Heavy metals and microbial loads in raw fecal sludge from low income areas of Ashanti Region of Ghana

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Abstract

This study was carried out to determine the heavy metals and microbial loads of raw public toilet sludge from low income areas (peri-urban and rural) of Ashanti Region of Ghana. Fecal sludges were sampled from public toilets. Methods outlined in Standard Methods for the Examination of Water and Wastewaters were used for the analyses of fecal sludge samples. Range of heavy metals concentrations were found as 0.039–5.216 mg/l and 0.010–1.488 mg/l for peri-urban and rural areas, respectively. These concentrations were in the order of Mn > Cu > Fe > Zn > Pb > Ar > Cd and Mn > Fe > Cu > Pb > Ar > Cd for peri-urban and rural areas, respectively. The range of bacteria loads was measured as 1.4 \times 10^6–4.5 \times 10^7 CFU/100 ml for peri-urban and 0.2 \times 10^6–4.5 \times 10^7 CFU/100 ml for rural areas. Similarly, range of helminths was determined as 1–18 eggs/100 ml for both peri-urban and rural areas. The study showed that the levels of heavy metals and microbial quantities were generally higher in peri-urban compared to rural areas. However, fecal sludge from these low income areas are not recommended for direct use in agriculture unless they are given further treatment. Composting is recommended as a promising and suitable method for effective treatment of fecal sludge resulting in a hygienically safe and economically profitable product.

Key words: fecal sludge, heavy metals, low income, microbial loads

INTRODUCTION

A large proportion of fecal sludge generated from onsite sanitation systems are not properly disposed of. An onsite sanitation system is defined as a system of sanitation where the means of storage are contained within the plot occupied by the dwelling and its immediate surroundings (WHO 2006). It may be disposed of on site or removed manually for safe disposal (WHO 2006). About 85% of the Ghanaian population is served by onsite sanitation systems (EAWAG and SANDEC 2006), including latrines, non-sewered public toilets and septic tanks. Unregulated disposal of fecal matter can cause nuisance and serious health impacts due to pollution of water sources where a significant proportion of the population in these countries depend on untreated water sources (Odai & Dugban-tey 2005).

As noted by Pescod (1971), Pradt (1971), Um & Kim (1986), Guo \textit{et al.} (1991) and Strauss \textit{et al.} (1997), the characteristics of collected fecal sludges vary greatly and depends on, among others, the season, type of on-site sanitation system (e.g., water closet/septic tank system, dry aqua privy, watertight vented pit latrines), emptying frequency (i.e., is the retention time in the facility), the...
extent of stormwater or groundwater infiltration into the sanitation facility and on user habits. Fecal sludge contains various heavy metals and microorganisms which have potential ecological, biological and health impacts (Hashem 2000).

The actual species and density of pathogens existing in raw fecal sludge depend on the health status of the local community and the sewage sludge treatment processes (Sasakova et al. 2005). Studies by Jensen et al. (1976) revealed that normal human stools consist of roughly 70–80% water and around 20–30% solid matter (Wyman et al. 1978). Studies in the composition of feces reported that the majority (84%) of the solid matter in feces is organic in nature (Lopez Zavala 2002) and is mainly composed of bacteria (~55%) and residual dietary fiber (17%) (Stephen & Cummings 1980). Previous studies by other researchers reported a figure of 30% for the bacterial component of fecal solids (Macneal et al. 1909). Fecal sludge provides a normal and good habitat for many microorganisms (Nemerow 1978; Dean & Lund 1981; Volk & Wheeler 1988).

The most common microorganisms present in fecal sludge are bacteria, fungi, actinomycetes and algae. These microorganisms are often heterotrophic in nature and thus rely on a carbon source derived from organic matter as food. Furthermore, the survival or inactivation of pathogens in the fecal sludge depends upon a number of factors, such as temperature, moisture content and competition from indigenous microflora (Ögleni & Özdemir 2009). Other factors, such as predation, pH, sunlight, oxygen, soil type and texture also influence the pathogen inactivation. Raw sludge may contain significant concentrations of heavy metals which are not degraded by the processes of sludge treatment. The heavy metals in sludge may arise from a number of sources including domestic sources (Carrondo et al. 1978). These metals include chromium, manganese, cobalt, iron, arsenic, zinc, lead, cadmium and mercury. Knowledge about the levels of these metals in sludge is important for treatment as exposure to excessive amounts may have adverse effects on public and environmental health. Studies by Carrondo et al. (1978) reported that the exposure to excessive concentrations of cadmium and mercury has produced adverse effects on health in certain communities. Fears exist that some of the heavy metals may have similar toxic effects.

