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FACULTE DES SCIENCES
DEPARTEMENT DE BIOLOGIE ET PHYSIOLOGIE VEGETALES
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CENTRE DE RECHERCHE DE FORMATION DOCTORALE SCIENCE DE LA VIE, SANTE ET ENVIRONNEMENT

REPUBLIC OF CAMEROUN
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UNIVERSITY OF YAOUNDE I
FACULTY OF SCIENCE
DEPARTMENT OF PLANT BIOLOGY
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CENTRE FOR RESEARCH AND DOCTORAL TRAINING IN GRADUATE STUDIES IN LIFE SCIENCE, HEALTH AND ENVIRONMENT

Variability of on-site sanitation faecal sludge of a tropical urban area and study of the factors affecting the fate of intestinal helminth eggs in planted drying beds for faecal sludge dewatering

Dissertation Defended for the Award of a Doctorate/Ph. D in Plant Biology

Par : **LETAH NZOUEBET Wilfried Arsène**
MSc. in Plant Biotechnology

Sous la direction de
KENGNE NOUMSI Ives Magloire,
Associate Professor, University of Yaounde I

Année Académique : 2018

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FACULTY OF SCIENCE

DÉPARTEMENT DE BIOLOGIE ET PHYSIOLOGIE VÉGÉTALES
DEPARTEMENT OF PLANT BIOLOGY

Yaoundé, le 22 OCT 2018

ATTESTATION DE CORRECTION

****

Nous soussignés, membres du jury de soutenance de la thèse de **Doctorat/Ph. D** en **Biologie et Physiologie Végétales**, soutenue le mercredi **05 septembre 2018** par Monsieur **LETAH NZOUEBET Wilfried Arsène**, Master ès Science, Matricule **05U058**, intitulée «***Variability of on-site sanitation faecal sludge of a tropical urban area and study of the factors affecting the fate of intestinal helminth eggs in planted drying beds for faecal sludge dewatering*** », certifions qu'il a effectué les corrections conformément aux remarques et recommandations du jury.

En foi de quoi, nous lui délivrons cette attestation de correction pour servir et valoir ce que de droit. /-

Président du Jury

Emmanuel Youmbi
Professeur

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15	ABOSSOLO née ANGUE Monique	Chargée de Cours	*Chef div. DAASR / FS*
16	BEKOA Etienne	Chargé de Cours	En poste
17	BISSO Dieudonné	Chargé de Cours	*Dir. P. Barrage Memvele*
18	EKOMANE Emile	Chargé de Cours	En poste
19	ESSONO Jean	Chargé de Cours	*C.E.A. MINES*
20	GANNO Sylvestre	Chargé de Cours	En poste
21	GHOGOMU Richard TANWI	Chargé de Cours	En poste
22	LAMILEN BILLA Daniel	Chargé de Cours	En poste
23	MBIDA YEM	Chargé de Cours	*CS/LABOGENIE*

24	MINYEM Dieudonné-Lucien	Chargé de Cours	*Dir. de Project "Hydro-MIN"*
25	MOUAFO Lucas	Chargé de Cours	En poste
26	MOUNDI Amidou	Chargé de Cours	*Chef Div. MINIMDT*
27	NJOM Bernard de Lattre	Chargé de Cours	En poste
28	NGO BELNOUN Rose Noël	Chargée de Cours	En poste
29	NGO BIDJECK Louise Marie	Chargée de Cours	En poste
30	NGUETCHOUA Gabriel	Chargé de Cours	En poste
31	NYECK Bruno	Chargé de Cours	En poste
32	ONANA Vincent	Chargé de Cours	En poste
33	TCHAKOUNTE J. épse NOUMBEM	Chargée de cours	*CT / MINRESI*
34	TCHOUANKOUE Jean-Pierre	Chargé de Cours	En poste
35	ZO'O ZAME Philémon	Chargé de Cours	*S.G. MINTP*
36	ANABA ONANA Achille Basile	Assistant	En poste
37	FUH Calistus Gentry	Assistant	*Sec. D'Etat/MINMIDT*
38	METANG Victor	Assistant	En poste
39	NOMO NEGUE Emmanuel	Assistant	En poste
40	TCHAPTCHET TCHATO De P.	Assistant	En poste
41	TEHNA Nathanaël	Assistant	En poste
42	TEMGA Jean Pierre	Assistant	En poste

Répartition chiffrée des Enseignants de la Faculté des Sciences de l'Université de Yaoundé I

	NOMBRE D'ENSEIGNANTS				
DÉPARTEMENT	**Professeurs**	**Maîtres de Conférences**	**Chargés de Cours**	**Assistants**	**Total**
B.C.	5 (1)	8 (3)	17 (12)	11 (4)	**41 (20)**
B.P.A.	10 (0)	9 (2)	11 (5)	14 (5)	**44 (12)**
B.P.V.	1 (0)	7 (0)	12 (4)	6 (6)	**26 (10)**
C.I.	7 (1)	10(1)	11 (2)	5 (2)	**33 (6)**
C.O.	9 (0)	10 (3)	13 (4)	2 (0)	**34 (7)**
I.N.	3 (1)	2 (0)	6 (0)	14 (3)	**25 (4)**
M.A.	5 (0)	7 (0)	18 (1)	5 (0)	**35 (1)**
M.B.	1 (0)	4 (1)	6 (2)	2 (0)	**13 (3)**
P.H.	7 (0)	11 (1)	19 (3)	3 (1)	**40 (5)**
S.T.	4 (0)	10 (1)	21 (4)	7 (0)	**42 (5)**
Total	**52 (3)**	**78 (12)**	**134 (37)**	**69 (21)**	**333 (73)**

Soit un total de 333 (73) dont :

- Professeurs 52 (3)
- Maîtres de Conférences 78 (12)
- Chargés de Cours 134 (37)
- Assistants 69 (21)

( ) = Nombre de Femmes

DEDICATION

To

My dear wife TCHANGOU TIAHA Suzy Stephanie and our child LETAH DE NZOUEBET Marc Johan

.

My parents Mr. and Mme LETAH

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ABSTRACT

This study describes the variability of on-site sanitation faecal sludge (FS) and the factors affecting the fate of intestinal helminth eggs in planted drying beds during sludge dewatering. The methodology started with a survey conducted at household levels against eight proposed indicators of hygienic safety, sustainability and functionality, and in relation to the Millennium Development Goal (MDG) 'improved' sanitation definition. Based on the heterogeneous stratified sampling method, a total of 602 households were randomly selected in different urban settlements of the Yaounde town and semi-structured interviews conducted with the households having direct access to latrines in order to collect data regarding the education level of householders, socioeconomic status of householders, management of toilet facilities as well as the health status of the latrine users. A total of 53 different samples originating from various sanitation systems found around the town represented by septic tanks (n=13), traditional pit latrines (n=30), ventilated improved pit latrines (n=4) and pipe equipped latrines (n=6) were sampled. The samples were analyzed for physico-chemical parameters (pH, electric conductivity, COD, BOD_5, NH_4^+, TKN, DM, water content), heavy metals (Cd, Pb, Mn, Cu, Fe, Cr and Zn) and helminth eggs using standard protocols. The variability of samples depending on the mentioned parameters was assessed using hierarchical cluster analysis (HCA) and principal component analysis (PCA). Regarding the specific objective which aimed at the study of factors affecting the fate of intestinal helminth eggs in planted drying beds, three hydraulic retention times were tested (free flow, 7 days retention time, 14 days retention time) as well as the growth rate of the plants were evaluated. The performance of the system expressed in terms of pollutants removal efficiencies were also calculated at each hydraulic retention time tested. The quality of biosolids accumulated on the bed units were also analyzed.

The results revealed the variation of the type of sanitation devices in use at household levels independent of the urban settlement with the predominance of the traditional pit latrines (52 %, n=602), followed by septic tanks (40 %, n=602). Some of the households investigated (3 %, n=602) didn't have any on-site sanitation technologies and practiced open defecation into the natural environment. The Pearson Chi-Square correlation test revealed significant relationships between the educational level of households (p<0.001), the monthly income of households (p<0.001) and the type of on-site sanitation systems at the household levels. Based on the survey results, 38.29 % of the investigated population (n=598) have suffered from several cases of faecal-oral diseases within the past six months of the survey date with prevalence varying with the current defecation practices in place. Looking at the detection frequency (positive test) of helminth eggs in the 53 raw sludge samples, the distribution of prevalence were *Ascaris lumbricoides* (64.15 %), *Taenia* sp. (32.07 %), *Enterobius vermicularis* (32.07 %), *Strongyloides stercoralis* (30.18 %), *Trichuris trichiura* (26.41 %), *Schistosoma mansoni* (20.75 %), *Hymenolepis nana* (20.75 %), *Fasciola hepatica* (20.75 %) and *Ankylostoma duodenale* (20.75 %). The parasite *A. duodenale* had the lowest detection frequency. The mean values of the prevalence recorded were 34.93 eggs/g DM (*F. hepatica*), 33.07 eggs/g DM (*A. lumbricoides*), 31.09 eggs/g DM (*A. duodenale*), 30.46 eggs/g DM (*T. trichiura*), 28.69 eggs/g DM (*Taenia* sp.), 27.06 eggs/g DM (*S. stercoralis*), 25.67 eggs/g DM (*E. vermicularis*), 18.68 eggs/g DM (*H. nana*), 23.98 eggs/g DM (*S. mansoni*) and 77.41 eggs/g DM (Total helminth eggs). There was a significant difference (α= 0.05 confidence level) in the concentration of the helminth eggs species between the groups of latrines (p<0.038). In general, the obtained concentrations of physico-chemical parameters were 7.25±0.70 (pH), 5.45±3.87 mS/cm (EC), 36.71±33.86 gO_2/L (COD), 4.55±4.23 gO_2/L (BOD_5), 0.57±0.55 g/L (NH_4^+), 1.70±1.49 g/L

(TKN), 41.65±7.58 % (DM) and 58.34±7.58 % (water content). However, the samples from traditional pit latrines and ventilated improved pit latrines exhibited higher concentration of organic parameters (COD, BOD_5) and dry matter content. Assessment in the variation of the sludge physico-chemical parameters as function of latrine type using one way ANOVA test ($\alpha=0.05$) revealed a strong significant difference in the distribution of the parameters COD ($p<0.04$), TKN ($p<0.033$) and DM ($p<0.00043$). With regards to the heavy metal concentrations, the values recorded were 0.35±0.34 mg/L (Cd), 0.44±0.39 mg/L (Pb), 1.68±1.45 mg/L (Cu), 5.01±3.72 mg/L (Zn), 7.40±6.20 mg/L (Fe), 16.56±11.85 mg/L (Mn), 0.28±0.27 mg/L (Cr). Assessment of the distribution with function in the type of latrines revealed the significant differences for the parameters Pb ($p<0.00517$), Fe ($p<0.000648$), Zn ($p<0.00413$). The PCA of the physico-chemical parameters for the pit latrines FS samples revealed that the fist component of the analysis explained 78 % of the total variance and is strongly correlated (positive) with COD (0.812), BOD_5 (0.589), NH_4^+ (0.731), DM (0.870), water content (0.870), TKN (0.866). Looking at the PCA for helminth eggs composition, the first component which explained 72.26 % of variation is positively correlated with *Ascaris lumbricoides* (0.564), *Hymenolepis nana* (0.558), *Trichuris trichiura* (0.736), *Schistosoma mansoni* (0.538), *Enterobius vermicularis* (0.613) and the total helminth eggs (0.757) while the first component of the PCA for heavy metals expressed 47.89 % of the total variance and positively correlated with the parameters Cu (0.55), Mn (0.72) and Cr (0.67). With regards to the hygienic quality of the outlet leachates coming from the planted drying bed units, the recorded mean concentrations in the leachates were in the order of 3.3 eggs/g of DM, 2.7 eggs/g of DM, 2.25 eggs/g of DM and 3.36 eggs/g of DM respectively for free flow, 7 days retention time, 14 days retention time and unplanted drying beds. Biosolids removed on the beds revealed high concentration of helminth eggs most of which belonged to the class of Nematoda, with *Ascaris lumbricoides* which is the most common species detected (80%). The removal efficiencies of helminth eggs were affected by the hydraulic retention times and the presence of plants ($p<0.05$).

This study revealed high concentrations in physico-chemical, heavy metals and helminth eggs recorded in the faecal sludge thereby constitutes a general health concern and the need for proper health and environmental protection measures must be stressed out to prevent diseases transmitted by helminth eggs and heavy metals due to untreated sludge discharge into the environment after latrine emptying or via direct agricultural use.

Keywords: Faecal sludge management, variability, on-site sanitation systems, health consideration, planted drying beds, tropical urban area, Yaounde.

RESUME

Le présent travail de recherche vise à décrire la variabilité des boues de vidange collectées dans les ouvrages d'assainissement autonomes et l'étude des facteurs affectant l'élimination des œuf d'helminthes par les filtres plantés de roseaux lors de la déshydratation des boues de vidange. La méthodologie adoptée consistait en des enquêtes auprès des ménages sur la base des huit indicateurs de l'Objectif du Millénaire pour le Développement (OMD) à savoir la qualité hygiénique, la durabilité et la fonctionnalité des ouvrages. Sur la base d'un échantillonnage aléatoire stratifié hétérogène, un total de 602 ménages ayant un accès direct aux latrines a été sélectionné dans différents secteurs urbains de la ville de Yaoundé et un questionnaire d'enquête semi-structuré a été administré dans le but de collecter les informations sur le niveau d'éducation du chef de ménage, le statut socio-économique du ménage, la gestion des ouvrages d'assainissement autonome et le statut sanitaire des utilisateurs des latrines. La corrélation entre les caractéristiques socio-économiques des ménages investiguées, le type d'ouvrage d'assainissement en place, le matériel de construction de l'ouvrage, la prévalence des maladies hydriques et la gestion des ouvrages a été analysée. Un total de 53 échantillons de boues de vidange a été collecté dans différents secteurs urbains de la ville représenté par les latrines traditionnelles (n=30), les fosses septiques (n=13), les latrines VIP (n=4) et les latrines à canon (n=6). La composition physico-chimique (pH, conductivité électrique, DCO, DBO_5, NH_4^+, TKN, matière sèches, teneur en eau), les teneurs en métaux lourds (Cd, Pb, Mn, Cu, Fe, Cr et Zn) et la concentration en œuf d'helminthes ont été analysés dans les échantillons suivant les protocoles standards. L'analyse en composante principale et l'analyse de la classification hiérarchique ont été effectuées pour l'étude de la variabilité des échantillons. S'agissant de l'objectif spécifique qui était d'étudier les facteurs affectant l'élimination des œufs d'helminthes lors de la déshydratation des boues de vidange au sein des filtres plantés de roseaux, trois temps de rétention hydrauliques (libre écoulement, rétention hydraulique de 7 jours, rétention hydraulique de 14 jours) ont été testés ainsi que le suivi des paramètres de croissance des plantes. Les performances épuratoires du système ont été évaluées ainsi que l'analyse de la qualité hygiénique des biosolides.

Une hétérogénéité dans la distribution des ouvrages d'assainissement autonomes au sein des ménages des différents secteurs urbains de la ville a été enregistrée avec une prédominance des latrines traditionnelles (52 %, n=602), suivi des fosses septiques (40 %, n=602). Cependant la défécation à l'air libre a été identifiée dans 3 % des ménages investigués. Le test de corrélation (Pearson Chi-Square) a revélé un effet significatif de l'influence du niveau d'éducation du chef de ménage ($p<0.001$), le revenu mensuel du ménage ($p<0.001$) et le type d'ouvrage d'assainissement au sein du ménage. Environ 38.29 % de la population étudiée (n=598) a mentionné avoir été atteinte des maladies liées à l'eau durant la période de six mois précédant la date des enquêtes, avec un taux de prévalence variant selon le type d'ouvrage d'assainissement en place. Les fréquences de détection des œufs d'helminthes identifiés dans les 53 échantillons de boues ont été de 64,15 % (*Ascaris lumbricoides*), 32,07 % (*Taenia* sp.), 32,07 % (*Enterobius vermicularis*), 30,18 % (*Strongyloides stercoralis*), 26,41 % (*Trichuris trichiura*), 20,75 % (*Schistosoma mansoni*), 20,75 % (*Hymenolepis nana*), 20,75 % (*Fasciola hepatica*), 20,75 % (*Ankylostoma duodenale*). La moyenne des prévalences en espèces parasitaires dans les échantillons a été de 34,93 œufs/g MS (*F. hepatica*), 33,07 œufs/g MS (*A. lumbricoides*), 31,09 œufs/g MS (*A. duodenale*), 30,46 œufs/g MS (*T. trichiura*), 28,69 œufs/g MS (*Taenia* sp.), 27,06 œufs/g MS (*S. stercoralis*), 25,67 œufs/g MS (*E. vermicularis*), 18,68 œufs /g MS (*H. nana*), 23,98 œufs/g MS (*S. mansoni*) and 77,41 œufs/g MS (Total helminth eggs). Une variation significative de la concentration en œufs d'helminthes a été observée entre les latrines investiguées (test d'ANOVA à un facteur, $p<0,038$, $\alpha= 0,05$). En général, les concentrations en paramètres physico-chimiques enregistrée étaient respectivement de 7,25±0,70 (pH), 5,45±3,87 mS/cm (Conductivité électrique), 36,71±33,86 gO_2/L (DCO), 4,55±4,23 gO_2/L (DBO_5), 0,57±0,55 g/L (NH_4^+), 1,70±1,49 g/L (NTK), 41,65±7,58 % (DM) et 58,34±7,58 % (teneur en eau). Dans les échantillons provenant des latrines traditionnelles y ont été enregistré de fortes teneurs en matière organique (DCO et DBO_5) et en matières sèches. Le type de latrine utilisé au sein des ménages a significativement affecté la qualité des boues brutes collectées (test ANOVA à un facteur, $\alpha=0.05$), spécifiquement pour les paramètres DCO ($p<0,04$), NTK ($p<0,033$) et les matières sèches ($p<0,00043$). Les teneurs en métaux lourds enregistrés dans les échantillons ont été respectivement de 0,35±0,34 mg/L (Cd), 0,44±0,39 mg/L (Pb), 1,68±1,45 mg/L (Cu), 5,01±3,72 mg/L (Zn), 7,40±6,20 mg/L (Fe), 16,56±11,85 mg/L (Mn) et 0,28±0,27 mg/L (Cr). L'étude de la distribution des métaux lourds en fonction des types de latrines a revélé une différence significative (test ANOVA à un facteur) pour la concentration en Pb ($p<0,00517$), Fe (p<0,000648) et Zn (p<0,00413). L'analyse en composante principale de la composition physico-chimique des échantillons a revélé 78 % des variations pour la première composante avec une forte corrélation pour les paramètres DCO (0,812), DBO_5 (0,589), NH_4^+ (0,731), MS (0,870), teneur en eau (0,870), NTK (0,866). Pour ce qui est de l'analyse en composante principale des paramètres parasitaires, la première composante a revélé 72,26 % des variations avec une corrélation positive pour les espèces *Ascaris lumbricoides* (0,538), *Hymenolepis nana* (0,558), *Trichuris trichiura* (0,736), *Schistosoma mansoni* (0,538), *Enterobius vermicularis* (0,613) et les œufs d'helminthes totaux (0,757). La première composante de l'analyse en composante principale de la composition en métaux lourds des échantillons a exprimé 47,89 % de la variance totale avec des corrélations positives pour les paramètres Cu (0,55), Mn (0,72) et Cr (0,67). L'analyse de la classification hiérarchique des échantillons par la méthode de Ward a organisé les échantillons en 4, 3 et 3 classes respectivement pour la composition physico-chimique, la composition parasitaire et celle en métaux lourds. Une différence significative a été observée entre les paramètres physico-chimiques ($p<0,048$). S'agissant de la qualité hygiénique des lixiviats issues de la déshydratation des boues de vidange, les concentrations des paramètres parasitaires enregistrées sont de l'ordre de 3,3 œuf/g MS, 2,7 œuf/g MS, 2,25 œuf/g MS, 3,36 œuf/g MS respectivement pour le libre écoulement, rétention hydraulique de 7 jours, rétention hydraulique de 14 jours et le filtre non planté (témoin). Les biosolides accumulés à la surface des lits plantés après déshydratation des boues de vidange ont été analysés. Ces biosolides ont des concentrations élevées en œufs d'helminthes, la plupart appartenant à la classe des Némathelminthes avec 80 % représenté par l'espèce *Ascaris lumbrides.* L'élimination des œufs d'helminthes dans les filtres plantés a été affectée significativement par la rétention hydraulique et la présence de plantes ($p<0,05$).

