

Sludge accumulation in an anaerobic pond and viability of helminth eggs: a case study in Burkina Faso

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ABSTRACT

Accumulation rates and pathogen concentrations in primary stabilization pond sludges in developing countries are important parameters for adequate sludge management and the safeguarding of public health with sludge reuse in agriculture. An anaerobic pond has been investigated for sludge accumulation rates and helminth egg viability after four years of operation in Burkina Faso. The rate of sludge accumulation was measured at 0.037 m³/capita-year or 2.26 kg dry weight/capita-year. An equation describing vertical distribution of total solids in the accumulated sludge was found to be adequately represented by a regression equation. Influent helminth egg concentrations were reduced on average by 90% in the anaerobic pond effluent. *Ascaris lumbricoides* and *Ancylostoma* sp. were the most common eggs present in the sludge after four years of operation. The average concentration of helminth eggs in pond sludge was 536 eggs/g TS, and the percentages of viability ranged from 10.8% (47 viable eggs/g TS) to 57.2 (1,772 viable eggs/g TS, with an average rate of 36% (336 viable eggs/g TS). From a sludge depth and section study, egg viability was found to be randomly distributed in the sludge layer.

Key words | anaerobic pond, egg viability, helminth, sahelian climate, sludge accumulation, sludge distribution

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INTRODUCTION

Wastewater stabilization ponds are a simple, low-cost and low-maintenance process for treating wastewater. Their usage in developing countries is advised when sufficient land is available and where the temperature is most favourable for their operation (Mara 2004; Nelson *et al.* 2004). A system is typically comprised of several different types of ponds in series, and usually the first pond is an anaerobic pond that serves as the primary treatment stage. The anaerobic pond's performance for BOD and SS removal is often improved in warm climates such those of sub-Saharan Africa. As with all primary stabilisation ponds, the anaerobic pond accumulates sludge that must be removed (desludged) in order to assure further sustainable operation of the pond. Raw wastewater and primary sludge

in developing countries, particularly in Sub-Saharan Africa, may contain significant concentrations of helminth eggs due to the high prevalence of infections related to the poor socio-economic conditions in these regions. The concentrations of these parasites must be known to estimate the risk they pose upon removal of the sludge from pond systems (Nelson 2003; Jiménez 2007; Sidhu & Toze 2009).

Saqqar & Pescod (1995) studied sludge accumulation in Jordan, Gonçalves (2002) reported data on sludge accumulation in Brazil, and Papadopoulos *et al.* (2003) and Picot *et al.* (2003) studied sludge accumulation patterns in anaerobic ponds under Mediterranean climatic conditions in France and in Northern Greece, respectively. Nelson *et al.* (2004) reported data on sludge accumulation,

characteristics and pathogen inactivation in Mexico, and stated that more regional data are needed to determine sludge accumulation rates sludge distribution and sludge characteristics. In Burkina Faso, no information is available on sludge characteristics and helminth egg concentrations in anaerobic ponds. Owing to the scarcity of data, the goal of this research was to evaluate sludge production and helminth egg viability in an anaerobic pond in the sahelian climate of Burkina Faso. The study comprises the following:

- (i) Determining the accumulation rate and distribution of sludge in an anaerobic pond
- (ii) Determining sludge characteristics
- (iii) Determining helminth egg concentrations and viability for risk assessment associated with sludge management for agriculture reuse, which is often the preferred option for farmers.

MATERIALS AND METHODS

Description of the experimental pond system

This work was carried out at the pilot scale wastewater stabilization pond system (12°22'N, 1°30'W) of the International Institute for Water and Environmental Engineering (2iE) of Ouagadougou, Burkina Faso. The system was designed for the sudano-sahelian climate, with a long dry season (from October to May) and a moderately favorable belt for solar energy, receiving 2,500 hours of solar energy per year with an intensity of 19.5–22.7 MJm⁻²d⁻¹. The rainy season from June to September was characterized by average pluviometer readings varying between 600 to 900 mm. The minimum monthly air temperatures varied from 16°C in January to 26.5°C in April, and the maximum ones varied from 32°C in January to 42°C in April. The monthly average temperature of the coldest month of the year (January) varied between 25°C and 26°C.

