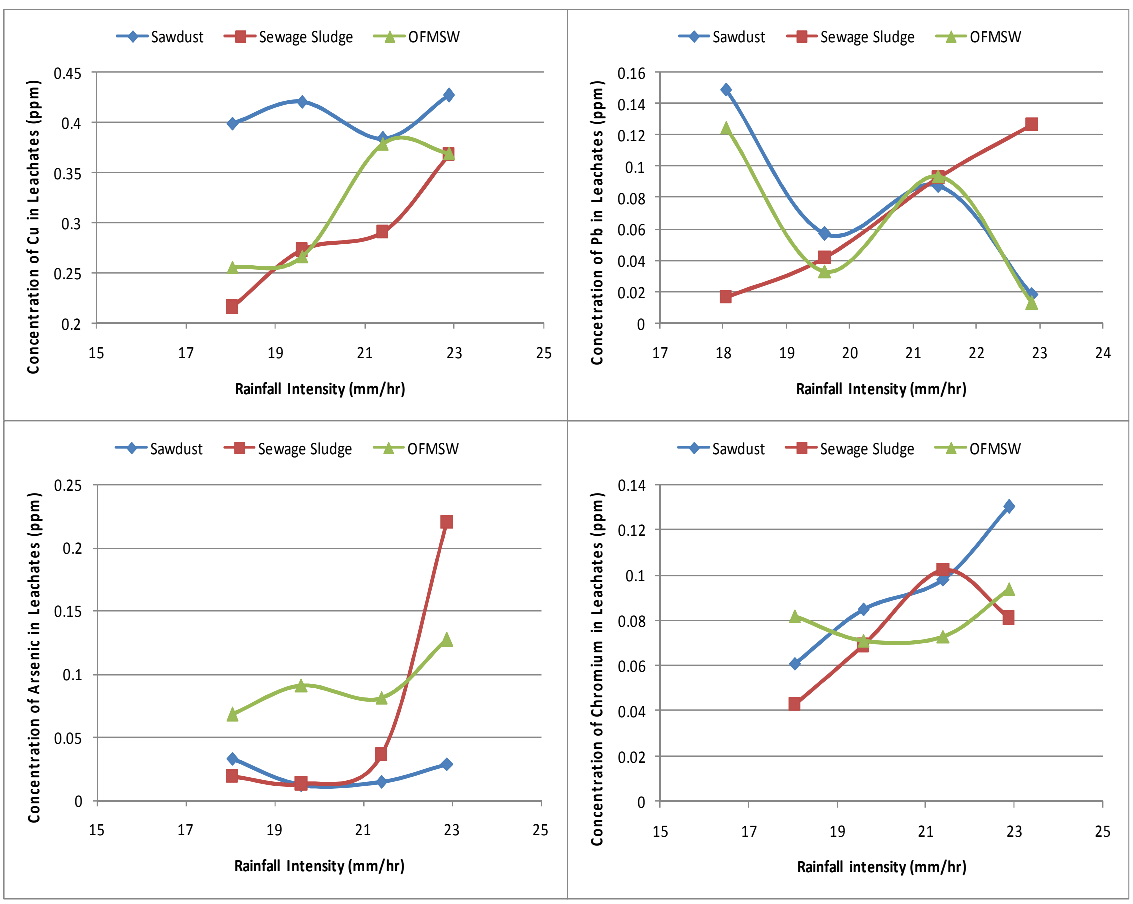

Fig. 6. Concentration of Cu, Pb, As and Cr in leachates versus rainfall intensity

of 3.62 - 8.15 mg/l were reported by [20] in Sweden and lower values (<0.01 - < 0.15 mg/L) reported in Taiwan [14]. Cadmium is toxic when inhaled in small quantity as dust during incineration at dumpsite because it is carcinogenic. It concentrates in the liver and kidneys. Cadmium can also deposit in other organs and tissues depending on its chemical form. The main concern is cancer induction from the beta particles associated with its radioactive decay, but cadmium also exhibits chemical toxicity, with health effects following inhalation exposure to high levels that can include damage to the respiratory system (bronchial and pulmonary irritation), headache, chest pains, muscular weakness, pulmonary edema, and death.

Fig. 8a shows the average concentration of heavy metals the leachates while Fig. 8b shows average leachability of heavy metals from the various waste types. Average leachability was obtained by dividing the average concentration of heavy metals in the leachates by the original concentration of the heavy metals in the wastes. In all cases, copper was the most leachable and sawdust was the most susceptible to copper leaching. This suggests that the original concentration of copper in sawdust was near saturation. This is reasonable because copper salts are commonly used as preservatives for timber by means of impregnation. On the other hand, cadmium, arsenic and lead exhibited the