Les teneurs élevées en composition physico-chimique, en métaux lourds et en œuf d'helminthes constituent une menace potentielle pour l'homme et l'environnement. La nécessité d'une meilleure gestion des boues de vidange s'impose aux regards des risques environnementaux et sanitaires que peut engendrer la décharge anarchique des boues de vidange dans l'environnement et/ou via l'utilisation directe en agriculture.

Mots clés: Gestion des boues de vidange, variabilité, assainissement autonome, considération hygiénique, filtres plantés de roseaux, milieu tropical urbain, Yaoundé.

CHAPTER I. GENERALITIES

I.1. Introduction

I.1.1. Context

The purpose of a sanitation system is to protect and promote human health and environmental conditions (Stenström et *al*., 2011, Joshua et *al*., 2017; Huda et *al*., 2018). Adequate sanitation is an important foundation for health, economic development and well-being (Brown et *al*., 2015; Tilley et *al*., 2014; Verbyla et *al*., 2013). In developing countries, urban areas are estimated to have higher sanitation coverage than rural areas (Carlton et *al*., 2012). But these statistics often mask the severity and complexity of sanitation challenges affecting towns and the urban poor. It was estimated that in 2010, 2.6 billion individuals did not have access to improve sanitation (Strande et *al*., 2014). The Sustainable Development Goals (SDGs) adopted by the UN General Assembly in 2015 aims to substantially improve water and sanitation globally, and includes two specific targets within Goal 6 for drinking water, sanitation and hygiene (WaSH): (i) by 2030, achieve universal and equitable access to safe and affordable drinking water for all; (ii) by 2030, achieve access to adequate, equitable sanitation and hygiene for all and end open defecation. Progress towards the Millennium Development Goals (MDGs) which preceded the SDGs was monitored globally based on the use of improved drinking water supplies and sanitation facilities. The SDGs aim at higher water and sanitation service provision and are being monitored using indicators which include elements of service quality that were not captured by the MDG indicators (Wolf et *al*., 2018). The generalized approach to define sanitation access for a single household is to assess the use of an 'improved' toilet technology (Jenkins et *al*., 2014), which may be less appropriate for rapidly growing cities where on-site sanitation technologies, such as pit latrines and septic tanks, are still used, despite the urban population growth. In such situations, sanitation facilities are likely to be emptied rather than moved (Tilley et *al*., 2014). Hence the safety of sanitation systems depends on safe faecal capture and containment (i.e. the design of the facility), provisions for safe faecal sludge management, including emptying, removal, treatment and disposal, or reuse (Taweesan et *al*., 2015). In low- and middle-income countries, most urban dwellers (>70 %) use mainly on-site sanitation systems such as unsewered latrines and septic tanks for excreta and wastewater disposal (Koné and Strauss, 2004; Niwagaba et *al*., 2014; Dodane et *al*., 2012; Klingel et *al*., 2002; Strauss et *al*., 1997).

Faecal sludge (FS) refers to the raw or partially digested slurry or solid that results from the storage of black water or excreta in on-site sanitation systems (Tilley et *al*., 2014). It contains extremely high pathogen concentrations, responsible for the elevated endemic rate of excreta-related diseases, especially among children (Feachem et *al*., 1983; Stenström et *al*., 2011). In areas where access to sustainable sanitation (where safe storage, collection, treatment and safe disposal/reuse of faeces and urine) is insufficient or poor, parasites spread in the natural environment (Kengne and Tilley, 2014). Ongoing latrines provision programs, aimed at achieving the post 2015 SDG sanitation target 6, still lacks service provision arrangements for collection/emptying, haulage, safe disposal, reuse or treatment of faecal sludge produced by on-site sanitation infrastructures. Half of the urban population in Africa suffers from diseases associated with poor sanitation, hygiene and water (Niwagaba et *al.*, 2014). Diseases associated with poor sanitation are particularly correlated with poverty and infancy and account for about 10 % of the global burden of disease (Aryal et al., 2012; De Silva et *al*., 2011; Hotez et *al*., 2008). It has been shown that only one gram of fresh excreta from an infected person can contain around 10^6 viral pathogens, 10^6-10^8 bacterial pathogens, 10^4 protozoans cysts or oocysts and 10-10^4 helminth eggs (Feachem et *al*., 1983). Systematic reviews suggest that improved sanitation can significantly reduce rates of diarrhoeal diseases (Matthew et *al*., 2017; Darvesh et *al.*, 2017; Huda et *al.*, 2018). Sludge management from on-site technologies has not been the priority of engineers or municipalities and has traditionally received little or no attention (Koné et Strauss, 2004). The proper management of faecal sludge includes collection, transportation, treatment and usage/disposal (Ingallinella et *al*., 2002). However, the management of FS in urban areas of developing countries is dramatic. It was estimated that about two million tons of FS is disposed daily into the natural environment without prior treatment in up to 40 % of the world's population including about 50 % of Sub-Saharan Africa (Ingallinella et *al*., 2002).

Cameroon and other countries of western Africa are not indifferent to this situation. A study carried out by Berteigne (2012) pointed out the poor management of FS in urban areas of Cameroon due to the absence of FS treatment technologies. The author estimated the quantity of FS discharge weekly into the environment ranging between of 730 to 900 m^3 and 1785 to 2271 m^3 respectively in the capital cities Yaounde and Douala. Thus, the FS treatment in this context is a need with the main objective of preserving health and protecting the environment. The most important step in designing treatment technologies is to quantify and characterize the faecal sludge to be treated. However, FS characteristics are not standard and they are difficult to determine due to the variety of on-site technologies in use and the local environmental conditions. Given the variability of FS, it is important to collect data for each specific location when designing treatment systems. Several environmental factors have been shown to affect the quality and variability of FS in on-site technologies (Strauss et *al.*, 1997; Strauss and Montangero, 2002; Fidjeland et *al*., 2013; Fidjeland et *al*., 2015). These factors are storage duration, intrusion of groundwater, toilet use, climate, and feeding habits. However, the characteristic of FS is known in literature and needs to be completed to have a general view of the situation. Indeed, Heinss et *al.* (1998) revealed two classes of FS produced under tropical conditions depending on the on-site sanitation source: sludge of low strength which are most stabilized (septage) and sludge of high strength which is highly concentrated coming from public toilets and bucket latrines. Additionally, the work carried out by Bassan et *al.* (2013) revealed the variation in the characteristics of sludge from on-site sanitations systems in Ouagadougou (Burkina Faso) without the influence of climatic seasons.

FS contains various organic/inorganic pollutants, heavy metals and pathogenic microorganisms which are potential ecological, biological and health effects. Regarding organic pollutants, the studies pointed out the high concentration of Total Kjeldahl Nitrogen, biological oxygen demand, and chemical oxygen demand in sludge with concentrations more than 10 to 100 times than those obtained in urban wastewater (Kengne et *al*., 2008; Kengne et *al*., 2009). The occurrence and diversity of pathogens existing in raw FS was found to depend on the health status of the local community (Traub et *al*., 2004). The most common pathogens present in sludge are faecal bacteria and helminth eggs (Feachem et *al*., 1983; Koné et *al*., 2007). Furthermore, microorganisms like fungi, algae and actinomycetes are also present in FS (Appiah-Effah et *al*., 2015). The survival or inactivation of pathogens in FS depends upon a number of factors, such as temperature, moisture content, predation and competition from indigenous microflora (Alum et *al*., 2014; Johansen et *al*., 2013; Williams et *al*., 2012). Raw sludge may contain significant concentration of heavy metals. The heavy metal in sludge may arise from a number of sources including domestic sources and include chromium, manganese, cobalt, iron, arsenic, zinc, lead, cadmium and mercury (Strande et *al.*, 2014; Appiah-Effah et *al*., 2015). Knowledge about the levels of these metals in raw sludge is very important for treatment and the reuse options. Despite the fact that various fecal sludge treatment technologies including centralized and decentralized systems have been developed, the overall treatment capacity is still relatively low in developing countries due to the economic concerns. Moreover, the standard limits for effluent quality control is mainly depending on organic compounds (COD, BOD), nitrogen and phosphorus. The sanitation control of pathogens in the effluent has not gained much attention so far. However, human health should not be endangered by residual pathogens remaining in the water after treatment. Constructed wetland (CWs) are widely used to treat faecal sludge due to their simple operation and low implementation costs (Kengne et *al.*, 2008, Kadlec and Wallace, 2008). Since they also perfectly fit into the landscape, they are an environmentally suitable approach favorably viewed by the general public.

I.1.2. Problem statement

The data on raw FS characteristics are still lacking in the world (Strande et *al.*, 2014). Many studies carried out in the field of faecal sludge management (FSM) were mainly focused on sludge transportation and treatment/reuse, and the excreta disposal facilities in use in households (storage devices) received very little attention even though the FS management chain starts with the storage devices (Lüthi and Parkinson, 2011). This is so because they represent the initial situation and hence require considerable attention. Thus, the assessment of the initial situation is crucial, as it provides the baseline information for decision-making by understanding what is important to know at the beginning of FS Management chain and the identification of shortcomings and challenges of existing FS Management systems in place in Yaounde. Baseline information should be of considerable importance for the mastery of the initial situation. For example, the storage device may indirectly affect human health and environmental conditions as well as the quality and variability of FS produced. Furthermore, with the implementation of resource recovery of on-site sanitation products, it is also important to evaluate constituents that may impact both humans and the environment. Although sanitation efficiency is an important parameter in FS treatment using planted drying beds, removal of pathogenic microorganisms is crucial to prevent the contamination of water resources and to limit any risk on human health. Planted drying beds are today a well-established technology for wastewater treatment.

I.1.3. Objectives of the research

The general objective of the present study is to investigate the variability of raw faecal sludge samples collected from various on-site sanitation systems in use in the context of the city of Yaounde and the study of factors affecting the removal of intestinal helminth eggs in planted drying beds during faecal sludge dewatering.

Specifically the objectives are:

- to describe the existing faecal sludge management practices in households of some settlements of Yaounde;
- to determine the prevalence and diversity of intestinal helminth eggs in raw sludge from various on-site sanitation systems as well as the potential health risks associated with the sanitation technologies in use;
- to characterize raw sludge for physico-chemical and heavy metals content;
- to assess the variability of pit latrines raw sludge produced in the context of Yaounde city;
- to assess the effects of hydraulic retention times and plant densities on the removal of intestinal helminth eggs by planted drying beds.

I.2. Literature review

I.2.1. Faecal sludge management and sanitation challenge in the world

Lack of universal access to water and sanitation results in well over a million preventable deaths each year and in both the water and sanitation sectors, there is crucial need for greater sustainability (Montgomery et *al*., 2009). Worldwide, about 2.6 billion people lack access to improved sanitation (WHO, 2006; WHO, 2011; Aryal et *al*., 2012). The achievement of the Millennium Development Goals (MDGs) for water and sanitation remains a chimera in view of current sanitation gap. The current generalized approach of defining sanitation access as single household use of an 'improved' toilet technology may be less appropriate for rapidly growing cities where on-site sanitation technologies such as pit latrines, and septic tanks continue to be used despite the over-increasing urban densities (Jenkins et *al*., 2014).

In such situations, sanitation facilities are likely to be emptied rather than moved (Pujari et *al*., 2012) so that the safety of sanitation systems depends at least as much on provisions for safe faecal sludge management including emptying, removal, treatment and disposal or reuse, as on safe faecal capture and containment (i.e. the design of the facility) (Stenström et *al*., 2011; Tilley et *al*., 2014). The situation is most severe in sub-Saharan Africa and South Asia with almost 30 per cent and 50 per cent of the population that are respectively affected. Yearly, about 1.8 million children under five years die, corresponding to about 4,900 young lives lost daily from diarrheal diseases (Stenström et *al*., 2011; Cairncross et *al*., 2010; Mara et *al*., 2010). Soil transmitted helminths and water related *Schistosomiasis* are among the most common parasitic infections worldwide with most case occurring in tropical and sub-tropical low income countries (Wolf et *al*., 2014). Despite the fact that sanitation needs are met through on-site technologies for a vast number of people in urban area of low-and middle-income countries, there is typically no management system in place resulting in the discharge of FS into the natural environment (Strande et *al*., 2014).

Given the immense problems and challenges in FSM, a large array of technical, economic and institutional/organizational measures are required to improve the situation. It is evident that the management of faecal sludge is a crucial need that must be addressed, and that it will continue to play an essential role in the management of global sanitation in the future.

I.2.2. On-site sanitation technologies

I.2.2.1. Definition

Sanitation is a multistep process in which human excreta and wastewater are managed from the point of generation to the point of use or ultimate disposal (Tilley et *al*., 2014). It is the complex-specific series of technologies and services for the management of these wastes (or resources) i.e. for their collection, containment, transport, transformation, utilization or disposal. In opposition to centralized sanitation systems, on-site sanitation systems or decentralized sanitation systems consist of the different technologies in use for the collection of excreta and grey water at household level. In low and middle-income countries, most urban dwellers (>70 %) use mainly on-site sanitation systems such as unsewered latrines and septic tanks for excreta and wastewater disposal (Strande et *al*., 2014; Taweesan et *al*., 2015) (Fig. 1).

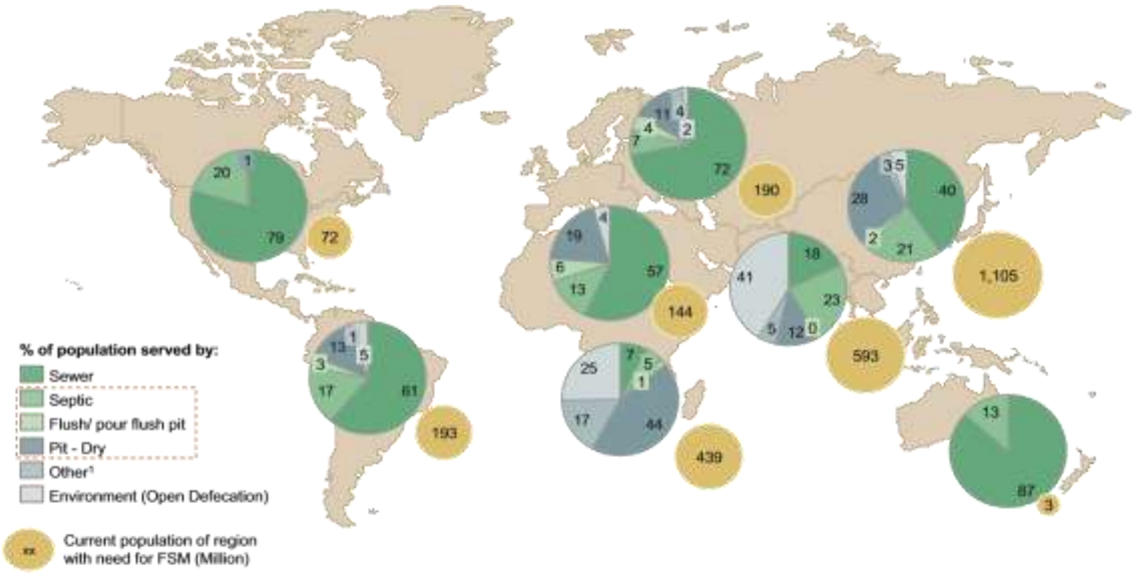


Fig. 1. Percentage of population served by on-site sanitation technologies in 2013 (Strande et *al*., 2014).

I.2.2.2. Typology of some on-site sanitation technologies in the world

The typology of the on-site sanitation technologies presented in this section is mainly from the compendium of sanitation technology (Tilley et *al*., 2014, modified).

I.2.2.2.1. Single pit latrine

The single pit is one of the most widely used/recognized sanitation technologies (Tilley et *al*., 2014). Excreta, along with anal cleansing materials (water or solids) are deposited into a pit. Lining the pit prevents it from collapsing and provids support to the superstructure (Fig. 2).