Pathogenic microorganisms and parasites which are present in the sludge used in the form of fertilizers can penetrate into ground waters and infect plants, and they can threaten human and animal health (Wolna-Maruwka 2008). It is therefore essential that fecal sludges be stabilized and hygienized before being utilized, according to environmental protection regulations for any beneficial purpose including agriculture. This work was therefore carried out to determine the concentration of heavy metals and microbial loads of raw public toilet sludge from low income peri-urban and rural areas of Ashanti Region of Ghana.

**MATERIALS AND METHODS**

**Study area**

Three peri-urban and three rural areas from three districts were randomly selected from the Ashanti Region of Ghana for the study. The peri-urban areas selected were Appeadu (Kumasi Metropolitan Assembly), Feyiase and Pramso (Bosomtwe district). Apromase (Ejisu Municipality), Abrankese and Onwi (Bosomtwe district) were also considered as the rural communities.

**Fecal sludge sampling**

Fecal sludge samples were collected from public toilets located in the study communities. Samples were collected in 1-l air-tight sterile plastic containers rinsed thoroughly with distilled water. Sample containers were completely filled to remove air. Four samples of public toilet sludge were
collected from each of the selected communities per visit. At the end of a visit, samples were mixed to form a composite sample for peri-urban and rural sludges, respectively. Fecal sludge samples were collected twice a month for a period of three months (July, August and September 2013). A total of 12 composite samples were collected from the peri-urban (6 composite samples) and rural areas (6 composite samples).

Fecal sludge samples were securely transported to the Environmental Quality Laboratory of the Kwame Nkrumah University of Science and Technology and analyzed for heavy metals such as copper (Cu), iron (Fe), lead (Pb), cadmium (Cd), zinc (Zn), manganese (Mn) and arsenic (Ar). Microbial parameters such as total coliform, fecal coliform, *Escherichia coli*, *Salmonella* spp., hookworm, *Ascaris*, *Schistosoma haematobium*, *Schistosoma mansoni* and *Trichuris trichiura* were also determined.

Fecal sludge sampling protocol was followed carefully to prevent contamination during sampling and transportation which may affect the results. The protocols used in the study were approved by the Departmental Ethics Committee.

**Methods of analysis of fecal sludge samples**

Methods outlined in *Standard Methods for the Examination of Water and Wastewaters* were used for the analyses of fecal sludge samples (APHA-AWWA-WEF 2005). The samples for microbial analysis were analyzed within 24 h after sampling while those for the heavy metals were preserved in a refrigerator maintained at 4 °C after being acidified with nitric acid to lower pH to a value of less than 2 (Mountassir *et al.* 2013).

The heavy metals were determined by atomic absorption spectrophotometric (AAS) method. Procedural blanks were prepared and aspirated along with the analytical samples in order to correct for background absorption (Olatunji & Osibanjo 2012). In terms of the microbial analysis, total and fecal coliform and *E. coli* were determined using the multiple tube fermentation technique using MacConkey and EC broth with an incubation period of 44 °C for selectivity. Using this method, the numbers of colony forming units (CFU) of bacteria were determined. The modified Baillenger method suggested by Schwartzbrod *et al.* (1989) was used to determine the number of parasitic eggs in the fecal sludge sample.

**Statistical analysis**

The study expressed measured results in terms of means, standard deviation and *p* value which were computed for both fecal sludge from peri-urban and rural areas using Microsoft Office Excel 2007.

**RESULTS AND DISCUSSION**

The concentrations of heavy metals and levels of microbial contamination of fecal sludge sampled from peri-urban and rural areas are presented in Tables 1 and 2.