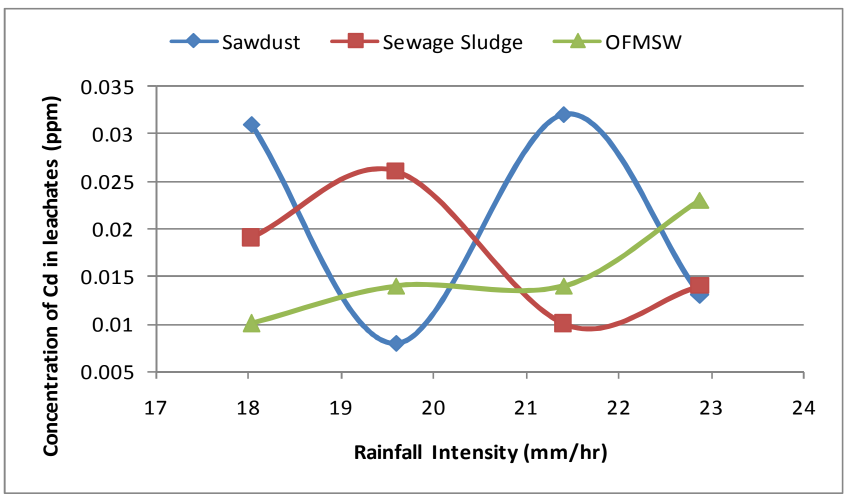

Fig. 7. Concentration of Cd in leachates versus rainfall intensity

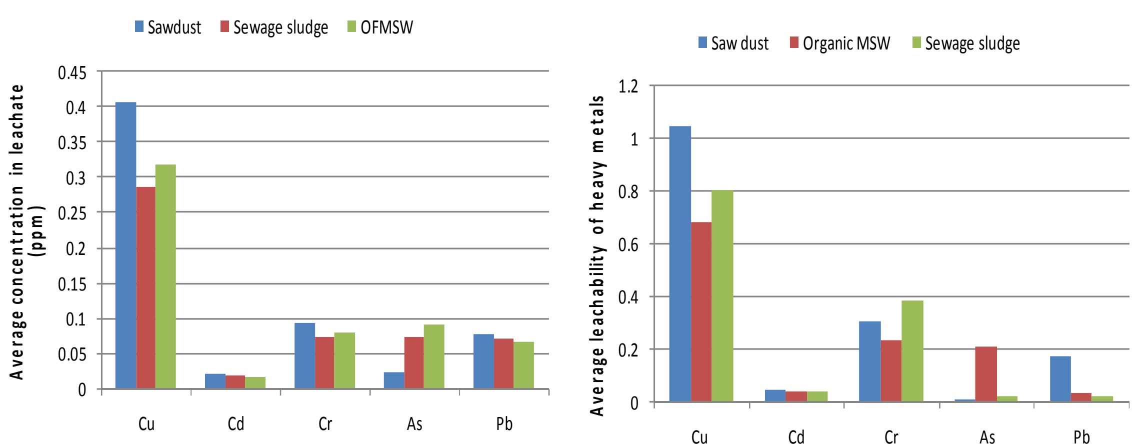

Fig. 8. (a) Average concentration of heavy metals in leachate (b) Average leachability of heavy metals

least leachability, suggesting a measure of affinity between these metals and the wastes. It should be noted that copper has a leachability value greater than 1. This value is unreliable as leachability should not be greater than 1. This can be attributed to either recording or experimental error. Generally, the concentrations of the potentially toxic metals recorded in the leachate samples were below permissible limits. This notwithstanding, continuous release of leachate from the solid waste and consequent transportation via runoff to farmland and surface water or seepage to groundwater could lead to accumulation. In the acid phase, concentrations are generally higher due to enhanced formation of dissolved organic matter and release of ammonia. Hence, the content of landfill/dumpsite must be managed, so that outputs are released into the environment in controlled and acceptable way.

The impacts from leachate migration depend on a number of site-specific factors. The most important factors are the location, waterway, geological or hydro geological and climatic conditions, together with the solid waste composition and quantity, the physical extent of the operation and age of the landfill. Poorly constructed and operated, or uncontrolled landfills persist with leachate breaks, uncovered trash, and unchecked banned hazardous compounds. Many contaminants (especially heavy metals) are trapped in the soils beneath dumpsites, resulting in risk of further long term environmental contamination. Because of their locations, recovered lands are subsequently cultivated (for vegetables by urban dwellers) which may lead to bioaccumulation of metals which can constitute a health risk. Contamination of water may occur when leachate from a landfill, via flow paths (on or under the surface), reaches groundwater or surface water. Having established the leachability of heavy metals from sawdust, sewage sludge and OFMSW, and taking into cognizance that these waste usually end up in landfills and open dumps as their final repository, there is need to highlight containment and mitigation measures. The problems associated with leachate may be minimized by limiting the amount of water getting in to the solid waste matrix. This can be achieved into a number of simple design and operational measures as follows

i. Ensuring surface water does not enter the landfilled areas, or areas prepared for future landfilling by construction intercepting ditches between the working areas and surrounding unused parts of the site.
ii. Ensuring water does not accumulate in the working area where waste is being landfilled.
iii. Keeping the open areas at the tipping face as small as practicable.
iv. Applying soil cover to the wastes at the end of each working day.
v. Progressively completing and grading areas of the site with a capping layer, as they reach their final design heights.

4. CONCLUSION

The results above suggest that, grasping the full picture of pollution potential of landfill/solid waste dump leachate is more complex than might at first be supposed. The content of heavy metals in the leachates was generally low. This might have been influenced by the variability and heterogeneity of the materials constituting the wastes, age of the waste and effects of some environmental factors such as temperature and amount of rainfall simulated. Moreover, all these factors interact and may vary considerably even in the relatively short term. Notwithstanding the low elemental characteristics of the leachates in this study, their continuous release into the environment could constitute hazards to the living organisms within their zone of influence.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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