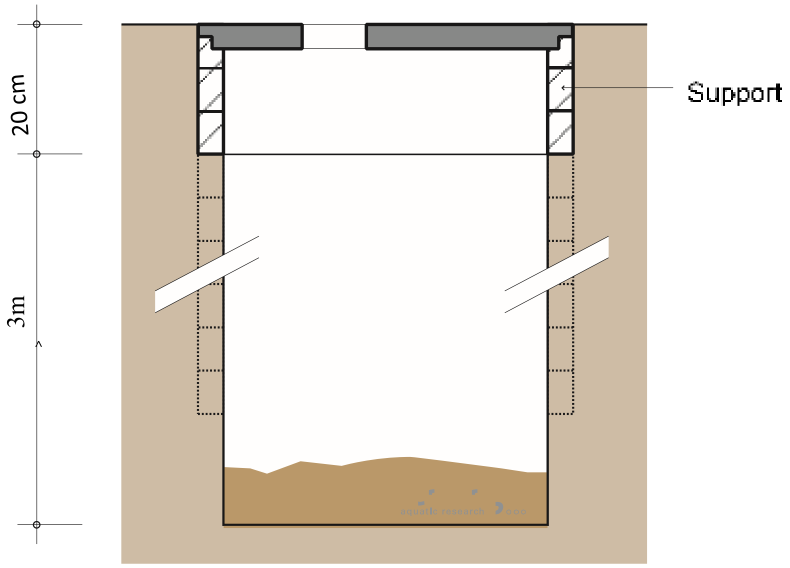


Fig. 2. Schematic representation of a pit latrine (Tilley et *al.*, 2014).

As the single pit fills, two processes limit the rate of accumulation: leaching and degradation. Urine and water percolate into the soil through the bottom of the pit and wall, while microbial action degrades part of the organic fraction.

I.2.2.2.1.1. Design considerations

On average, solids accumulate at the rate of 40 to 60 L per person/year and up to 90 L per person/year if dry cleansing materials such as leaves or paper are used (Tilley et *al.*, 2014). The volume of the pit should be designed to contain at least 1,000 L. Typically, the pit is at least 3 m deep and 1 m in diameter. If the pit diameter exceeds 1.5 m, there is increased risk of collapse. Depending on how deep they are dug, some pits may last 20 or more years without emptying. To prevent groundwater contamination, the bottom of the pit should be at least 2 m above groundwater level, the thumb rule. As liquid leaches from the pit and migrates through the unsaturated soil matrix, pathogenic germs are sorbed to the soil surface and can be removed prior to contact with groundwater (Esrey, 2001). The degree of removal varies with soil type, distance travelled, moisture and other environmental factors. A minimum horizontal distance of 30 m is normally recommended to limit exposure to microbial contamination.

I.2.2.2.1.2. Appropriateness

Treatment processes in a single pit (aerobic, anaerobic, dehydration, composting, …) are limited and therefore pathogen reduction and organic degradation is not significant (Tilley et *al.*, 2014). However, since the excreta are contained, pathogen transmission to the user is limited. A single pit is appropriate for rural and peri-urban areas; in densely populated areas they are often difficult to empty and/or have insufficient space for infiltration. Single pit is especially appropriate when water is scarce and where there is a low groundwater table.

I.2.2.2.1.3. Health aspects

A single pit is an improvement to open defecation; however, it still poses health risks (Tilley et *al*., 2014):

- leachate can contaminate groundwater;
- stagnant water in pits may promote insect breeding;
- pits are susceptible to failure and/or overflowing during flood.

The single pit should be constructed at an appropriate distance from homes to minimize flies and odour nuisances and to ensure convenience and safety.

I.2.2.2.2. Single ventilated improved pit (VIP)

The single VIP is a ventilated improved pit. It is an improvement of the single pit described in section I.2.2.2.1 because continuous airflow through the ventilation pipe vents odour and acts as a trap for flies as they escape towards the light (Tilley et *al*., 2014) (Fig. 3).

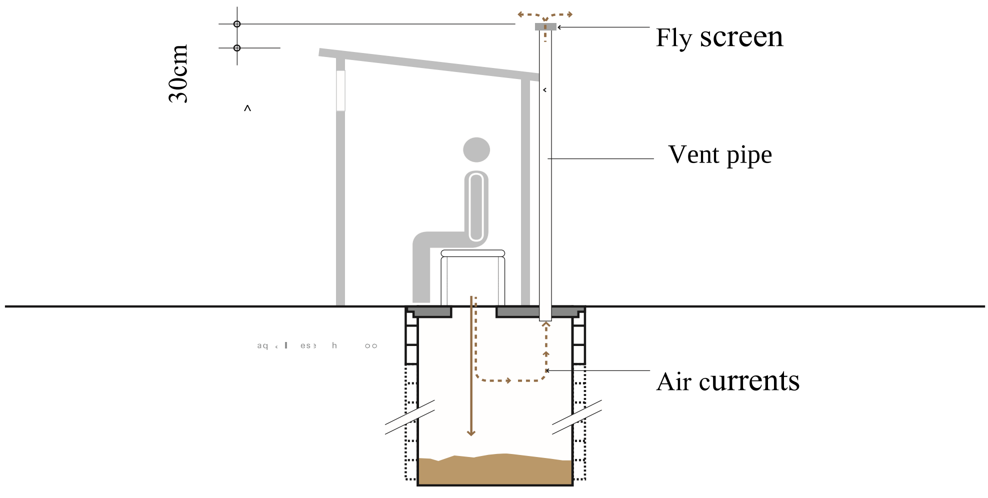


Fig. 3. Schematic representation of a VIP latrine (Tilley et *al*., 2014).

Despite their simplicity, well-designed single VIPs can be completely odour free and more pleasant to use than some other water-based technologies (Tilley et *al*., 2014). The appropriateness and health aspects of the single VIP are similar to those of the single pit (see section above).

I.2.2.2.2.1. Design considerations

The vent pipe should have an internal diameter of at least 110 mm and reach more than 300 mm above the highest point of the toilet superstructure (Tilley et *al*., 2014). Wind passing over the top creates a suction pressure within the vent pipe and induces an air circulation (Fig. 3). Air is drawn through the User interface into the pit, moves up inside the vent pipe and escapes into the atmosphere. The heat difference between the pit (cool) and the vent (warm) creates an updraft that pulls the air and odour up and out of the pit. Care should be taken that objects such as trees or houses do not interfere with the air stream. The vent works best in windy areas, but where there is little wind, its effectiveness can be improved by painting the pipe in black.

I.2.2.2.3. Fossa Alterna

The Fossa Alterna is a short cycle alternating, waterless (dry) double pit technology. Compared to the VIP, which is just designed to collect, store and partially treat excreta, the Fossa Alterna is designed to make an earth-like product that can be used as a nutrient-rich soil conditioner (Tilley et *al*., 2014) (Fig. 4). Fossa Alterna is dug to a maximum depth of 1.5 m and requires a constant input of cover material (soil, ash, leaves). The cover material should be added to the pit after defecation (not urination). The soil leaves introduce a variety of organisms like worms, fungi, and bacteria which help in the degradation process. Additionally, ash helps to control flies, reduces odours and makes the mix slightly more alkaline. The full pit degrades while the second pit is filling, which ideally should take one year (Fig. 4).

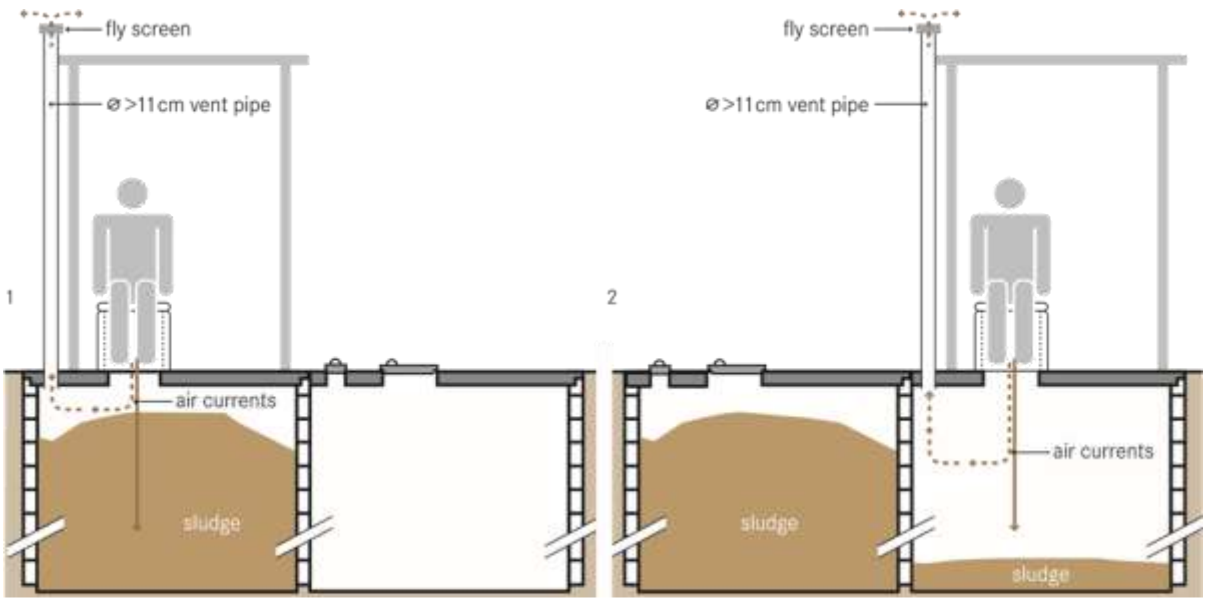


Fig. 4. Schematic representation of a Fossa alterna latrine (Tilley et *al*., 2014).

I.2.2.2.3.1. Design and considerations

A fossa Alterna pit would fill over a period of 12 to 24 months depending on its size and the number of users. Even though the pits are shallow (1 to 1.5 m), each of them can be used by a family of six for one year (Tilley et *al*., 2014). The Fossa Alterna technology will only work properly if the two pits are used sequentially and not concurrently. Therefore, an adequate cover for the out of service pits is required. The system should be used for urine, but water should not be added (small amounts of anal cleansing water can be tolerated). Water encourages the development of vectors and pathogens, but it also fills the pore spaces and deprives aerobic bacteria of the oxygen that is required for degradation. In flood-prone areas and where the groundwater table is too high, the Fossa Alterna could be raised or built entirely above ground to avoid water intrusion and groundwater pollution.

I.2.2.2.3.2. Appropriateness

The Fossa Alterna is appropriate for rural and peri-urban areas. It is especially suitable for water-scarce environments. It is a useful solution for areas that have poor soil and could benefit from the use of the stabilized humic material as soil amendment. The system is not appropriate for grey water as the pit is shallow and the conditions must remain aerobic for degradation. Furthermore, the Fossa Alterna is not suited for rocky or compacted soils that are difficult to dig or for areas that flood frequently.

I.2.2.2.3.3. Health aspects

By covering faeces with soil, ash and/or leaves, flies and odours are kept to a minimum. The same precautions that are taken when handling compost should be taken with the humus derived from Fossa Alterna.

I.2.2.2.4. Twin pits for pour flush

This technology consists of two alternating pits connected to a pour flush toilet (Fig. 5). The blackwater and in some cases grey water is collected in the pits and allowed to slowly infiltrate into the surrounding soil. Over time, the solids are sufficiently dewatered and can be manually removed with a shovel.

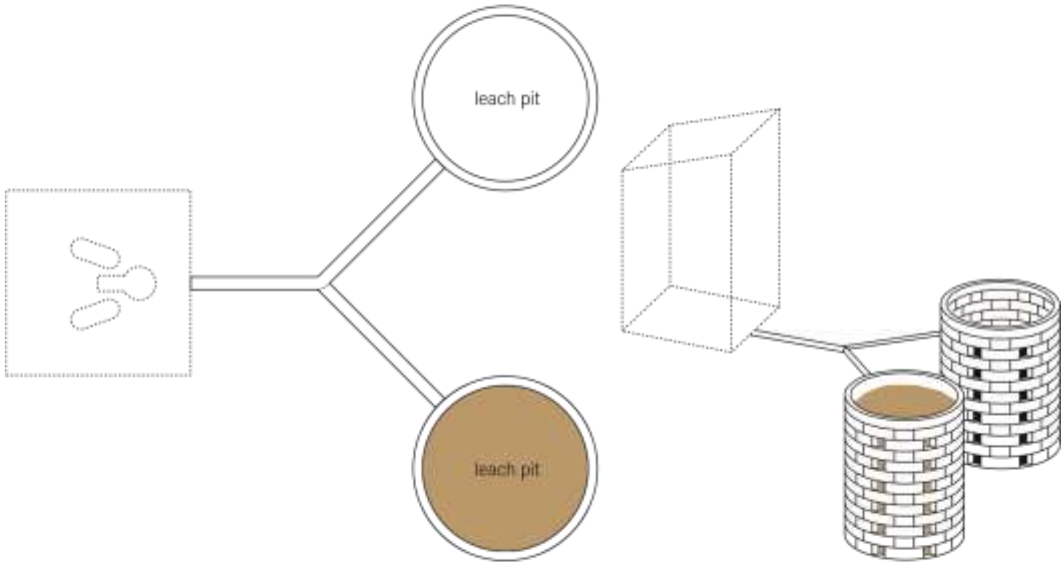


Fig. 5. Schematic representation of a pit for pour flush (Tilley et *al.*, 2014).

The system can be designed in various ways; the toilet can be located directly over the pits or at a distance from them. The superstructure can be permanently constructed over both pits or it can move from side to side depending on which one is in use.

I.2.2.2.4.1. Design considerations

The pit should be of an adequate size to accommodate a volume of waste generated over one or two years. This allows the content of the full pit enough time to transform into a partially sanitized, soil-like material that can be manually excavated. It is recommended that the twin pits be constructed over 1 m apart from each other to minimize cross contamination between the maturing pit and the one in use (Tilley et *al.*, 2014). There is a risk of groundwater pollution when pits are located in areas with a high or variable water table, and/or fissures or cracks in the bedrock.

I.2.2.2.4.2. Appropriateness

Twin pits for pour flush are a permanent technology appropriate for areas where it is not possible to continuously build new pit latrine. If water is available, this technology is appropriate for almost every type of housing density. However, too many wet pits in a small area is not recommended as the soil matrix may not be of sufficient capacity to absorb all the liquid and the ground could become oversaturated. This technology is suitable in areas with soil of good absorptive capacity and not suitable for areas with high groundwater table or where there is frequent flooding (Tilley et *al.*, 2014).

I.2.2.2.4.3. Health aspects

Although it is a commonly accepted sanitation option, some health concerns however exist (Tilley et *al*., 2014):

- leachate can contaminate groundwater;
- stagnant water in pits may promote insect breeding;
- pits are susceptible to failure and/or overflowing during flood.

I.2.2.2.5. Dehydration vaults

Dehydration vaults are used to collect, store and dry (dehydrate) faeces (Fig. 6). Faeces will only dehydrate when the vaults are well ventilated, watertight to prevent external moisture from entering, and when urine and anal cleansing water are diverted away from the vaults (Tilley et *al*., 2014).

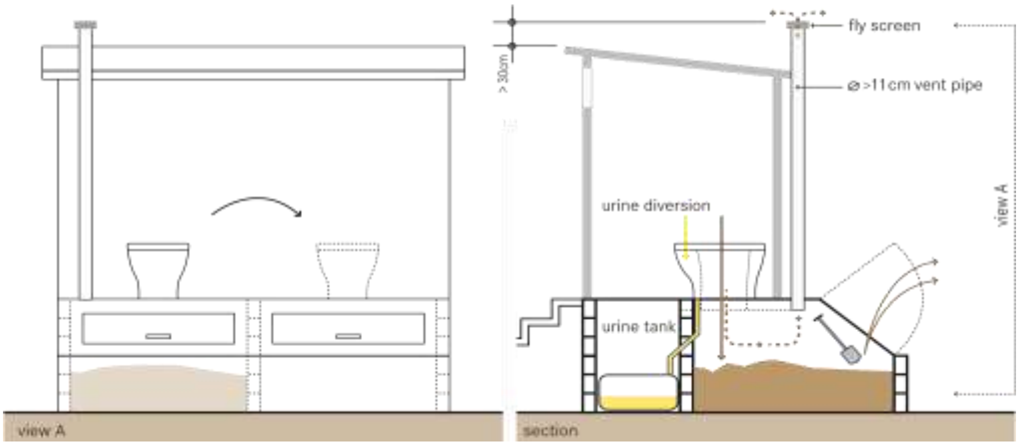


Fig. 6. Schematic of a dehydration vault (Tilley et *al*., 2014).

When faeces are not mixed with urine and other liquids, they dry quickly. In the absence of moisture, organisms cannot grow, pathogens are destroyed and smell minimized. The use of two alternating vaults allows the faeces to dehydrate in one vault while the other vault fills. To prevent flies, minimize odours and encourage drying, a small amount of ash, lime, dry soil or sawdust should be used to cover after each use.

I.2.2.2.5.1. Design considerations

Dehydration vaults can be constructed indoors or with a separate superstructure. A vent pipe is required to remove humidity from the vaults and control flies and odours. The chamber should be airtight for proper functioning of the ventilation. They should be made of sealed brickwork or concrete to ensure that surface runoff cannot enter (Tilley et *al.*, 2014). The WHO recommends a minimum storage time of six months if ash or lime are used as cover material (alkaline treatment), otherwise the storage should be for at least 1 year for warm climate (> 20 °C average) and 1.5 to 2 years for colder climates.

I.2.2.2.5.2. Appropriateness

Dehydration vaults can be installed in almost every setting, from rural to dense urban areas, because of the small land area required, minimal odours and ease to use. If used in urban context, this technology relies on a transport service for the dried faeces and urine since urban users normally do not have an interest and/or opportunity to use it locally (Tilley et *al.*, 2014). Dehydration vaults are especially appropriate for water-scarce and rocky areas or where the groundwater table is high. They are also suitable in areas that are frequently flooded because they are built to be watertight.

I.2.2.2.5.3. Health aspects

The technology can be clean, comfortable, and easy-to-use. It is crucial that the users are well trained to understand how the technology works and appreciate its benefits. When the vaults are kept dry, there should not be any problems with flies or odours. After the recommended storage time, the faeces should be very dry and relatively safe to handle, provided that they did not get wet. However, a low health risk remains (Tilley et *al.*, 2014).