**Heavy metals**

Although copper (Cu) as a heavy metal is essential for human health, too much of it can cause significant health problems. The measured concentrations of Cu in peri-urban areas were generally variable where as those of rural areas were fairly constant (Figure 1). The mean concentrations (+ standard deviation) of Cu were 3.978 ± 0.439 mg/l and 0.339 ± 0.059 mg/l for peri-urban and rural areas, respectively (*p* < 0.0001) (Table 1). The measured concentrations of Cu in both peri-urban and rural sludge exceeded the Ghana EPA maximum permissible limit of discharge (2.0 mg/l). The
study however, showed higher levels of Cu in peri-urban sludge compared to that of the rural sludge and this could be attributed to the leachates from the solid waste dump sites mostly located near the public toilets in peri-urban areas. The Cu metal might have come from disposal of waste from

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Peri-urban</th>
<th>Rural</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cu</strong></td>
<td>3.978</td>
<td>0.339</td>
</tr>
<tr>
<td><strong>Fe</strong></td>
<td>2.492</td>
<td>0.930</td>
</tr>
<tr>
<td><strong>Pb</strong></td>
<td>0.160</td>
<td>0.050</td>
</tr>
<tr>
<td><strong>Cd</strong></td>
<td>0.045</td>
<td>0.013</td>
</tr>
<tr>
<td><strong>Zn</strong></td>
<td>2.235</td>
<td>1.291</td>
</tr>
<tr>
<td><strong>Mn</strong></td>
<td>4.571</td>
<td>0.992</td>
</tr>
<tr>
<td><strong>Ar</strong></td>
<td>0.152</td>
<td>0.025</td>
</tr>
</tbody>
</table>

Table 1 | Summary of analysis of heavy metals’ concentration in fecal sludge

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Peri-urban</th>
<th>Rural</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total coliform</strong></td>
<td>2.5</td>
<td>2.1</td>
</tr>
<tr>
<td><strong>Fecal coliform</strong></td>
<td>4.0</td>
<td>3.1</td>
</tr>
<tr>
<td><strong>E. coli</strong></td>
<td>3.4</td>
<td>2.8</td>
</tr>
<tr>
<td><strong>Salmonella spp.</strong></td>
<td>1.5</td>
<td>1.2</td>
</tr>
<tr>
<td><strong>Hookworm</strong></td>
<td>13.6</td>
<td>10.9</td>
</tr>
<tr>
<td><strong>Ascaris</strong></td>
<td>10.1</td>
<td>8.2</td>
</tr>
<tr>
<td><strong>S. haematobium</strong></td>
<td>4.2</td>
<td>3.1</td>
</tr>
<tr>
<td><strong>S. mansoni</strong></td>
<td>8.8</td>
<td>7.3</td>
</tr>
<tr>
<td><strong>T. trichiura</strong></td>
<td>4.7</td>
<td>3.9</td>
</tr>
</tbody>
</table>

Table 2 | Summary of analysis of microbial parameters in fecal sludge

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Peri-urban</th>
<th>Rural</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cd</strong></td>
<td>3.978</td>
<td>0.339</td>
</tr>
<tr>
<td><strong>As</strong></td>
<td>2.492</td>
<td>0.930</td>
</tr>
<tr>
<td><strong>Pb</strong></td>
<td>0.160</td>
<td>0.050</td>
</tr>
<tr>
<td><strong>Cu</strong></td>
<td>0.152</td>
<td>0.025</td>
</tr>
</tbody>
</table>