The anaerobic pond was built in 2004 as the first treatment pond in a series of ponds comprised of one anaerobic pond (AP), one facultative pond (FP) and one maturation pond (MP). The plant treats wastewater from the 2iE campus. With a hydraulic retention time of three days, the anaerobic pond was constructed in replacement of a primary settling tank that was found to be inefficient for

the loads applied. The anaerobic pond receives screened raw wastewater which enters the pond at 1 m depth and discharges at 300 mm below the surface. The anaerobic pond has a vertical geometry form of a cylinder-cone, and the surface is egg-shaped, with the top surface of 103 m² and the bottom surface of 8 m². Its total depth is 3.1 m with 0.5 m free board and a wall slope of 2/3. Its effective depth is 2.6 m and the volume is 181 m³.

During the four years of operation (from October 2004 to September 2008) the pond received flow rates ranging from 40 to 66 m³d⁻¹, with an average flow rate of 55 m³d⁻¹. This flow rate variation corresponded to the volumetric organic loading of 104 to 225 g BOD m⁻³d⁻¹. The organic load was equivalent to 448 PE.

Sampling method

Sludge sampling was performed in September 2008 during bathymetric surveys of the distribution of sludge in the anaerobic pond after four years of continuous operation. The pond was divided in 12 bathymetric sections spaced by 1 m as shown in the Figure 1. The sludge layers in the pond were measured for depth and samples were collected to determine sludge characteristics and the type and concentration of helminth eggs. The sludge depth was measured with the white towel test technique described by Mara (2004). With a pre-prepared grid representing the pond, five points (as illustrated in Figure 1) were chosen for full depth sludge samples; grab samples were also taken at different depths of 10 cm, from the bottom (level zero) to the top of sludge layer.

The sludge cores were collected using a transparent plexiglass tube with a diameter 60 mm and length of 3.5 m.

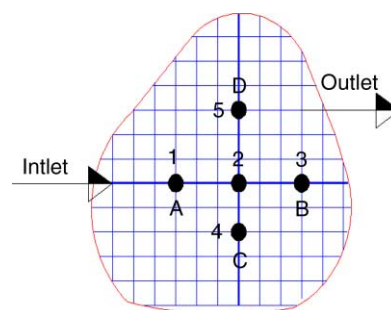


Figure 1 | Pre-prepared grid of the anaerobic pond.

The tube was opened at its base and supplied with a movable faucet which adheres well to the base of the tube, preventing any flow when it is closed.

The faucet was tied at its two sides by a long rope hanging freely inside the tube. The procedures of sludge cores sampling consisted of: i) to lower the tube vertically into the pond (at point of sampling) until it reaches the bottom; ii) then, the rope was pulled and the faucet traps the column of sludge; and iii) the tube was then taken away in an upright position and the sludge was collected at the tube base by opening the faucet and removing the overlaying water. For grab sampling at different depths, a device called a “shaft syringe” was used (Figure 2). This was comprised of syringes of 50 ml attached at different levels around an iron shaft. A rope was attached at the piston of the syringe which permitted the sludge to be aspirated. Each rope attached to a syringe was identified by a label that marked the depth of the corresponding sludge sample. Three shaft syringes were used simultaneously. The first shaft syringe was fixed at the zero level for the bottom sampling collection and the remaining syringes were fixed at intervals of 30 cm. The second shaft syringe was fixed at the distance of 10 cm from the end on the shaft and the others were spaced at 30 cm intervals. The third shaft syringe was fixed at the 20 cm level from the end of the shaft and the remaining syringes were spaced at 30 cm intervals. The shaft syringes permitted simultaneous sludge sampling at different depths spaced at 10 cm intervals.

Basic physical and chemical properties of the sludge samples were measured, including pH, conductivity, total solids (TS), fixed solids (FS) and volatile solids (VS) according to *Standard Methods* (2005). Sludge density and percentage of water content (WC) were also measured.

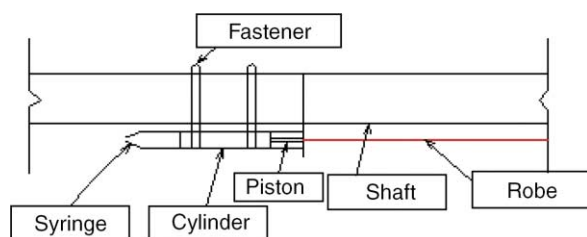


Figure 2 | Device of shaft syringe.

Helminth eggs concentration and viability test

There are different analytical procedures to recover and detect viable and non viable helminth eggs. For this study, the helminth eggs and their viability were determined by combining the US EPA protocol (1999) modified by Schwartzbrod (2003) with the adapted safranin O (2.5% in H₂O) dying method developed by de Victorica & Galvan (2003). This procedure permitted an accuracy of recovered eggs amounting to 75.5% when applied to biosolid analysis (Bowman *et al.* 2003).