I.2.2.2.6. Composting chamber

Composting refers to the process by which biodegradable components are biologically decomposed by microorganisms (mainly bacteria and fungi) under aerobic conditions. A composting chamber is designed to convert excreta and organic matters into compost (Tilley et *al.*, 2014) (Fig. 7).

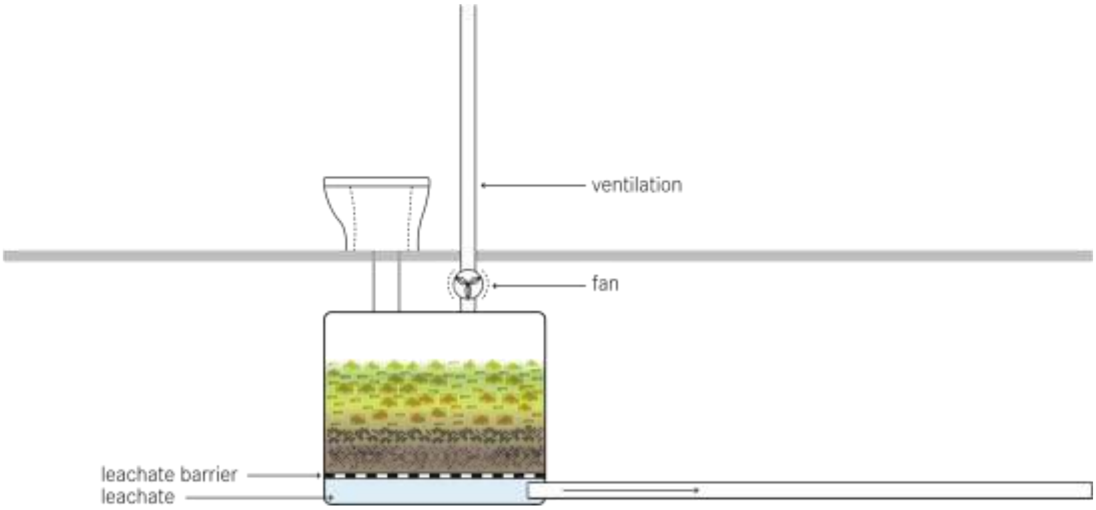


Fig. 7. Schematic view of a composting latrine (Tilley et *al.*, 2014).

Compost is a stable, inoffensive product that can be safely handled and used as a soil conditioner. This technology usually requires four main parts: a reactor (storage chamber); a ventilation unit to provide oxygen and allow gases (CO_2, water vapour) to escape; a leachate collection system and an access door to remove the mature product. Excreta, organic, food waste and bulking material such as wood chips, sawdust, and ash or paper are mixed in the chamber. There are four factors that ensure the good functioning of the system (Tilley et *al.*, 2014) :

- sufficient oxygen, provided by active or passive aeration;
- proper moisture (ideally 45 to 70 % moisture content);
- internal temperature of 40 to 50 °C (achieved by proper chamber dimensioning);
- a 25:1 C: N ratio which can be adjusted by adding bulking material as a carbon source.

I.2.2.2.6.1. Design considerations

A composting chamber can be designed in various configurations and constructed above or below ground, indoors or with a separate superstructure. A design value of 300 L/person/year can be used to calculate the required chamber volume (Tilley et *al.*, 2014). A ventilation channel under the heap can be beneficial for aeration.

I.2.2.2.6.2. Appropriateness

Since this technology is compact and waterless, its especially suitable for areas where land and water are limited, or where there is a need for compost. It can also be installed in rocky areas or where the groundwater table is high. In cold climates, a composting chamber should be indoors to ensure that low temperatures do not inhibit the microbial processes. This technology is not appropriate for the collection of anal cleansing water or grey water; if the reactor becomes too wet, anaerobic conditions will cause odour problems and improper degradation (Tilley et *al.*, 2014).

I.2.2.2.6.3. Health aspects

If the composting chamber is well designed, the users will not have to handle the material during the first year. A well-functioning composting chamber should not produce odour and flies (Tilley et *al.*, 2014). When removing the final product, it is advisable to wear protective clothing to prevent contact with partially composted material.

I.2.2.2.7. Septic tank

A septic tank is a watertight chamber made of concrete, fiberglass, PVC or plastic, through which black water and greywater flows for primary treatment (Tilley et *al.*, 2014). Settling and anaerobic processes reduce solids and organics, but the treatment is only moderate (Fig. 8). Liquid flows through the tank and heavy particles sink to the bottom, while scum (mostly oil and grease) floats to the top. Over time, the solids that settle at the bottom are degraded anaerobically. However, the rate of accumulation is faster than the rate of decomposition and the accumulated sludge and scum must be periodically removed. Generally, the removal of 50 % of solids, 30 to 40 % of BOD and 1-log removal of *E. coli* can be expected in a well-designed and maintained septic tank; even though efficiencies vary greatly depending on operation and maintenance, climatic conditions (Tilley et *al.*, 2014).

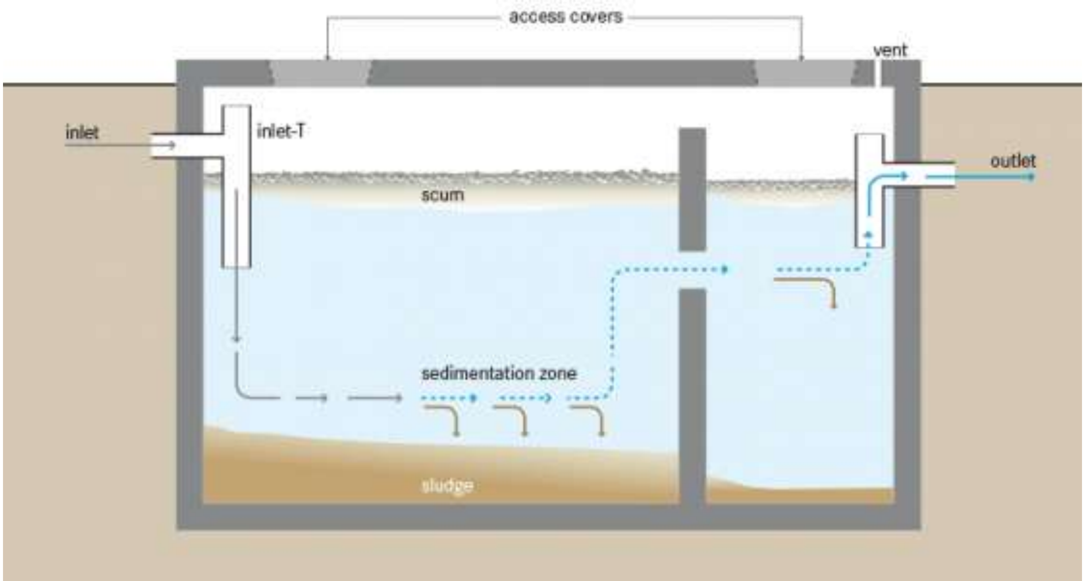


Fig. 8. Schematic view of a septic tank (Tilley et *al.*, 2014).

I.2.2.2.7.1. Design considerations

A septic tank should have at least two chambers (Tilley et *al*., 2014). The first chamber should be at least 50 % of the total length and when there are only two chambers, it should be two thirds of the total length. Most of the solids settle out in the first chamber (Fig. 8). The separation between the chambers is to prevent scum and solids from escaping with the effluent. The T-shaped outlet pipe further reduces the scum and solids that are discharged. Septic tanks should be vented for controlled release of odorous and potential harmful gases. The design of a septic tank depends on the number of users, the amount of water used per capita, the average annual temperature, the desludging frequency and the characteristics of the wastewater (Tilley et *al.*, 2014).

I.2.2.2.7.2. Appropriateness

This technology is most commonly applied at household level. Larger multi-chamber septic tanks can be designed for groups of houses and public buildings. A septic tank is appropriate where there is a way of dispersing or transporting effluent. Because the system must be regularly desludged, a vacuum truck should be able to access the location (Tilley et *al.*, 2014).

I.2.2.2.7.3. Health aspects

Under normal operating conditions, users do not come in contact with the influent or effluent. Effluent, scum and sludge must be handled with care as they contain high levels of pathogenic organisms. Users should be careful when opening the tank because noxious and flammable gases may be released.

I.2.2.2.8. Anaerobic baffled reactor (ABR)

An anaerobic baffled reactor (ABR) is an improved septic tank with a series of baffles under which the wastewater is forced to flow (Fig. 9). The increased contact time with the active biomass (sludge) results in improved treatment (Tilley et *al.*, 2014).

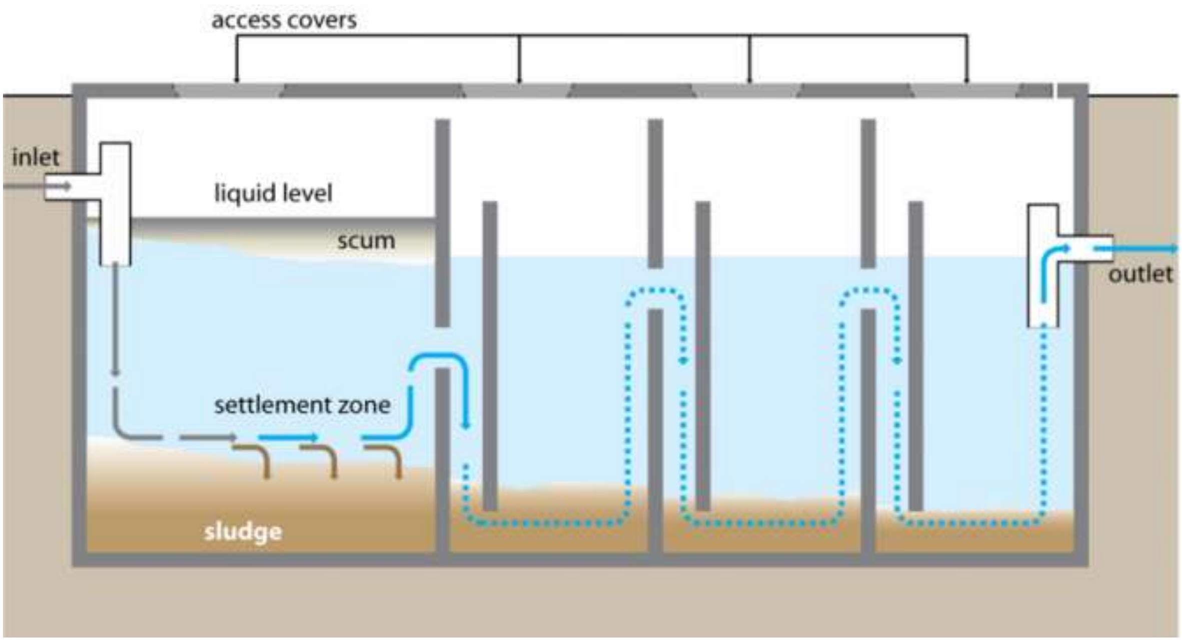


Fig. 9. Schematic of an anaerobic baffled reactor (Tilley et *al*., 2014).

The up flow chamber provides enhanced removal and digestion of organic matter. BOD may be reduced by up to 90 % which is far superior to its removal in a conventional septic tank.

I.2.2.2.8.1. Design considerations

Most settleable solids are removed in a sedimentation chamber in front of the ABR (Fig. 9). Typical inflow range from 2 to 200 m^3 per day. Critical design parameters include a hydraulic retention time (HRT) between 48 to 72 hours, up flow velocity of the wastewater below 0.6 m/h and the number of up flow chambers (3 to 6) (Tilley et *al.*, 2014). Accessibility to all chambers is necessary for maintenance and the tank should be vented to allow for controlled release of odorous and potentially harmful gases.

I.2.2.2.8.2. Appropriateness

This technology is easily adaptable and can be applied at household level, in small neighbourhoods or even in bigger catchment areas. It is most appropriate where a relatively constant amount of black-water and grey water is generated (Tilley et *al.*, 2014). ABRs can be installed in every type of climate, although the efficiency is lower in colder climates. They are not efficient at removing nutrients and pathogens. The effluent usually requires further treatment (Tilley et *al.*, 2014).

I.2.2.2.8.3. Health aspects

Under normal operating conditions, users do not come in contact with the influent or effluent. Effluent, scum and sludge must be handled with care as they contain high level of pathogenic organisms (Tilley et *al.*, 2014). The effluent contains odorous compounds that may have to be removed in a further polishing step.

I.2.2.2.9. Anaerobic filter

An anaerobic filter is a fixed-bed biological reactor with one or more filtration chambers in series (Tilley et *al*., 2014). As wastewater flows through the filter, particles are trapped and organic matter is degraded by the active biomass that is attached to the surface of the filter material (Fig. 10).

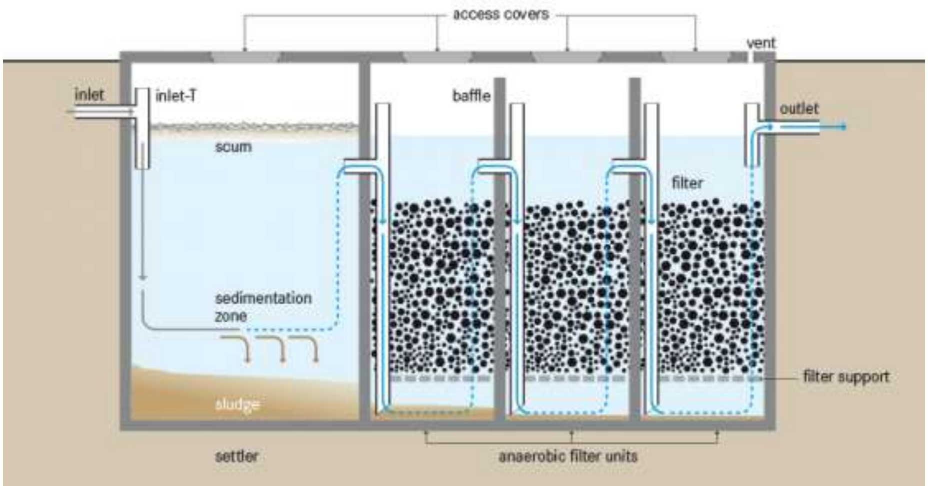


Fig. 10. Schematic of an anaerobic filter (Tilley et *al*., 2014).

With this technology, suspended solids and BOD removal can be as high as 90 %, but it is typically between 50 % and 80 %. Nitrogen removal is limited and normally doesn't exceed 15 % in terms of total nitrogen. The health aspects of this system are similar to those of ABR.

I.2.2.2.9.1. Design considerations

Pre- and primary treatment is essential to remove solids and garbage that may clog the filter. Most settleable solids are removed in a sedimentation chamber in front of the anaerobic filter. Anaerobic filter is usually operated in up flow mode because there is less risk that the fixed biomass will be washed out. The water level should cover the filter media by at least 0.3 m to guarantee an even flow regime. The hydraulic retention time (HRT) is the main design parameter that influences filter performance. An HRT of 12 to 36 hours is recommended (Tilley et *al*., 2014). The ideal filter should have a large surface area for bacteria to grow, with pores large enough to prevent clogging.

The surface area ensures increase contact between the organic matter and the attached biomass that effectively degrades it. Ideally, the material should provide between 90 to 300 m^2 of surface area per m^3 of occupied reactor volume. Typical filter material ranges from 12 to 55 mm in diameter. Materials commonly used include gravel, crushed rocks or bricks, cinder, pumice, or specially formed plastic pieces, depending on local availability.

I.2.2.2.9.2. Appropriateness

This technology is easily adaptable and can be applied at household level, in small neighbourhoods or even in bigger catchment areas. It is most appropriate where a relatively constant amount of black water and grey water is generated. Accessibility by vacuum truck is important for desludging. It can be installed in every type of climate, although the efficiency is lower in colder climates (Tilley et *al.*, 2014). Depending on the filter material, complete removal of worm eggs may be achieved and the effluent usually requires further treatment.

I.2.2.2.10. Biogas reactor

A biogas reactor or anaerobic digester is an anaerobic treatment technology that produces a digested slurry (digestate) that can be used as fertilizer and biogas that can be used for energy (Tilley et *al*., 2014) (Fig. 11).

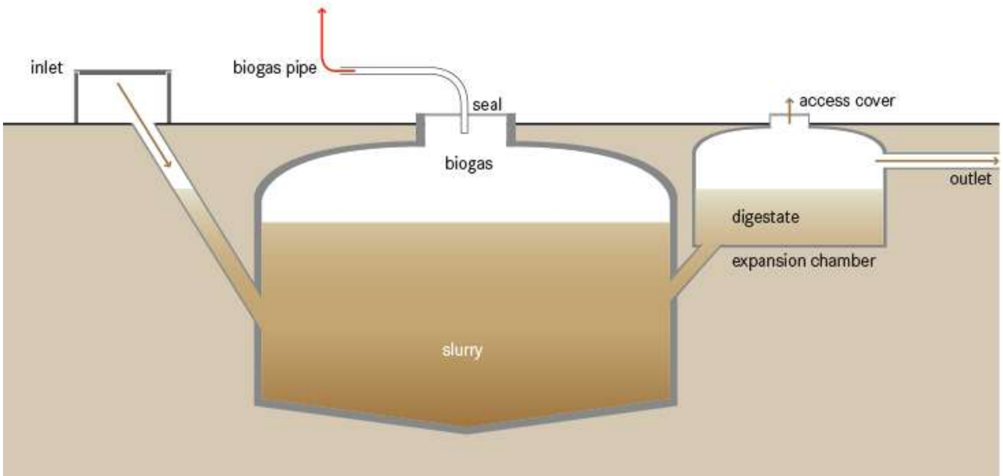


Fig. 11. Schematic of a biogas reactor (Tilley et *al*., 2014).

Biogas is a mix of methane, carbon dioxide and other trace gases which can be converted to heat, electricity or light. The biogas reactor is an airtight chamber that facilitates the anaerobic degradation of black water, sludge and or biodegradable waste. It also facilitates the collection of the biogas produced in the fermentation processes in the reactor (Tilley et *al.*, 2014). The gas forms in the slurry and collects at the top of the chamber, mixing the slurry as it rises. The digestate is rich in organics and nutrients, almost odourless and pathogens are partly inactivated.