Figure 1 | Mean concentrations (mg/l) of heavy metals (Cd, As, Pb) in peri-urban and rural fecal sludge. Vertical bars show the standard errors of means (n = 3).
petrochemicals and agro-based industries, which contain pesticides and fertilizer residues (Pierce et al. 1998). The levels of Cu could also be as a result of natural (wind-blown dust, decaying vegetation, forest fires) or human-induced (mining, industrial works, agrochemicals) activities. On the basis of iron (Fe) concentrations, recorded mean values ranged from a minimum of 2.166 mg/l to a maximum of 2.723 mg/l for peri-urban areas and a minimum of 0.872 mg/l to a maximum of 0.968 mg/l for rural areas (Table 1). The presence of iron could be as a result of infiltration as rainfall seeps through the soil and dissolves iron in the earth’s surface and carries it into the toilet pits (Dima et al. 2006). The Fe in the peri-urban sludge slightly exceeded the Ghana EPA maximum permissible level of 2.0 mg/l whereas that of the rural sludge was within the limit. This means that fecal sludge can be discharged into the environment without any effect of Fe. The mean levels of lead (Pb) measured were higher in the peri-urban sludge compared to that in the rural areas (Table 1). The presence of Pb in the sludge could be as a result of the disposal of unapproved materials such as lead-acid batteries, rubber and plastics which are disposed of into toilet pits. A study by Appiah-Effah et al. (2014) on fecal sludge management in low income areas revealed that users of public toilets dispose of materials such as plastics, bottles and stones into the pit. The levels of Pb may also be due to leachate from the dump sites usually located close to public toilets, where used motor oils and discarded electronic gadgets, including televisions, calculators and stereos (Woodbury 1992) are disposed of. There were variations in levels of Pb across the different sampling periods (Figure 1). The levels of Pb in rural sludge agrees with the Ghana EPA maximum permissible limit (0.10 mg/l) for discharge whereas that of the peri-urban sludge slightly exceeded it. This indicates that peri-urban sludge could not be discharged into the environment directly without any form of treatment. The results indicated higher levels of cadmium (Cd) in peri-urban areas compared to the rural areas \((p < 0.0002)\) (Table 1) but they were lower than the Ghana EPA permissible limit of <0.1 mg/l. In the environment, cadmium is reported to be toxic to especially animals and microorganisms. The observed levels of Cd in the fecal sludge may be from diffuse sources such as food products, detergents and body care products, and storm water (Ulmgren 2000a, 2000b). Leachate from dump sites which may contain disposed nickel-cadmium batteries and plastics stabilized with cadmium could also contribute to the levels of Cd.

The mean concentrations of 2.235 \(\pm\) 0.102 mg/l and 1.291 \(\pm\) 0.096 mg/l were measured for peri-urban and rural areas, respectively, for zinc (Zn) (Figure 2). The presence of Zn in the sludge may be due to leaching of zinc residue contained in waste after electroplating, smelting, ore processing (ATSDR 1999) and deodorants and cosmetics disposed off at the dump site usually located close to the public toilet. More Zn was observed in the peri-urban sludge compared to that of the rural

![Figure 2](https://iwaponline.com/wpt/article-pdf/10/1/124/89209/wpt0100124.pdf)
which exceeded the Ghana EPA maximum level of 2.0 mg/l. This could be true as more blacksmiths were identified in the peri-urban areas compared to the rural areas. Analyses of fecal sludge samples showed the levels of manganese and arsenic in the peri-urban areas to be $4.571 \pm 0.320$ mg/l and $0.152 \pm 0.027$ mg/l, respectively (Figure 2). However, the concentrations of manganese (Mn) and arsenic (As) were respectively $0.992 \pm 0.160$ mg/l and $0.025 \pm 0.005$ mg/l for rural areas (Table 1). Arsenic concentration in fecal sludge is of importance due to its potential effects on humans and other living organisms. As the level of As was exceeded in the peri-urban sludge, the rural sludge remained within the permissible limits of the Ghana EPA (0.20 mg/l). The levels of As may be due to the use of washing products for the cleaning of the toilets and medicines which may be disposed of into toilet pits. Soil particles could also contribute to the concentration of As as it contains relatively high contents of As (Guillemet et al. 2009).

The concentrations of heavy metals in mg/l of fecal sludge from rural areas were significantly less compared to those obtained for peri-urban areas. These concentrations were in the order of Mn > Cu > Fe > Zn > Pb > Ar > Cd and Zn > Mn > Fe > Cu > Pb > Ar > Cd for peri-urban and rural areas, respectively. These present results of heavy metals' concentrations in the sludge agree with other studies reporting similar contaminations levels (Kuffour et al. 2013).