RESULTS

Sludge distribution and accumulation

After four years of operation the volume of sludge was measured at 66 m³, representing 36.5% of the pond volume. This percentage is slightly higher than that (one-third full of sludge) recommended by Mara (2004) for anaerobic pond desludging.

With an organic load equivalent to 448 PE, the sludge accumulation rate for the anaerobic pond was calculated to be 0.037 m³/capita year. This rate is greater than those reported by Picot *et al.* (2003) in France (0.017 m³/capita year), and Nelson *et al.* (2004) in central Mexico (0.022 m³/capita year). The rate obtained in this study is relatively similar to the value of 0.04 m³/capita year reported by Mara (2004) in warm climates, the value of 0.05 m³/capita year reported by Pena *et al.* (2000) in Columbia, and the value of 0.0519 m³/capita year reported by Gonçalves (2002) in Brazil.

The rate of sludge accumulation expressed in dry weight per person per year was 2.26 kg dw/capita- year. This value is less than the median value of 6 kg dw/capita year obtained on 19 primary facultative ponds located in the south of France, in operation from 13 to 24 years, reported by Picot *et al.* (2005). The lower accumulation rate in Burkina Faso may be partly due to higher temperature and higher anaerobic degradation.

Sludge characteristics

Data on sludge characteristics are shown in Table 1. Temperature and pH showed weak variation in the sludge

Table 1 | Sludge characteristics

Parameters	Mean	Min	Max	σ
Temperature °C	26.5	22.3	31.2	2.8
pH	6.4	6.4	6.5	0.01
Conductivity $\mu\text{S cm}^{-1}$	2,988	1,862	4,480	865
Density	1.1	11	1.13	0.02
Water content %	93.9	86.9	99.7	2.4
Total solids (TS) %	6.1	0.2	13	2.4
Fixed solids (%TS)	50.6	28.3	80.5	7.4
Volatile solids (%TS)	49.4	19.5	71.7	7.4

even if the global trend slightly decreased with sludge depth (from the top to the bottom), whereas the conductivity increased from the bottom to the top. The ranging values of WC (86.9%–99.7%) and TS (0.2%–13%) show that the sludge consistency ranged from liquid to pasty forms; the higher values for TS were observed in the first five centimeter depths starting at the bottom of the pond. The average values found for VS of less than 50% indicated the sludge was well digested.

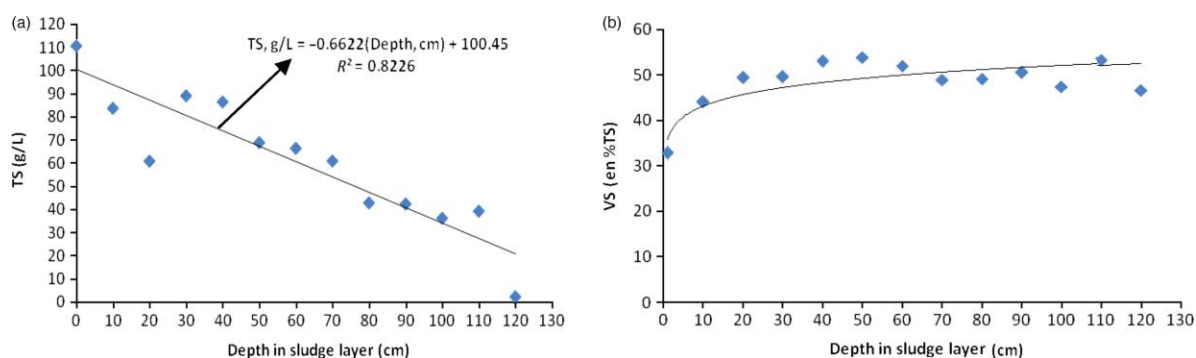
The solids concentrations expressed in term of total solids (TS) were found to be correlated with depth within the sludge layer, with a coefficient of determination R^2 equal to 0.82 (Figure 3(a)). Nelson *et al.* (2004) have found similar correlation of TS with depth ($R^2 = 0.84$) in anaerobic and facultative pond sludge layers. In accordance with these authors, this regression equation can be used to estimate the solids concentration of the sludge if the thickness of sludge layer is known. This information is useful to develop more accurate methods for sludge

accumulation and biodegradation estimation and can help for predicting appropriate methods for sludge removal.