I.2.2.2.10.1. Design considerations

Biogas reactors can be brick-constructed domes or prefabricated tanks, installed above or below ground, depending on space, soil characteristics, available resources and the volume of waste generated. The hydraulic retention time (HRT) in the reactor should be at least 15 days in hot climates and 25 days in temperate climates. For highly pathogenic inputs, a HRT of 60 days should be considered (Tilley et *al.*, 2014). Normally, biogas reactors are operated in the mesophilic temperature range of 30 to 38 °C. A thermophilic temperature of 50 to 57 °C would ensure the pathogens destruction but can only be achieved by heating the reactor.

I.2.2.2.10.2. Appropriateness

This technology can be applied at household level, in small neighbourhoods or for the stabilization of sludge at large wastewater treatment plants. It is best used where regular feeding is possible. Often, a biogas reactor is used as an alternative to septic tank, since it offers a similar level of treatment, but with the added benefit of biogas.

I.2.2.2.11. Arborlo system (Fill and Cover)

The 'Arborloo' is a shallow pit that is filled with excreta and organic material, covered with soil and planted with a tree or plant (vegetable or ornamental) (Fig. 12). This ensures the utilization of parts of the nutrients in the pit. The production of pumpkin in Mozambique is doubled by planting the seeds in Arborloo pits (Tilley et *al.*, 2014). In Ethiopia many users of Arborloo pits have chosen to plant pumpkin (*Cucumis melo* (Cucurbitaceae)) rather than trees and in Zimbabwe, tomatoes (*Solanum lycopersicum* (Solanaceae)) are grown as an alternative (Tilley et *al.*, 2014).

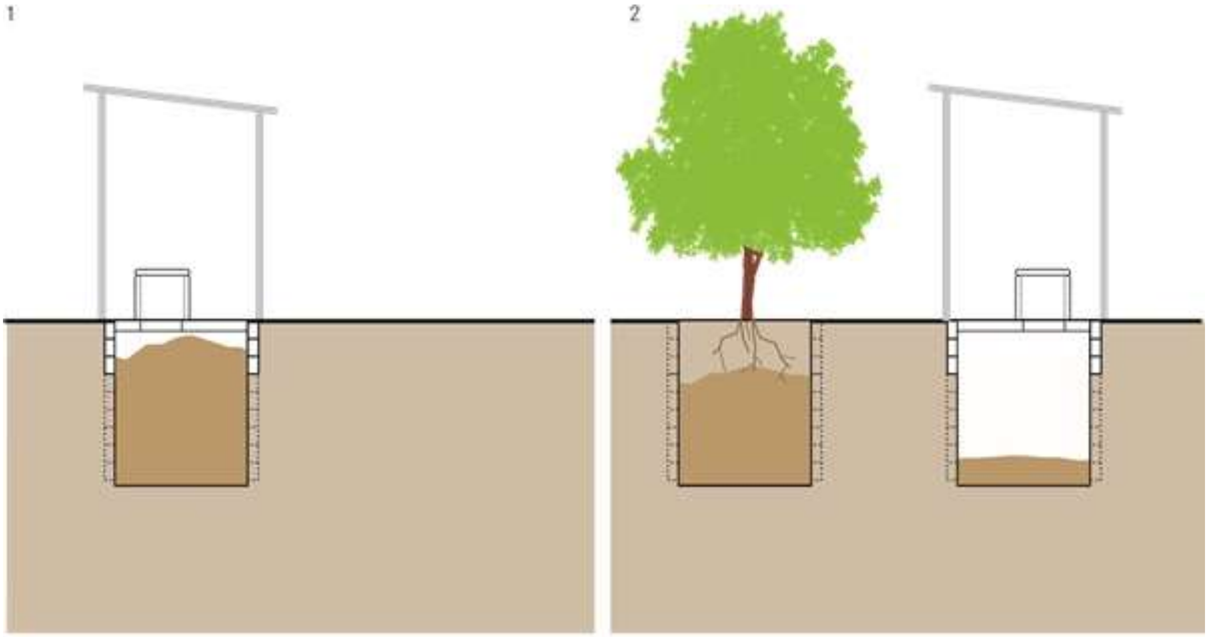


Fig. 12. Schematic of an Arborlo system (Tilley et *al.*, 2014).

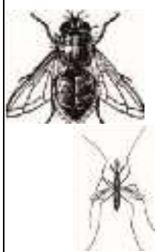
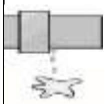
In Mozambique, trees, pumpkins, and a range of vegetables have been planted in abandoned pit toilets (Tilley et *al.*, 2014). The planting of banana trees in pit latrines is also a common practice in Malawi. Alternatively, a pit can be used for the disposal of excreta/sludge taken from a different technology. This has been practis with the contents from bucket latrines where the content of the buckets is covered with a layer of soil and left for about 2 years for the destruction of pathogenic organisms (Tilley et *al.*, 2014).

In the Aborloo, the exposure to pathogens is small if the pit is properly covered. Exposure occurs during the planting of the tree for the persons involved in the activity, but users do not come in contact with the faecal material. Exposure may also occur in water logged areas through groundwater contamination. To date, there are no epidemiological or health risk data to describe the health impact of this disposal/reuse technology. When a pit is filled, regardless of whether plants or a tree is planted on top, it should be well covered to avoid contact with the buried excreta (Tilley et *al.*, 2014). With time, the contents will degrade and reduce in volume. Additional filling should then be made with soil and not with additional excreta or garbage.

I.2.3. On-site sanitation systems and environmental pollution

Most on-site sanitation systems depend upon the capacity of the soils in the unsaturated or aeration zone to accept and purify effluent. These functions may be in conflict under certain conditions but they both relate, directly or indirectly, to the regime of groundwater movement. The risks of aquifer pollution are substantially affected by groundwater hydrology. Aquifers (waterbearing layers of soil) lie in the saturated zone below the water table There are two main health risks commonly associated with water quality degradation from improper on-site sanitation: faecal-oral disease transmission, and nitrate poisoning (Mara et *al*., 2010). Nitrate standards may be violated from latrine leachate, especially in arid areas where dilution of nitrogen loadings is consequently limited. High nitrates can lead to methaemoglobinaemia, (also known as "blue baby" syndrome) (Bednarek et *al*., 2014; Ryoo et *al*., 2014). The risk of diarrhoea and infection with parasites related to exposure pathways are categorized into low, acceptable and high for the risk groups (i.e. users, farmer, worker and community). Depending on the pathogen and the quantity of material to which individuals or groups are exposed (Table I), the infection risk may be low, acceptable or elevated (Stenström et *al*., 2011, modified).

Table I. Key exposure/transmission pathways associated with sanitation technologies (Stenström et *al*., 2011 modified).

Exposures	Illustrations	Descriptions	Risk categories
Ingestion of excreta (e1)		The transfer of excreta (urine and/or faeces) through direct contact to the mouth from the hands or items in contact with the mouth.	High
Dermal contact (e2)		The infection where a pathogen is entering through the skin (through the feet or other exposed body part) (Example hookworms)	Acceptable
Contact with flies/mosquitoes (e3)		Includes the mechanic transfer of excreta from a fly to a person or food items. Also, include bites from a mosquito or other biting insects which could be carrying a disease	High
Inhalation of aerosols and particles (e4)		Refers to the inhalation of micro-droplets of water and particles which may not be noticeable, but which may carry a pathogen dose and emanate from or is a result of a sanitation technology.	Low
Contaminated groundwater/surface water (e5)		Refers to the ingestion of water, drawn from a ground or surface source, that is contaminated from a sanitation technology	High
Contact with overflowing/leaking contents (e6)		Refers to subsequent contact because of malfunction of a sanitation technology. (Example - pit or tank overflowing because of flooding, groundwater intrusion or general malfunction)	Acceptable
Falling into pit/container/excavation (e7)			Low
Ingestion of urine (e8)		Refers to the specific case of ingestion of urine (reference to E) from handling practices of specific technologies.	Low
Consumption of contaminated produce (vegetables) (e9)		Refers to consumption of plants (Example lettuce) that have been grown on land irrigated or fertilized with a sanitation product or where accidental contamination is likely to occur.	High

I.2.4. Indicators of improved, safe and sustainable sanitation

Adequate sanitation, together with good hygiene and safe water are fundamental to good health and to social and economic development (Mara et *al*., 2010). Providing sustainable sanitation needs to address not only technology implementation, but also cost, ownership and space issues (Van Minh and Nguyen-Viet, 2011). Sustainability with respect to sanitation implies that the system needs to comprise of collection, storage, transport and treatment of human excreta, grey water, solids wastes, and storm water and the safe disposal or reuse of end products (Obani and Gupta, 2016). A sustainable sanitation system should be technically feasible, acceptable and contribute to health improvement and environmental protection. Table II describes the eight indicators developed to assess safety and sustainability of on-site sanitation system by the Joint Monitoring Program (JMP) for water and sanitation (Jenkins et *al*., 2014). The first three (1-3) indicators assess the technical design of the facility, the next two indicators (4 and 5) assess availability and access to safe faecal waste management services and the last three indicators (6, 7 and 8) assess the functionality.

Table II. Indicators for classifying on-site sanitation systems as improved (I) (JMP definition), hygienically safe and sustainable (SS), and functioning (F) in low income communities (Jenkins et *al.*, 2014).

System aspects	Indicator description	Indicator type	Definition and measurement applied in this study
Facility design	1- Pit with slab or better	I, SS	Above-ground technology is basic pit with slab; build with concrete, brick, rock or other hard material.
	2- Waste contained in pit	I, SS	Technology has waste pit, septic tank, or concrete to sewer with no exterior waste drain pipe observed by enumerator (assumed if unable to observe)
	3- Below ground pit/tank lined	SS	Below ground technology is part or fully lined, septic tank, or is connected to sewer, to allow for safe waste emptying, and protect shallow groundwater
Waste management (emptying, transport, disposal)	4- Hygienic emptying service locally available	SS	Vacuum tanker service to extract pit waste in sealed tanks and dispose into municipal treatment systems reported as locally available, or user intends to use service to empty in near future
	5- Plot accessible to hygienic emptying service vehicles	SS	Enumerator observation of device physical accessibility (Car, tanker or tug) or actual use of tanker/tug to empty within last 03 years
Functional condition	6- Structurally safe to use	F	Enumerator observation that slab/floor is not collapsing into pit nor in state prohibiting safe use (assumed if unable to observe and not reported)
	7- Not completely full of waste	F	Enumerator observation of pit fullness by measuring depth from slab/top to surface of sludge (assumed if unable to observe and not reported)
	8- Facility has half height walls and half height door or more	F	Enumerator observation of toilette facility, roof, door and height
	8A- (high standard) Facility has roof, full height walls and door	F	Enumerator observation of toilette facility, roof, door and height

I.2.5. Faecal sludge

I.2.5.1. Definition and typology

Faecal sludge is a mixture of solids and liquids, containing mostly excreta, urine and water, in combination with sand, grit, trash and/or various chemical compounds (Tilley et *al*., 2014). Faecal sludge comes from on-site sanitation technologies, i.e. it has not been transported through a sewer (Strauss et *al*., 2003). Faecal sludge forms a major health risk due to the presence of pathogens (Feachem et *al*., 1983). In urban slums, where open defecation and excreta disposal in the open storm water drains is very common, this health risk is a reality. Major contaminant constituents in sludge from pit latrines and septic tanks are organic matter in the form of COD, nutrients and pathogens (bacteria, viruses and parasites) (Katukiza et *al.*, 2012). Their concentration is higher than in the municipal wastewater (Table III). Heinss et *al.* (1998) subdivided faecal sludge into two types based on their concentrations:

- the type A FS is sludge coming from public toilets or public surfaces (market, hostel, …) and that are stored for some few days or weeks only. They are relatively highly concentrated and are biochemically unstable;
- the type B FS is sludge coming from on-site sanitation disposals (pit toilet, septic tanks, ...). They have been stored for many years and are less concentrated and partially stable.

In general, FS are characterized by a high content of organic and dry matter (Table III) with the concentration 10 to 100 times more than those found in domestic wastewater. Table III shows the characteristics of two types of sludge.

Table III. Faecal sludge from on-site sanitation systems in tropical countries: characteristics, classification and comparison with tropical sewage (Heinss et *al*., 1998).

Information	type A faecal sludge (unstable)	type B faecal sludge (partially stable)	Domestic wastewater
Example	Type A (High strength)	Septic tanks	Tropical wastewater
Characterization	Highly concentrated, mostly fresh faecal sludge; stored for days or week only	Faecal sludge less concentrated, generally stored for many years, more stable than faecal sludge from public toilets.	
COD (mg/L)	20 – 50,000	< 10,000	500 – 2,500
COD/BOD	2 :1-5 :1	5:1-10:1	2:1
N- NH_4 (mg/L)	2 – 5,000	< 1,000	30 - 70
TS (mg/L)	≥ 3.5 %	< 3 %	< 1 %
SS (mg/L)	≥ 30,000	~7,000	200 - 700
Helminth eggs (n°/L)	20 – 60,000	= 4,000	300 – 2,000

I.2.5.2. Factors affecting the quality of faecal sludge in on-site sanitation technologies

Strauss et *al.* (1997) showed the quality of faecal sludge to be influenced by variables such as the storage duration, the temperature, the intrusion of groundwater, the mixture with solid waste and the tank emptying technology (Fig. 13). In general, the longer the sludge stays without being emptied, the more stable it becomes. However, it begins to form crust and becomes difficult to empty.

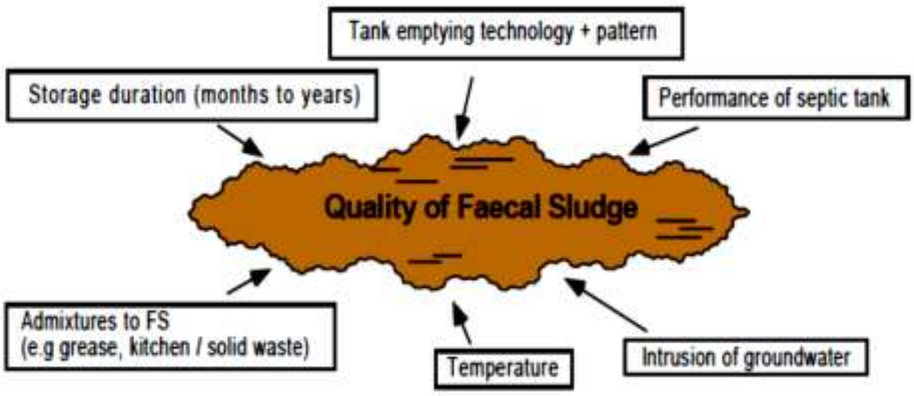


Fig. 13. Representation of factors affecting the quality of faecal sludge in sanitations technologies (adapted from Strauss et *al*., 1997).

I.2.5.3. Faecal sludge management

With the high population growth rate of developing countries, there is still a high proportion of people (2.6 billions) who do not have access to improved sanitation (Medland et *al.*, 2016). In these countries, 65 to 95 % of households rely on on-site sanitation for excreta disposal (Ingallinella et *al*., 2002). This represents a huge amount of faecal waste to manage in a context of absence or non-significant availability of treatment plants. Koné and Strauss (2004) estimated the production of faecal sludge to an average of 1000 m^3/day in a town of 1 million inhabitants among which only 300 to 500 m^3 are properly managed. This means that at least 2/3 of the faecal sludge produced is improperly managed.

In Cameroon, the study of Berteigne (2012) estimated that the FS production in Douala and Yaounde, the two main towns of the country are respectively 1800 m^3/week and 900 m^3/week. Furthermore, these cities have no FS treatment plants. The situation represents a serious threat to human health and environment taking into consideration their high pathogen content. In fact, as reported by Feachem et *al*. (1983) and reiterated by WHO (2006), the improper management of wastewater and excreta are responsible of a good number of water-borne diseases (Table IV) that cause millions of deaths every year mainly among children.

Table IV. Classification of infectious diseases linked to excreta and their responsible germs (source Feachem et *al*., 1983 modified).

Pathogen	**Common name for infection caused**	**Present in:**		
		urine	**faeces**	**sullage**
Bacteria				
Escherichia coli	diarrhoea	+	+	+
Leptospira interrogans	leptospirosis	+		
Salmonella typhi	typhoid fever	+	+	+
Shigella spp.	shigella dysentery		+	
Vibrio cholerae	cholera		+	
Viruses				
Poliovirus	poliomyelitis		+	+
Rotaviruses	enteritis		+	
Protozoa				
Entamoeba histolytica	amoebic dysentery		+	+
Giardia intestinalis	giardiasis		+	+
Helminths - parasite eggs				
Ascaris lumbricoides	ascaridiasis		+	+
Fasciola hepatica	liver fluke		+	
Ancylostoma duodenale	ancylostomiasis		+	+
Necator americanus	necatoriasis		+	+
Schistosoma spp.	schistosomiasis/ billharziosis	+	+	+
Taenia spp.	cysticercosis/taeniasis		+	+
Trichuris trichiura	trichuriasis		+	+

Most FS treatment options nowadays seek to ensure sustainability and continuity while minimizing cost as much as possible. Some of the proper treatment options comprise batch-operated settling-thickening units, non-aerated stabilization ponds, combined composting with municipal organic refuse; extended aeration followed by pond polishing (Klingel et *al*., 2002; Strauss et *al.*, 2003) (Fig. 14). Co-composting can be carried out with organic waste, producing a solid fraction that can be valorised in agriculture. Planted and unplanted drying beds could be exploited, producing leachate which can either be subjected to a secondary treatment or discharged back to the environment, depending on the level of pollution within it. Settling/thickening tanks or anaerobic digestion are techniques exploited in other places, followed by joint treatment with wastewater, the use of waste stabilization ponds, biofilms or constructed wetlands. In all cases, the solid part of the waste effluent either undergoes co-composting with organic solid waste or it is naturally dried, all with the aim of agriculture reuse.