**Microbial parameters**

Fecal sludges contain pathogenic organisms and are liable to undergo biological action and thus should be handled with care (Environment Agency 2004). The high concentration of microorganisms may create a severe health risk when fecal sludge is discharged to receiving waters. There were slight variations in the total coliform population measured across the study duration. However, significantly high values were recorded for the third sampling (Figure 3). The total coliform population in fecal sludge from peri-urban areas ranged from $1.7 \times 10^7$ CFU/100 ml to $3.6 \times 10^7$ CFU/100 ml with a mean of $2.5 \times 10^7$ CFU/100 ml ± 0.71 (Table 2). There was no significant variation between the coliform counts in peri-urban and rural areas. Fecal coliform bacteria are indicators of fecal contamination and of the potential presence of pathogens associated with wastewater or sewage sludge (Environmental Factsheet 2003) and, for that matter, fecal sludge. The measured concentrations of fecal coliform for peri-urban areas ranged from $3.6 \times 10^7$ CFU/100 ml to $4.5 \times 10^7$ CFU/100 ml and $0.4 \times 10^6$ CFU/100 ml to $4.5 \times 10^6$ CFU/100 ml for rural areas ($p = 0.0012$) (Table 2). Significantly higher levels of fecal coliform populations were observed in fecal sludge sampled from peri-urban areas compared to the rural areas (Figure 3) but both however exceeded the maximum permissible limit (400 CFU/100 ml) defined by the Ghana EPA. In the peri-urban areas the mean

![Figure 3](https://iwaponline.com/wpt/article-pdf/10/1/124/89209/wpt0100124.pdf)
concentrations of E. coli population determined were $3.4 \times 10^6 \pm 1.05$ CFU/100 ml and $2.8 \times 10^6 \pm 1.50$ CFU/100 ml for rural areas ($p = 0.0191$) (Figure 4). The levels of Salmonella spp. ranged from $1.4 \times 10^6$ CFU/100 ml to $1.7 \times 10^6$ CFU/100 ml and $0.2 \times 10^6$ CFU/100 ml to $1.7 \times 10^6$ CFU/100 ml for peri-urban and rural areas, respectively (Table 2). Salmonella spp. has been considered the causal agent of the largest number of enteric infections in the world (Bell & Kyriakides 2002).

Figure 5 graphically illustrates the pattern of the measured levels of hookworm, Ascaris, S. haematobium, S. mansoni and T. trichiura. The mean hookworm ova were analyzed as 13.6 eggs/100 ml and 10.9 eggs/100 ml for peri-urban and rural areas, respectively ($p = 0.2096$). Helminth eggs (Ascaris, S. haematobium, S. mansoni and T. trichiura) are one of the most resistant pathogenic structures that might be found in fecal sludge. The mean number of Ascaris eggs were measured as 10.1 eggs/100 ml and 8.2 eggs/100 ml for peri-urban and rural areas, respectively. The measured range of values of S. haematobium was 2.0 to 5 eggs/100 ml for peri-urban and 1.1 to 5.0 eggs/100 ml for rural areas. Analysis of S. mansoni in 100 ml of fecal sludge samples showed a mean of $8.8 \pm 2.34$ eggs and $7.3 \pm 4.11$ eggs for peri-urban and rural areas, respectively ($p = 0.0302$) (Table 2). Observation on the periods of analysis for T. trichiura appears to show slight variations for both peri-urban and rural areas (Figure 5); however, it was not statistically significant (Table 2).
The eggs contained in the fecal sludge are not always infectious but are infectious when they are viable and the lavae develops. Similarly, the prevalence of the eggs could be attributed to human origin. Fecal sludge from peri-urban areas generally exhibited more numbers of eggs compared to that of rural areas (Figure 5).

CONCLUSIONS

Results from the study showed that the levels of heavy metals and microbial quantities were generally higher in peri-urban areas compared to rural areas. The variations in monitored parameters could be explained by a high sludge age or a high retention time of sludge in rural public toilets which may increase the mortality of fecal microorganisms. However, fecal sludge from both peri-urban and rural areas generally exceeds the Ghana EPA maximum permissible limits. This means that fecal slurdes are not recommended for direct use in agriculture unless they are given further treatment. Composting is recommended as a promising and suitable method for effective treatment of fecal sludge resulting in a hygienically safe and economically profitable product.

ACKNOWLEDGEMENTS

The authors would like to gratefully acknowledge the Water and Sanitation Management Teams, public toilet attendants within the selected peri-urban and rural communities for their kind help. Thanks to Bernard, Michael, Chris, Solomon and Barbara who assisted during sampling. Kingsley is also acknowledged for his help with the laboratory analysis of parameters. This study was financially supported by the SaniUP Project by the Bill and Melinda Gates Foundation.

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