The ratio of volatile solids to total solids was considered as an approximate measure of the fraction of organic matter in the sludge. Considering the vertical distribution of volatile solids within the sludge layer (Figure 3(b)), no relationship was found between the concentration of VS expressed in terms of % TS and the depth in sludge layer. The main conclusion that can be drawn was that the sludge in the first 10 cm layer from the bottom of pond was more mineralized, with a concentration of VS varying from 33% to 44% of TS.

Helminth removal in the anaerobic pond

The influent helminth eggs concentrations were variable, ranging from zero to 15 helminth eggs per litre with an average of 10 eggs/l. The helminth eggs detected in raw wastewater were those of *Ascaris lumbricoides* (0 to 10 eggs/l), *Ancylostoma* sp. (0 to 4 eggs/l), *Trichuris trichiura* (0 to 1 egg/l), and *Trichostrongylus* sp. (0 to 1 egg/l). The four genera of helminth eggs identified in the raw sewage represented the following percent composition: *Ascaris lumbricoides* (45.5%), *Ancylostoma* sp. (37%), *Trichuris trichiura* (9%) and *Trichostrongylus* sp. (8.5%). The concentrations of helminth eggs were representative of the campus wastewater of 2iE and illustrate the level of prevalence among students. The concentrations are lower than those reported in literature reviews for urban area wastewaters in Africa and others developing countries. The concentration of eggs in wastewater and sludge are likely to reflect the prevalence in the community (Llyod & Frederick 2000).

**Figure 3** | Total solids (left) and volatile solids (right) as a function of depth in sludge layer. Depth 0: correspond to the bottom of pond.

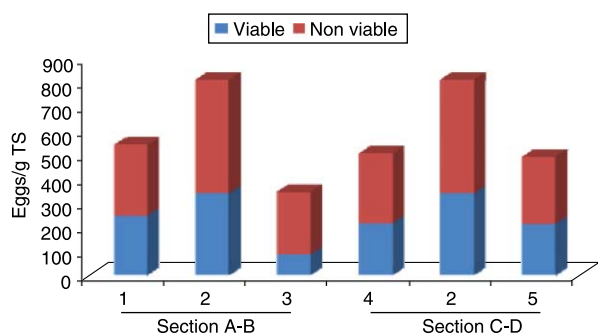


Figure 4 | Distribution of helminth eggs in sludge along the length and width of the pond.

The findings in this study are representative of the 2iE campus, where students and staff receive hygiene education and integrated interventions such as de-worming to reduce the risk of helminth transmission.

Routine monitoring of helminth eggs in the anaerobic pond (HRT = 3 days) for one year showed a removal efficiency of 90%; the raw sewage and pond effluent contained a mean of 10 and 1 eggs per litre, respectively. It is widely assumed that nematode eggs are removed from all types of wastewater stabilisation ponds by sedimentation, and is a function of hydraulic residence time (Ayers et al. 1993).

Accumulation of helminths eggs in the sludge

All the species observed in raw sewage were found present in the sludge layers: *Ascaris lumbricoides*, *Ancylostoma* sp, *Trichuris trichiura* and *Trichostrongylus* sp. The vertical distribution of helminth eggs was studied at five locations along Section A–B (Figure 1) and included locations near the inlet (location 1), middle (2), outlet (3); and the crosswise Section C–D, which included the right side (4) and the left side (5). At the sampling points, the thicknesses of sludge layer were: 1 (48 cm), 2 (126 cm), 3 (57 cm), 4 (67 cm), 5 (56 cm).

The concentration of total helminth eggs showed (Figure 4) higher values in the middle point, (location 2) with 807 eggs/g TS, than near the inlet (538 eggs/g TS) and the outlet 343 eggs/g TS. At the right side (point 4) and the left side (point 5), these concentrations were, respectively, 504 eggs/g TS and 489 eggs/g TS. The average concentration was 536 eggs/g TS. Regarding the distribution of eggs at the five locations, it is likely the concentration of eggs was a function of the height of accumulated sludge with a maximum observed in the middle of the pond. The results on column sludge measured show the following species composition (%) of helminths eggs per g/TS: *Ascaris*

Table 2 | Vertical distribution of the species of helminth eggs found in sludge layer

Depth (cm)	<i>Ascaris lumbricoides</i>		<i>Ancylostoma</i> sp.		<i>Trichuris trichiura</i>		<i>Trichostrongylus</i> sp.		Total count eggs/g TS	
	V	NV	V	NV	V	NV	V	NV	V	NV
0	11	36	90	109	0	4	18	34	119	183
10	31	114	33	45	0	1	0	0	64	161
20	38	116	35	42	0	0	8	3	81	161
30	95	202	258	157	0	0	67	11	421	371
40	58	150	150	313	0	0	35	35	243	497
50	116	138	29	65	0	0	15	15	160	218
60	60	181	72	108	0	0	24	12	157	301
70	65	158	328	486	0	13	53	53	446	709
80	37	137	131	561	0	0	19	0	187	698
90	19	152	9	222	0	9	19	5	47	388
100	120	88	133	387	0	0	44	44	297	519
110	114	31	265	500	1	20	0	31	380	581
120	1,327	442	442	885	2	0	0	0	1,772	1,327

Notes: V, viable; NV, non viable. Depth 0: correspond to the bottom of pond.