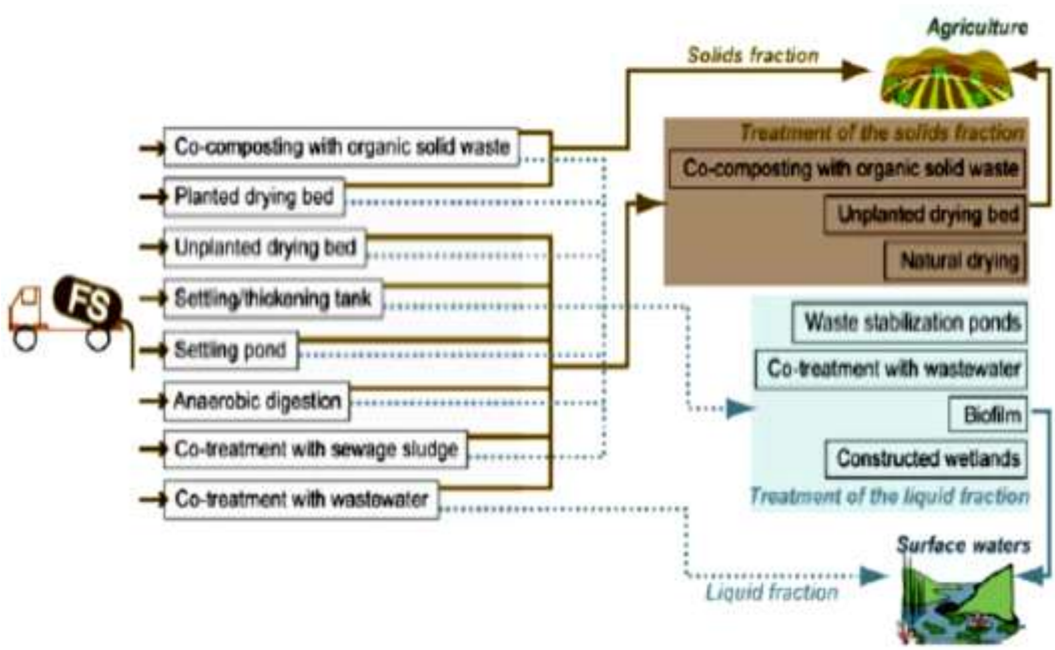


Fig. 14. Overview of the sustainable options for faecal sludge treatment (Koné and Strauss, 2004).

I.2.5.4. General Concerns

With the implementation of resource recovery, it is important to evaluate constituents that may impact both humans and the environment. These include the presence of pathogens and heavy metals. Social factors such as acceptance in using products from FS treatment and market demand also need to be considered to ensure uptake of the intended end uses (Strande et *al*., 2014).

I.2.5.4.1. Pathogens

FS contains large amounts of microorganisms, mainly originating from the faeces. The microorganisms can be pathogenic and exposure to untreated FS constitutes a significant health risk to humans, either through direct and indirect exposure (Feachem et *al*., 1983). The transmission cycle of pathogens can be interrupted by putting barriers in place to block transmission paths and prevent cycle completion. FS need to be treated to an adequate hygienic level depending on the end uses and disposal options.

I.2.5.4.2. Heavy metals

Heavy metals are a concern due to their toxicity and long-term negative effects on soil (Strande et *al.,* 2014). They are a major concern if sludge are mixed with industrial effluents that are not adequately pre-treated. Heavy metals can also enter the sewer systems at the household level through the relatively common practice of improper disposal of wastes containing heavy metals (e.g. batteries, solvents, paints) into the system. The total metals concentration in the sludge differs from the bioavailable metals concentration as the organic matter in sludge can bind metals in a form that is not biologically available. There is still no regulatory limit for heavy metals in sludge for land application in African countries. However, an overview of regulatory limits for heavy metals has been set in industrialized countries (Strande et *al*., 2014) (Table V).

Table V. Regulations for heavy metal concentrations in the US and Europe for the land application of treated wastewater sludge (Biosolids) (From Strande et *al.,* 2014).

Parameters	Concentration limits (mg/kg)		
	Exceptional quality of biosolids (McBride, 1995)	Eco label compost (Hogg et *al*., 2002)	Use of biosolids in Spain Hogg et *al*., 2002)
AS	41	-	-
Hg	17	-	-
Fe	-	-	-
Pb	300	100	750
Ni	420	50	300
Cr	1,200	100	1,000
Zn	2,800	50	2,500
Se	36	-	-

Some heavy metals have bio-importance as trace elements but the bio toxic effects of many of them in human biochemistry are of great concern Strande et al. (2014). Hence, there is a need for proper understanding of mechanism involved, such as the concentrations and oxidation states, which make them harmful (Appiah-Effa et al., 2015). It is also important to know their sources, leaching processes, chemical conversions and their modes of deposition in polluting the environment, which essentially supports life. In general the toxicity of metal ions to mammalians systems is due to chemical reactivity of the ions with cellular structural proteins, enzymes and membrane system (Mahurpawar, 2015). The target organs of specific metal toxicities are usually those organs that accumulate the highest concentrations of the metal in vivo. This is often dependent on the route of exposure and the chemical compound of the metal i.e. its valiancy state, volatility, lipid solubility …

Metals have been shown to causes acute as well as chronic poisoning in man and other experimental animals. Harmful effects of individual metals are presented briefly in Table VI below:

Table VI**.** Clinical aspects of heavy metals chronic toxicities (Mahurpawar, 2015).

Metal	Target Organs	Primary Sources	Clinical effects
Arsenic	Pulmonary Nervous System, Skin	Industrial Dusts, Medicinal Uses Of Polluted Water	Perforation of Nasal Septum, Respiratory Cancer, Peripheral Neuropathy: Dermatomes, Skin, Cancer
Cadmium	Renal, Skeletal Pulmonary	Industrial Dust And Fumes And Polluted Water And Food	Proteinuria, Glucosuria, Osteomalacia, Aminoaciduria, Emphysemia
Chromium	Pulmonary	Industrial Dust And Fumes And Polluted Food	Ulcer, Perforation of Nasal Septum, Respiratory Cancer
Manganese	Nervous System	Industrial Dust And Fumes	Central And Peripheral Neuropathies
Lead	Nervous System, Hematopoietic System, Renal	Industrial Dust And Fumes And Polluted Food	Encephalopathy, Peripheral Neuropathy, Central Nervous Disorders, Anemia.
Nickel	Pulmonary, Skin	Industrial Dust, Aerosols	Cancer, Dramatis
Mercury	Nervous System, Renal	Industrial Dust And Fumes And Polluted Water And Food	Proteinuria

I.2.5.4.3. Social factors

Different societies and cultures have different reactions and approaches to the management of human excreta that must be taken into consideration when evaluating the best end use for faecal sludge (Strande et *al*., 2014). Some cultures reject the use of excreta altogether, whereas others have a long history of excreta use in agriculture. In a society where the use of FS is strictly taboo, other solutions such as co-treatment with other waste streams, use in building materials or as fuel might be more appropriate and accepted technologies (Joseph et *al.*, 2014).

I.2.5.4.4. Policies and laws regulating faecal sludge management in Cameroon

Expertise in urban sanitation in Cameroon are scattered or overlap between different Ministries and different Municipalities (Urban Council and District Municipalities) without operational structures and without a coordinating structure. The existing policies are rather general and governing the management of the environment and community health, but no specific mention of liquid waste sanitation. The decrees implementing the Framework Law on Environment (1996) and the Water Act (2001) are not yet published.

Before the decree No. 2004/320 of 8 December 2004 reorganizing the Government, the Ministry of Urban Development and Housing E.g. Ministry of Town planning intervened in the field of sanitation through the sub-directorate of sanitation (Art. 22). So, participating in the monitoring and coordination of the remediation work and drainage in cities. It also intervened in monitoring and coordinating the collection, removal and waste treatment operation that also fell within the jurisdiction of the Municipalities (Art. 3 of Law No. 015 of 15 July 1987 establishing Urban Communities).

Similarly, the Ministry of Energy and Water (Decree No. 2004/320 of 8 December 2004) former Ministry of Mines, Water and Energy, through the Water Department (Art. 32, 33) and the sub-directorate of sanitation (Art. 42, 43, 45) is working for wastewater management, control and maintenance of sanitation facilities. The Ministry of Energy and Water participated in the structuration with regards to the collection and treatment of waste water, domestic, rainwater and various urban areas in relation to other administrations. The terms of the collaboration were unfortunately not specified, which led to a complacency and a rejection of responsibility by both sides. The action fields of urban communities and district municipalities (under the Ministry of Territorial Administration and Decentralization) are confusing and overlapping in the waste management field. Indeed, according to Law No. 015 of 15 July 1987 on the creation of urban communities, "health and safety" (Art. 3) are for the urban community as "sewage treatment" and "sanitation" are incumbent upon the District/Municipalities (Art. 11), which are subdivisions of the Urban Community (Art. 1).

In 2011, Cameroon adopted a national sewerage strategy enabling it to define an action plan on liquid waste. Specifically, it will increase the access of urban and rural populations to improved sanitation; increasing the national coverage of 34% in 2010 to 57% in 2020. It will also ensure the reliability and effectiveness, financial and environmental sustainability and acceptability by the budgets of households and the Government of the new services offered.

I.2.6. Valorisation of faecal sludge

I.2.6.1. Agricultural value

The use of FS as soil conditioner can range from deep row entrenchment of untreated FS (Still et *al.*, 2012), to bagged compost that is sold as a commercial product for household level use in horticulture (Strande et *al.*, 2014). Using FS as soil amendment has many benefits over using chemical fertilizers alone (Koné and Strauss, 2004). Organic matter in FS can increase soil water holding capacity, build structure, reduce erosion and provide a source of slowly released nutrients. As mentioned by other authors (Still et *al*., 2012; Strande et *al.*, 2014; Koné and Strauss, 2004), when using FS as a soil conditioner, its fate and social acceptance can be closely linked to its potential commercial value. Other factors that need to be considered include nutrients, which may or may not be available in the ratio required by soil and crop systems. Koné et *al*. (2010) demonstrated that the quantity of FS produced yearly by a human contains nearly enough plant macro- and micro-nutrients to grow the quantity of food they require in a year (taken as 250 kg of cereals) as shown in Table VII below.

Table VII. Nutrient content of urine and faeces and mass of nutrients required to grow 250 kg of cereals (Drangert, 1998).

Nutrients	Urine (kg)*	Faeces (kg)**	Total (kg)	Nutrients needed for 250 kg cereals (kg)
Nitrogen (N)	4.0	0.5	4.5	5.6
Phosphorus (P)	0.4	0.2	0.6	0.7
Potassium (K)	0.9	0.3	1.2	1.2
Total amount of N+P+K	5.3	1.0	6.3	7.5

(*500 L/capita/year; **50 L/capita/year)

I.2.6.2. Aquaculture value

The nutrients in FS can be used in aquaculture, when growing fish in waste stabilization ponds with effluents from FS treatment plant. The nutrient can increase the growth of plankton or increase the growth of aquatic plants such as water spinach (*Pistia stratiotes*) (Noumsi et *al*., 2005). Plankton can be harvested for use as fish feed in aquaculture and aquatic plants can be harvested for animal feed or human consumption. However, faecal bacteria can accumulate in the internal organs and gills of fish. Protective barriers to prevent transfer to human include cooking fish thoroughly before consumption, transferring the fish into clean water ponds for 2 or 3 weeks before consumption or maintaining faecal coliforms count of less than 1,000 CFU/100 mL (WHO, 2006). Fish can also act as intermediate hosts to helminths which is a concern with FS (Feachem et *al*., 1983).

I.2.6.3. Building materials

Dried FS can be used in the manufacturing of ceramics, cement and bricks, and in the production of clay-based products. Dried wastewater sludge and FS have been shown to have qualities that are similar to other traditional raw materials such as limestone, and clay material (Strande et *al*., 2014). FS is commonly used in cement production in Japan as an alternative fuel or by incorporating the ash resulting from sludge incineration into the cement (Strande et *al*., 2014).

I.2.6.4. Production of Biogas

The anaerobic digestion of FS faecal sludge produces a mixture of gaseous compounds, commonly referred to as 'biogas' (Tilley et *al.*, 2014). The mixture of gases that is commonly produced is presented in Table VIII. The mixture and amount of gas produced depends on operating parameters such as stability of the sludge (Strande et *al.*, 2014). Biogas has a high-energy content due to the high calorific value of methane and can therefore be used as a fuel.

Table VIII. Gases produced during anaerobic digestion (adapted from Strande et *al*. (2014)).

Substance	Symbol	Percentage (%)
Methane	CH_4	50-70
Carbon dioxide	CO_2	30-40
Hydrogen	H_2	5-10
Nitrogen	N_2	1-2
Water vapour	H_2O	0.3
Hydrogen sulphide	H_2S	traces

I.2.6.5. Incineration/co-combustion

Incineration is the complete combustion of organic matter at high temperatures and can either be a disposal mechanism or provide a way to generate electricity or heat. Incineration of wastewater sludge is relatively common in Europe and US. Incineration reduces sludge to ash (10 % of initial volume) which is mainly composed of remaining inorganic material and at the same time destroys all pathogens due to the high processing temperatures (Strande et *al.*, 2014). The calorific value of wastewater sludge typically ranges from 10-29 MJ/kg, while calorific value of FS is reported to be 17 MJ/kg solids, compared to an average coal value of 26 MJ/kg (Muspratt et *al.*, 2014).

I.2.7. Faecal sludge and transmission of helminthic diseases

I.2.7.1. Helminthiasis: a common disease

Generally there are 5 million people suffering from helminthiasis, mainly in developing countries. Helminthiasis is particularly common in regions where poverty and poor sanitary conditions are dominant. Under these circumstances helminthiasis incident rates attain 90 %. There are several kinds of helminthiasis, Ascariasis being the most common and endemic in Africa, Latin America and the Far East. Even though the mortality rate is low, most of the people infected are children under 15 years with problems of faltering growth and/or decreased physical fitness. Around 1.5 million of these children will probably never bridge the growth deficit, even if treated. Helminthiasis is transmitted through: (a) the ingestion of polluted crops, (b) contact with polluted sludge, faeces or wastewater, and (c) the ingestion of polluted meat (Jimenez, 2007).

I.2.7.2. Classification of helminth eggs in wastewater and sludge

Helminth eggs are the most difficult biological parasites to inactivate in wastewater and sludge. In developing countries, in particular, they are present in high concentrations and are the cause of many diseases that impact seriously on the human population (Maya et *al*., 2012). Helminth eggs are transmitted and spread through an infection cycle which includes different stages and hosts. The faecal-oral route of transmission is shown below (Fig. 15).

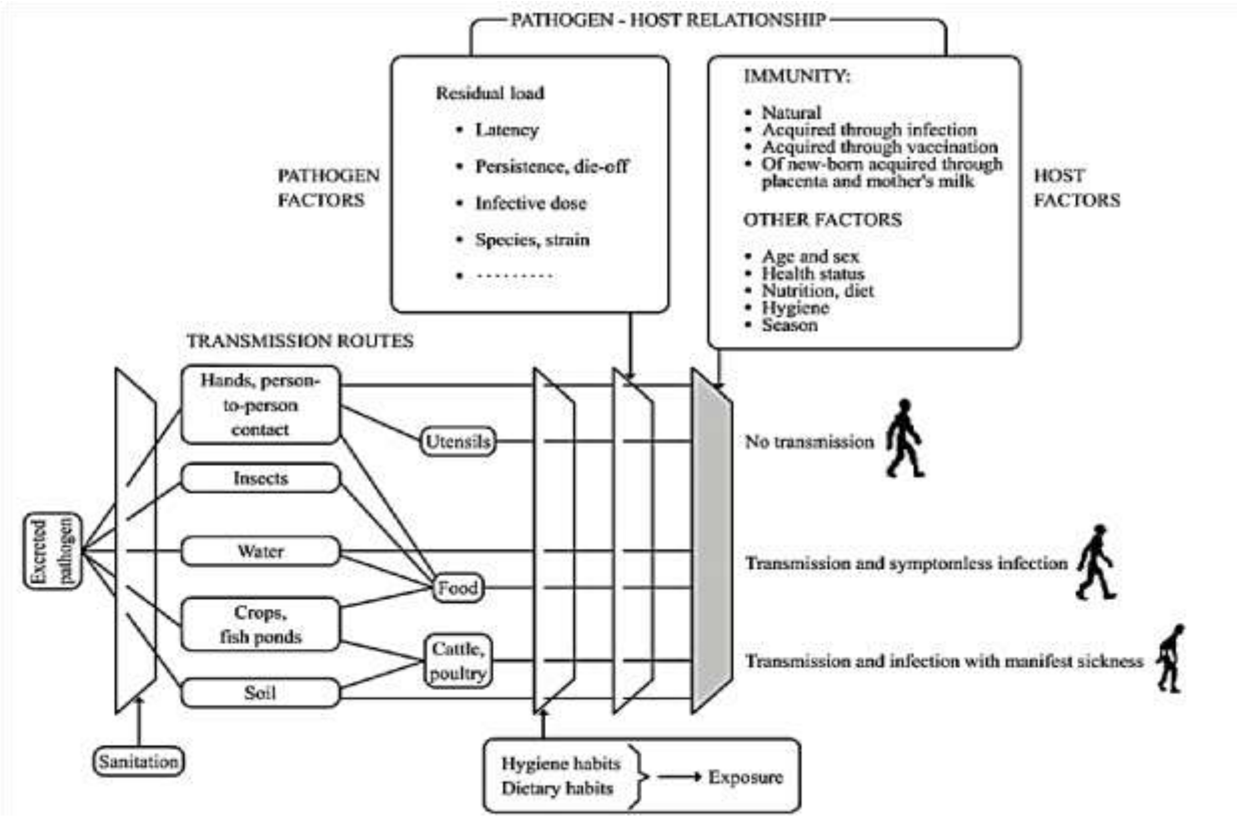


Fig. 15. Spread of pathogens in excreta from an infected individual to a healthy individual (Carr and Strauss, 2001).

There are three different types of helminths found in wastewater and sludge: (i) Platyhelminths, or flat worms, (ii) Nemathelminths, Nematodes, and (iii) Annelids (Fig. 16). In the sanitary engineering field, only the first two are of importance. A common characteristic of helminths is that they reproduce through eggs and the eggs of different helminths differ in shape and size.

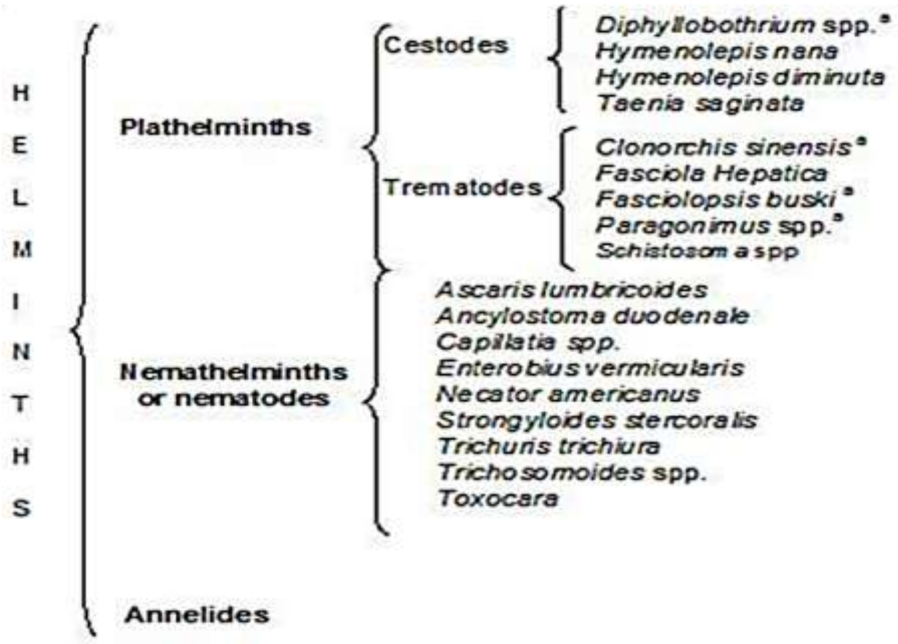


Fig. 16. Classification of helminth eggs found in wastewater and sludge ([a]Reported only in wastewater and sludge from some region of Asia) (Jimenez, 2007).

I.2.7.3. Helminth life cycle

Helminthiasis infective agents are the eggs, not the worms. Worms cannot live in wastewater or in sludge because they need a host. Therefore, part of the control strategy for helminthiasis is to remove the eggs from wastewater and later inactive them in the sludge produced from wastewater treatment. Helminths are pluri-cellular worms; they are not microbes although their eggs are microscopic. Helminths come in different types and sizes (from 1 mm to several m in length), with several life cycles and ideal living environments. Besides humans some of them have intermediary hosts (such as *Schistosoma* spp. that live temporarily in a snail). Helminths' life cycle is very complex and different from that of bacteria and protozoan, which are well-known microbes in the wastewater treatment field (Jimenez et *al.*, 2000).

I.2.7.3.1. Cestodes life cycle (*Teania* sp.)

Teania sp. is the causal agent of Cysticercosis. *Taenia* species are the most common cestode parasites of humans. More than 60 million people are infected with *T. saginata* (beef tapeworm) worldwide and about four million are infected with *T. solium* (pork tapeworm). The life cycle of a *Taenia* species can be seen in Fig. 17. *T. saginata* has a cosmopolitan distribution, but is more common in developing countries where hygiene is poor and the inhabitants have a tendency of eating raw or insufficiently cooked meat. *T. saginata* is the most common adult tapeworm found in man. *T. solium* is virtually extinct in Europe and the USA. Cysticercosis is an infection of both humans and pigs with the larval stages of the parasitic cestode, *T. solium*. This infection is caused by ingestion of eggs shed in the faeces of a human tapeworm carrier [1]. Pigs and humans become infected by ingesting eggs or gravid proglottids [2, 7]. Humans are infected either by ingestion of food contaminated with faeces, or by autoinfection. In the latter case, a human infected with adult *T. solium* can ingest eggs produced by that tapeworm, either through faecal contamination or, possibly, from proglottids carried into the stomach by reverse peristalsis. Once eggs are ingested, oncospheres hatch in the intestine [3, 8], invade the intestinal wall, and migrate to striated muscles, as well as the brain, liver, and other tissues, where they develop into cysticercoid [9]. In humans, cysts can cause serious sequellae if they localize in the brain, resulting in neurocysticercosis. The parasite life cycle is completed, resulting in human tapeworm infection, when humans ingest undercooked pork containing cysticerci [4]. Cysts evaginate and attach to the small intestine by their scolex [5]. Adult tapeworms develop, (up to 2 to 7 m in length and produce less than 1000 proglottids, each with approximately 50,000 eggs) and reside in the small intestine for years [6].

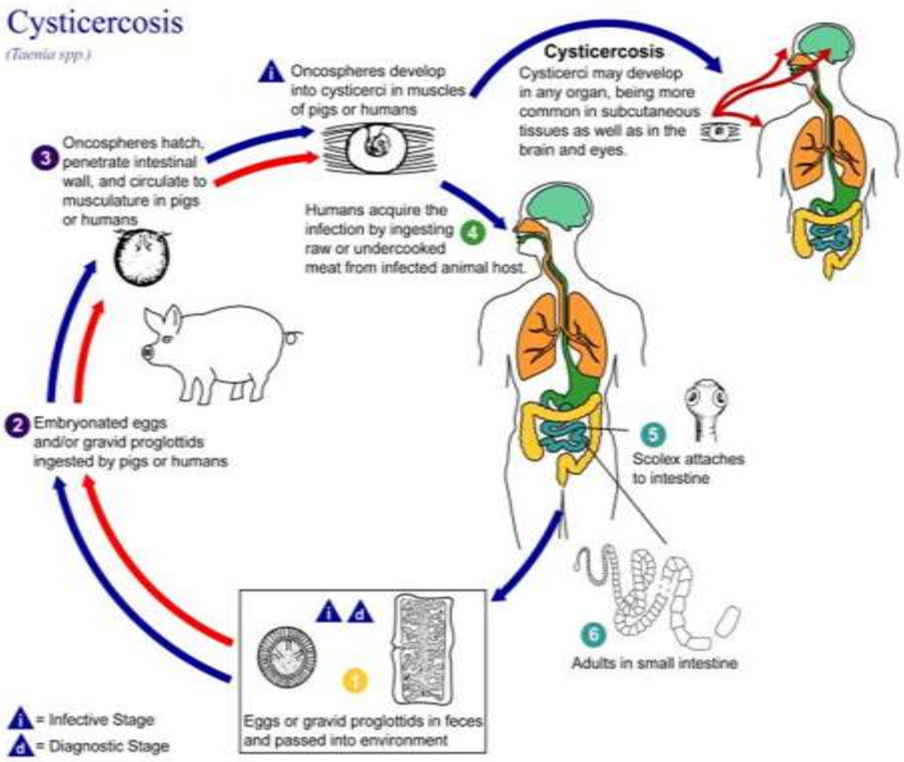


Fig. 17. Life cycle of *Taenia* spp., the causal agents of Cysticercosis (CDC, 2013).

I.2.7.3.2. Trematodes life cycle

The life cycles of *Fasciola*, *Fasciolopsis* and *Echinostoma* species are complex, requiring more than one intermediate host. Adult worms inhabit the liver or bile ducts of the definitive host (human), where they lay many eggs which are deposited into the environment in the faeces. They are immature when passed. If they are passed into water, they become mature in nine to 15 days at the optimum temperature of 22-25 °C. Immature eggs are discharged in the biliary ducts and in the stool [1] (Fig. 18). Eggs become embryonated in water [2], eggs release miracidia [3], which invade a suitable snail intermediate host [4], including many species of the genus *Lymnae*. In the snail, the parasites undergo several developmental stages (sporocysts [4a], rediae [4b], and cercariae [4c]). The cercariae are released from the snail [5] and encyst as metacercariae on aquatic vegetation or other surfaces. Mammals acquire the infection by eating vegetation containing metacercariae. Humans can become infected by ingesting metacercariae-containing freshwater plants, especially watercress [6]. After ingestion, the metacercariae excyst in the duodenum [7] and migrate through the intestinal wall, the peritoneal cavity, and the liver parenchyma into the biliary ducts, where they develop into adults [8]. In humans, maturation from metacercariae into adult flukes takes approximately 3 to 4 months. The adult flukes (*Fasciola hepatica*: up to 30 µm by 13 µm; *F. gigantica*: up to 75 µm) reside in the large biliary ducts of the mammalian host. *Fasciola hepatica* infect various animal species, mostly herbivores. The life cycle of the *Echinostomes* differs by one minor point: the cercariae [4c] encyst wither within the tissues of the intermediate host [4] in which sporocysts [4a] and rediae [4b] develop, or penetrate and encyst in other animals such as amphibians or fish.

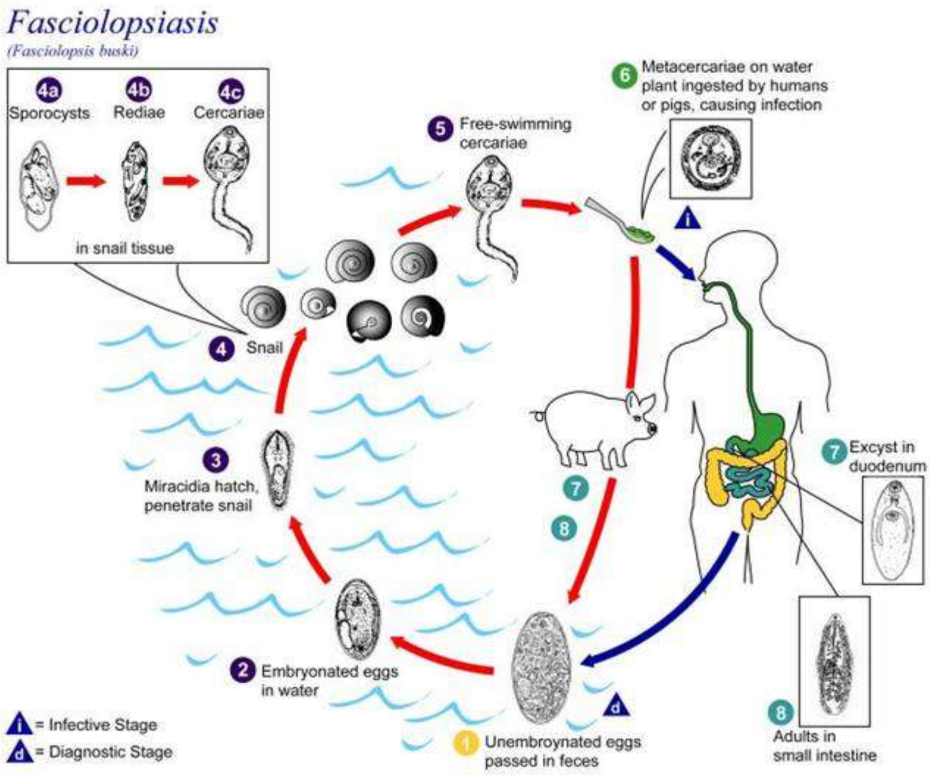


Fig. 18. Schematic life cycle of *Fasciola*, *Fasciolopsis* and *Echinostoma* species (CDC, 2013).

I.2.7.3.3. Nematodes life cycle (*Capillaria philippinensis*)

The complete life cycle is not known however; human infection is initiated by the consumption of raw fish. The infective larvae are found in the intestine of the fish. When infected fish are eaten by humans, the larvae mature and the adult worms live in the intestinal mucosa, mainly in the jejunum, where they are usually present in large numbers. Larval stages, oviparous and larviparous females are also found in the host's intestine, which suggests that the nematode multiplies in the intestine resulting in auto-infection as in *Strongyloides* infection. The eggs are passed out in the faeces and embryonate in the soil, a process which takes about 12 days. The eggs are ingested by fresh-water fish, they hatch and develop into the infective form in the intestine of the fish (Fig. 19).

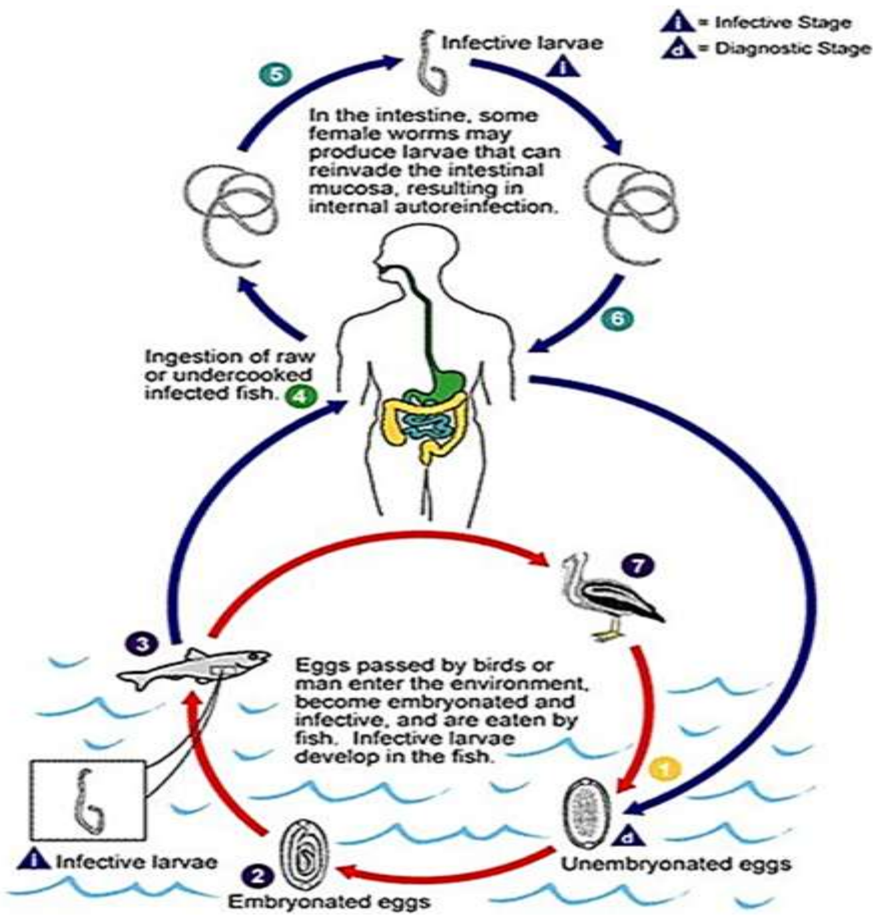


Fig. 19. Schematic life cycle of *Capillaria philippinensis* (CDC, 2013).

Typically, unembryonated eggs are passed out in the human stool [1] (Fig. 22) and become embryonated in the external environment [2]; after ingestion by freshwater fish, larvae hatch, penetrate the intestine, and migrate to the tissues [3]. Ingestion of raw or undercooked fish results in infection of the human host [4]. The adults of *C. philippinensis* (males: 2.3 to 3.2 mm; females: 2.5 to 4.3 mm) reside in the human small intestine, where they burrow in the mucosa [5]. The females deposit unembryonated eggs. Some of these become embryonated in the intestine, and release larvae that can cause autoinfection. This leads to hyper infection (a massive number of adult worms) [6]. *C. philippinensis* is currently considered a parasite of fish eating birds, which seem to be the natural definitive host [7].

I.2.8. Helminth eggs characteristics

An important characteristic of helminth ova is that they are covered by 3-4 layers. The 1-2 outer layers are formed with mucopolysacharides and proteins. The middle layers consist of chitinous and serve to give structure and mechanical resistance to the eggs. Finally, the inner layer is composed of lipids and proteins and is useful to protect eggs from desiccation, strong acid and bases, oxidants and reductive agents as well as detergent and proteolytic compounds. Thus, the combination of all these layers is responsible for making eggs very resistant to several environmental conditions (Maya et *al.*, 2012). Helminth ova of concern in the sanitary field measure between 20 and 80 µm with a density of 1.06-1.15 and are gelatinous which makes them very sticky. All these properties determine the behaviour of helminth ova during wastewater and sludge treatment. First, it is very difficult to inactivate them unless the temperature is raised above 40°C or moisture is reduced to below 5 % (TS > 95%). But details about the contact time under these conditions and other related environmental factors are generally not well-defined for every type of helminth ova genus or for high helminth ova content. Only for *Ascaris* has a contact time of 10-20 days at temperatures above 40°C been reported (WHO, 2006). In wastewater treatment, the inactivation conditions mentioned can hardly be achieved, while in sludge treatment they are feasible. Thus, helminth ova are normally removed from wastewater and inactivated in sludge.

I.2.9. Physiochemical and biological factors that affect the survival of pathogenic microorganisms in the environment

I.2.9.1. Temperature

Most pathogens are inactivated at temperatures well above 60 °C when cell proteins and nucleic acids are denatured. As the temperature increases, less time is needed for pathogen inactivation (Strande et *al*., 2014). Heat resistance of the helminth eggs is due to the presence of a cuticle composed of several layers. This cuticle prevents the flow of certain substances (strong acids and bases, oxidants). However, temperatures above 45 °C can increase the permeability of the shell eggs of *Ascaris*, allow the entrance of bad compounds and increase the rate of drying eggs. The decrease in water content of eggs produced by desiccation can reduce the movement of the larvae, thereby contributing to their decomposition (Sanguinetti et *al*., 2005).

I.2.9.2. Time

The duration of the treatment time in treatment systems or the storage of treated sludge can result in pathogen reduction, as they have limited survival time in adverse conditions. In faeces, most bacteria can only survive between 1 week and 2 months. For example, *Salmonella* spp. survives averagely for 30 days and faecal coliform for 50 days (Feachem et *al.*, 1983). Helminth eggs however are very persistent, and can maintain viability for several months to years. The required storage duration for pathogen reduction also depends on the ambient temperature. For example, Niwagaba et *al*. (2014) recommends storage time of FS for up to one year at an ambient temperature of 35 °C, and two years at 20 °C. Storage at temperature less than 10 °C do not result in adequate inactivation (Tawfik et *al.*, 2015).

I.2.9.3. Sorption

Helminth eggs tend to sorb or settle, and hence partition with the solids fraction in FS treatment systems. In settling tanks, about 50 % of the helminth eggs are separated from the liquid fraction due to settling (Heinss et *al*., 1983). In filtration that occurs with drying beds, the majority of helminth eggs remain with the solid fraction, as does 90 % of indicator bacteria (Rachmadi et *al*., 2016).

I.2.9.4. Desiccation

Evaporation resulting in desiccation or dehydration reduces pathogens, as microorganisms need water for survival. Water activity is represented by the ratio of water vapour pressure of the sludge to the water vapour pressure of pure water under the same conditions (Carrington, 2001). Pure water has water activity of 1, and most pathogens cannot survive under water activity of 0.9 while some yeast and eggs survive in much drier conditions (e.g. drying beds) if the water content gets below a certain point where desiccation has an effect.