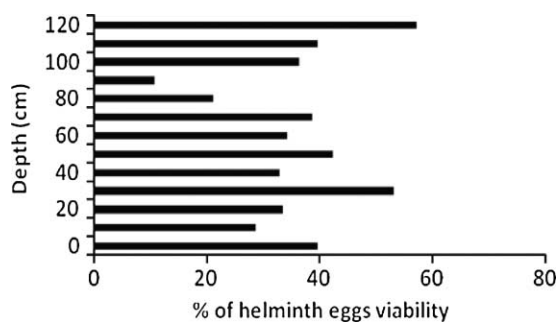


Figure 5 | Eggs viability along the depth profile.

lumbricoides 38.5%, *Ancylostoma* sp. 55.8%, *Trichuris trichiura* 0.5%, and *Trichostrongylus* sp. 5.2%. *Ascaris lumbricoides* and *Ancylostoma* sp. were the most common eggs present in the sludge after four years operation.

Viability of helminth eggs in the sludge

The main risk in sludge management in term of public health is the viable fraction of helminth eggs and the potential for infection (Zerbini & Chermicharo 2001 in Von Sperling *et al.* 2003). The pond sludge, after four years of operation, showed a percentage of viable eggs (along Section A–B) of 46 percent near the inlet (1), 42 percent at the middle (2), and 24 percent near the outlet (3). The percent viability was similar at the two sides on the pond along the section C–D with 42 percent of helminth eggs viability. The viabilities observed were less than 50% at each sample location, with a slightly decrease from the inlet to the outlet along the length of pond (section A–B). No significant trend was observed along the width (section C–D).

Table 2 presents the vertical distribution of the species of helminth eggs in the sludge in units of eggs/g TS that was found at regular intervals from the bottom (level zero) to the top layer (120 cm); the top layer corresponds to recently deposited sludge. All the samples (100%) analysed at different depth locations were positive for viable helminth eggs. This could mean that there is not yet a safe sludge depth in the vertical distribution of helminth eggs in this study. The percentage of helminth egg viability (Figure 5) varied widely, from a minimum 10.8% (47 viable eggs/g TS) measured at the level of 90 cm from the bottom to a maximum of 57.2% (1,772 viable eggs/g TS) measured at level 120 cm from the bottom (i.e., in the surface layer). The

average percentage viability was 36% (336 viable eggs/g TS). The percentage of viable helminth eggs observed at different depths in the sludge layers were found to be randomly distributed without a clear trend. While it might be expected that the distribution of viable eggs would decrease with depth in sludge layer, this was not the case: In our study, the random distribution could be explained by spatial heterogeneity and re-suspension of sediment induced by gas production in the anaerobic sludge layer. The presence of viable helminth eggs at the deepest sludge layer confirm that public health issues must be considered for desludging and agriculture reuse.

CONCLUSION

In this study the rate of sludge accumulation in an anaerobic pond in a sahelian climate was estimated to be 0.036 m³/capita-year or 2.26 kg dw/capita-year. The measured distribution of total solids and moisture content showed that the sludge consistency varied from liquid to pasty. The vertical distributions of TS and VS indicate a consolidation and mineralization of sludge with depth.

The removal efficiency of helminth eggs from the wastewater was 90% in the anaerobic pond, with had a hydraulic residence time of 3 days. The prevailing helminth species found in the sludge were *Ancylostoma* sp. and *Ascaris lumbricoides*. The higher percentage of viable helminth eggs were found in the surface layers of sludge. Although helminth egg viability decreased with depth in the sludge layer, the residual percentage of viable eggs found after 4 years of operation demonstrate the need for further treatment before final disposal or reuse for land application. Sludge treatment should be done at low cost taking into account the financial constraints prevailing in sub-Saharan Africa regions. Co-composting and drying bed technology for sludge treatment will be our next investigations for sludge management.

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