I.2.9.5. UV

Solar/UV radiation in the range of 300-400 nm effectively inactivates pathogens by denaturing DNA molecules via photochemical reactions (Borrely et *al.*, 1998). UV light has been shown to effectively inactivate *E. coli* in waste stabilization ponds (Konate et *al.*, 2013). However, it is important to remember that for this mechanism to be effective, the light rays must be able to penetrate the FS during treatment. This mechanism is therefore most likely only occurring at the surface, as the high organic matter and turbidity prevents penetration of UV radiation.

I.2.9.6. pH

Most microorganisms can only survive and grow within a range of 2-3 pH units, and very few can survive below pH 3 and above pH 10. In this way, chemical addition for pH control can result in pathogen reduction (Pecson et *al*., 2007). However, the pH can also upset composting and anaerobic digestion processes and it is therefore important to consider downstream treatment steps when employing pH control for pathogen reduction. Many pathogenic microorganisms are adapted to neutral pH (7). Highly acidic or alkaline conditions will have an inactivating effect. Addition of lime to excreta in dry latrines and to sewage sludge increases pH and can inactivate microorganisms. The speed of inactivation depends on the pH value, e.g. it is much more rapid at pH 12 than at pH 9.

I.2.9.7. Ammonia and oxygen

It is well established that aqueous ammonia is effective at inactivating microorganisms, but the exact mechanisms are not yet fully understood. As described by Vinneras (2013), possible mechanisms for bacterial inactivation are that NH_3 denatures proteins, destroys membrane potentials, or causes rapid alkalinization of the cytoplasm resulting in a critical loss of potassium (K). Viral inactivation is possibly due to the cleavage of RNA; but for larger organisms, such as helminth eggs, the mechanisms are still not fully understood. Ammonia disinfection has been shown to be effective in urine sewage sludge (Pecson et *al*., 2007), and compost (Adamtey et *al.*, 2010). It is aqueous NH_3 that is responsible for microbial inactivation, not the ammonium ion (NH_4^+). The pK_a of ammonia is 9.25 (the pH where 50 % is NH_3 and 50% is NH_4^+), and the percentage of NH_3 concentration based on the pH can be determined by the equation:

$$NH_3, \% = \frac{100}{1+[H+]/Ka}$$

The total aqueous NH_3 concentration will also depend on temperature and total ammoniacal nitrogen concentration ($NH_3 + NH_4^+$). For NH_3 disinfection to be effective, the pH has to be above 8.5 (jiirn Vinneras, 2013). Also, the microbial activities are dependent on oxygen availability. The lack of oxygen suppresses the overall metabolism of many nematodes and influences a number of different activities (Etewa et *al*., 2014; Katakam et *al*., 2014).

I.2.9.8. Predation

The biological factors that have been shown to affect parasite eggs include fungi and various invertebrates. The experimental results indicated that ovicidal fungi were capable of attacking and destroying *Ascaris lumbricoides* eggs combined to the heating of environment conditions. The survival of microorganisms is generally longer in material that has been sterilised than in an environmental sample containing other organisms (WHO, 2006). Organisms may affect each other by predation, release of antagonistic substances or competition (Niwagaba et *al*., 2014).

I.2.9.9. Moisture

Moisture is related to organism survival in soil and faeces. A moist soil favours the survival of microorganisms and a drying process will decrease the number of pathogens, e.g. in latrines (Williams et *al*., 2012).

I.2.10. Planted drying beds for faecal sludge and wastewater treatment

In the past several decades, planted drying beds have become a popular option for faecal sludge treatment and have been recognized as attractive alternatives to conventional wastewater treatment methods. This is due to their high pollutant removal efficiency, easy operation and maintenance, low energy requirements, high rates of water recycling, and potential for providing significant wildlife (Kadlec and Wallace, 2008; Vymazal, 2011). In terms of performance efficiency, most of the developing countries have warm tropical and subtropical climates, and it is generally acknowledged that planted drying beds are more suitable for wastewater and faecal sludge treatment in tropical than in temperate regions (Kadlec and Wallace, 2008; Kengne et *al.*, 2008). A warm climate is conducive to year-round plant growth and heightened microbiological activity which in general have positive effects on treatment efficiency (Poh-Eng and Polprasert, 1998). Planted drying beds in the tropics, which are exposed to higher temperatures and direct sunlight throughout the year, have higher year-round plant productivity and a concomitant decrease in the time necessary for microbial degradation.

I.2.10.1. Impact of planted drying beds design and operational variables

Pollutant removal efficiency in planted drying beds (PDBs) depends on a number of variables including pollutant loading, hydrologic regime, vegetation type and density, and temperature, all of which may be highly variable among various systems (Brix et *al*., 2007). Most commonly, pollutant removal is often accomplished by manipulating the system's hydraulic conditions and by selecting the appropriate type of dominant vegetation (Kadlec and Wallace, 2008).

I.2.10.1.1. Hydraulic loading rate

Hydraulic conditions strongly influence the biotic community composition, biochemical processes and the fate of pollutants in PDBs (Kadlec and Wallace, 2008; Gueye et *al*., 2016). The length of the hydraulic retention time (HRT) during which the pollutants are in contact with the substrate and the plant rhizosphere, is well known to be a crucial controlling factor in determining the removal efficiency of contaminants (Stottmeister et *al*., 2003). A longer HRT allows the extensive interaction between contaminants and wastewater. At a longer HLR, wastewater moves rapidly to the outlet reducing the contact time among the wastewater, the rhizosphere, and the microorganisms. However, longer HRTs typically require larger land space and higher capital cost, which are key factors in operation. Thus, studying the effects of different HRTs on the removal performance of pollutants in planted drying beds systems is important.

I.2.10.1.2. Presence of vegetation

It is generally assumed that planted drying beds outperform unplanted controls mainly because the plant rhizosphere stimulates microbial community density and activity by providing root surface for microbial growth, and a source of carbon compounds through root exudates (Vymazal and Kröpfelová, 2009; Wu et *al*., 2016). Aquatic macrophytes can affect the redox status of drying beds sediments by releasing oxygen from their roots into the rhizosphere and thereby stimulating aerobic decomposition (Brix and Arias, 2005). The better oxidizing condition in planted beds appears to enhance the biodegradation process by transferring oxygen down to the root system which in turn stimulates the density and diversity of the microbial community and enhance the microbial activities associated with the rhizosphere (Vymazal, 2011). In tropical climates where the plants grow faster and throughout the year, the uptake of nutrients has been reported in several studies.

I.2.10.1.3. Type of vegetation

While the positive role of macrophytes on contaminant removal in planted drying beds has been established, species selection is always one of the important considerations. A number of studies on the removal of conventional pollutants demonstrated that selection of macrophytes species matters (Kengne et *al*., 2008; Gueye et *al*., 2016). Different vegetation species have different capacities for nutrient uptake and accumulation of heavy metals (Diop et *al*., 2015), as well as variable effects on the functioning and structure of bacterial communities involved in the removal of contaminants in planted drying beds (Ruiz Rueda et *al*., 2008). In addition, plant communities consisting of multiple plant species with different seasonal growth patterns and root characteristics may be able to enhance the performance of a wetland. In a comparative study of the efficiency of contaminant removal between five emergent plant species, Yang et *al.* (2007) reported that *Pennisetum purpureum* had highest nutrient removal rates during the periods from May to June, and *Canna indica* showed the highest removal rate during the month of August. The removal rate of *Phragmites communis* was the highest during the month of December. This finding implied that the removal efficiency of contaminants varied with season and patterns of plant growth, and the most vigorous growth period of the plants corresponded to high contaminant removal rates.

I.2.10.1.4. Seasonal variation

Reduction of pollutant concentration in planted drying beds is mainly due by the biotic, temperature-dependent activity, consequently, the influence of temperature is an important parameter when pollutant treatment effectiveness of planted drying beds is evaluated (Kadlec, 2009; Song et *al*., 2013). In general, the efficiency of treatment decreases at low temperature primarily because of reduced biotic activity.

I.2.10.2. Overview of removal mechanisms in planted drying beds

I.2.10.2.1. Gravity separation

Gravity is probably the most common mechanism employed for liquid-solid separation in faecal sludge treatment. It can achieve the separation of suspended particles and unbound water (Strande et *al*., 2014). Particles that are heavier than water settle out under quiescent conditions at rates based on the sizes of particles, suspended solids concentration, and flocculation. The four types of settling mechanisms include discrete particle, flocculent, hindered, and compression. Discrete particle settling occurs in lower concentration waste streams when particles settle out individually without reacting with other particles. Flocculent settling occurs when particles join together and merge, increasing their mass and settling velocity (Fig. 20).

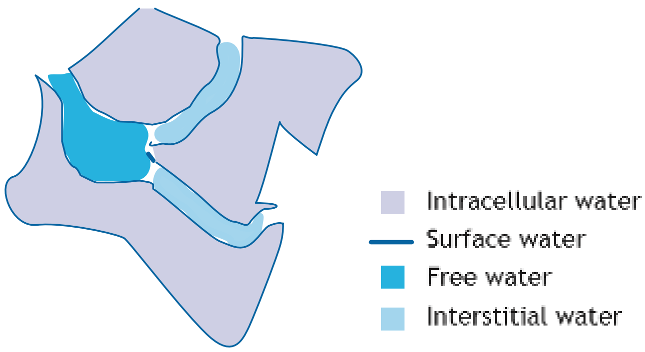


Fig. 20. Water forms in a sludge flock (modified from Kopp and Dichtl, 2001 cited by Strande et *al*., 2014).

This is important for smaller particles that are held together through Van der Waals forces, resulting in increased settling velocities. Hindered settling occurs in highly concentrated waste streams, where the particles settle out together as a “blanket”. Compression occurs at the bottom of a settling tank when the sludge blanket is “squeezed” by the weight of the solids above, removing more liquid.

I.2.10.2.2. Filtration and sedimentation

Sedimentation has been reported to be effective in removing helminth eggs (Alexandros and Akratos, 2016; Vacca and Dominici, 2015), due to their higher settling velocities (e.g., ~ 0.1 mm/s) (Sengupta et *al.*, 2011). Filtration is also a commonly applied mechanism for liquid-solids separation in faecal sludge. Several filtration media (e.g. membrane, granular) and types (e.g. slow, rapid, gravity, driven or pressurized) are applied to water, wastewater and treated sludge (bio solids) processing. However, in faecal sludge management (FSM) the most common types are unplanted and planted drying beds. These processes use filter media to trap solids on the surface of the filter bed, while the liquid percolates through the filter bed and is collected in a drain, or evaporates in the solids. In filter drying beds, slow filtration is occurring with filtration rates of 0.1-0.4 m/h, which requires less operation and maintenance than faster rates (Strande et *al.*, 2014). The parameters having the greatest impact on slow filtration efficiency are the characteristics of the influent, the type of filtration media and the filter loading rate (Leverenz et *al.*, 2009). During operation of the filter, the effective pore sizes will become smaller as particles are trapped in the filter, and the growth of a biological biofilm develops on the media (Figure 21).

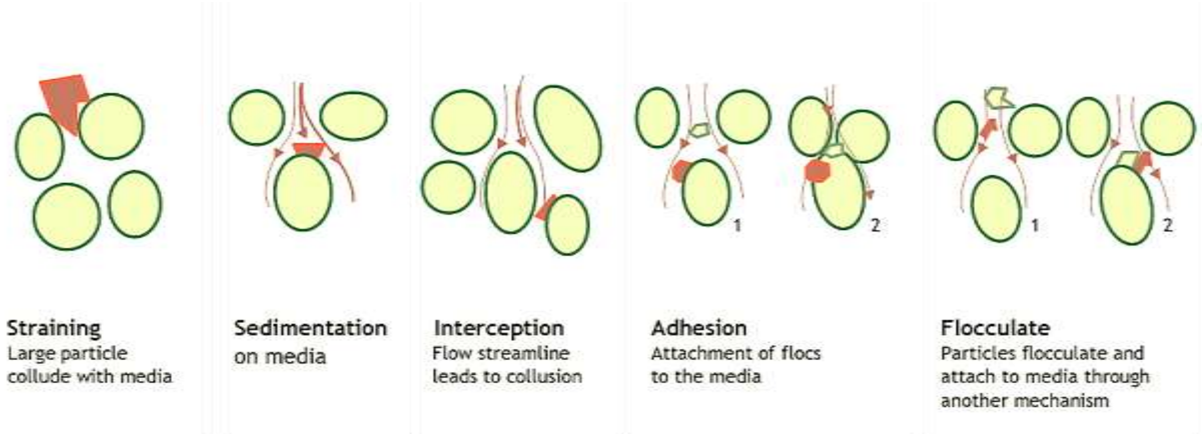


Fig. 21. Schematic representation of the mechanisms affecting flow in filter media (modified from Kopp and Dichtl, 2001 cited by Strande et *al.*, 2014).

I.2.10.2.3. Evaporation and evapotranspiration

Evaporation occurs when water is released into the air as vapour, and transpiration is the process by which plants release water vapour to the air as part of their metabolic processes (Beebe et *al.*, 2014; Tuttolomondo et *al.*, 2016). Evapotranspiration is the combination of these two mechanisms. In addition to filtration, dewatering in drying beds is also occurring through the evaporation and with planted drying beds through evapotranspiration (Strande et *al.*, 2014). For both mechanisms to occur, the surrounding environment needs to have an evaporative demand, which means that the air is not saturated (Towler et *al.*, 2004). Evapotranspiration is also dependent on regional meteorological factors including air temperature, relative humidity, solar radiation, and wind speed as well as planted drying beds design features including plant species diversity.

I.2.10.2.4. Heat drying

Heat drying is used to evaporate and dewater wastewater sludge (Biosolids) beyond what can be achieved with other more passive, or conventional methods. Heat drying achieves both weight and volume reduction, as water is lost in the form of vapour. The temperature of the sludge is increased through energy transferred from an external heat source, which allows the evaporation of free water at the sludge surface at a rate depending on the ambient air temperature, humidity, flow and pressure and the exposed sludge surface (Kim and Parker, 2008). As heat is continuing to be transferred, internal moisture is also being transferred to the surface and evaporates at a rate that depends on the physical characteristics of the sludge, the temperature and the moisture content.

I.2.10.2.5. Biological mechanisms

Biological mechanisms are essential in the achievement of treatment objectives through transformation of organic matter and nutrients. They are also important in understanding mechanisms of pathogen reduction. Biological treatment harnesses the metabolism and growth rate of microorganisms in naturally occurring process. The biodegradable organic matter in FS varies depending on the source, but usually needs to be stabilized prior to final end use or disposal. Stabilization involves the degradation of ready degradable material, leaving behind more stable and less degradable organics. This is important in order to reduce the oxygen demand, odours, and allows easy storage and manipulation (Chazarenc et *al*., 2009).

I.2.10.3. Overview of the fate of helminth eggs in faecal sludge treatment plant

Basically, to remove helminth ova from faecal sludge/wastewater it suffices to realize that there are in fact particles forming a fraction of the suspended solids. This is why the helminth ova content is related to the total suspended solids content (TSS) in wastewater-specifically, to the amount of particles measuring 20-80 μm (Jimenez, 2007). As helminth ova are particles, mechanisms used to remove suspended solids are also useful in removing helminth ova from wastewater. These mechanisms are sedimentation, filtration and coagulation flocculation.

I.2.10.3.1. Waste stabilization ponds

Waste stabilization ponds are very efficient at removing all kinds of pathogens (Jimenez, 2007). They remove up to 6 bacteria log, up to 5 viruses log and almost all the protozoa and helminth ova. These performances are higher than those observed in conventional processes (1-2 bacteria log and 70-99% of protozoa and helminth ova) without disinfection, as is the case of the activated sludge process. Several factors contribute to producing this efficiency (sedimentation, temperature, sunlight, pH, microorganism's predation, adsorption and absorption), but concerning helminth ova, sedimentation is the main one. To efficiently remove helminth ova in waste stabilization ponds a minimum of 5-20 days is required depending on the initial content with at least twice as much to reduce thermo tolerant coliforms to less than 1000 MPN/100 mL. Furthermore, in order to control Cryptosporidia, around 38 days' hydraulic retention time is needed. Most helminth eggs are retained in the first anaerobic pond.

I.2.10.3.2. Planted drying beds

In artificial wetlands, helminth eggs are removed by filtration through the soil and adhesion to roots. There are several kinds of plants that can be used for this purpose, such as very small floating plants with few or no roots, like *Lemna* or duckweed, or long plants like *Phragmites*, a common reed. Besides removing pathogens, wetlands are also efficient at removing nitrogen, phosphorus and heavy metals. Several wetlands have been installed in different countries, but few pathogen removal studies have been carried out due to the high cost and complexity of the analytical techniques involved. Pathogen removal depends on climate, type of wetland and the kind of plant used. Wetlands remove 90-98 % of thermo tolerant coliforms, 67 -84 % of MS2 coliphages and 60-100 % of protozoa. Better performances are obtained with hydraulic retention times of over 4 days in surface flow wetlands. To remove 100 % of helminth ova it is necessary to combine wetlands with filtration. Horizontal flow gravel bed has been used as a filter for this purpose. The removal takes place mostly within the first 25 m, but the length can be considerably reduced if sand is used as filtration media instead (Kadlec and Wallace, 2009). As yet there is not enough knowledge on how to better control wetlands' efficiency, and concerning helminth ova more research is still needed to define specific conditions for removing them in different circumstances. Additionally, there is no available information on the survival of helminth ova retained in wetlands (Jimenez, 2007).

CHAPTER II. MATERIAL AND METHODS

II.1. Localization of the study area

This study was carried out in the city of Yaounde (Cameroon). Yaounde is an urban area of approximately 256 km^2 and is located between about 700–800 m above the sea level. The town had an estimated population of 2,4 million inhabitants in 2011 (BUCREP, 2012). The City faces overpopulation like many other urban cities in developing countries with a density of 14,000 inhabitants/km^2. Parrot et *al*. (2009) mentioned that more than half (51 %) of the capital consists of slums with no piped water supply and without centralized sanitation and waste disposal infrastructure. The population has to rely mainly on shallow dug wells and springs for their drinking water sources (Graf et *al*., 2010) (Fig. 22)

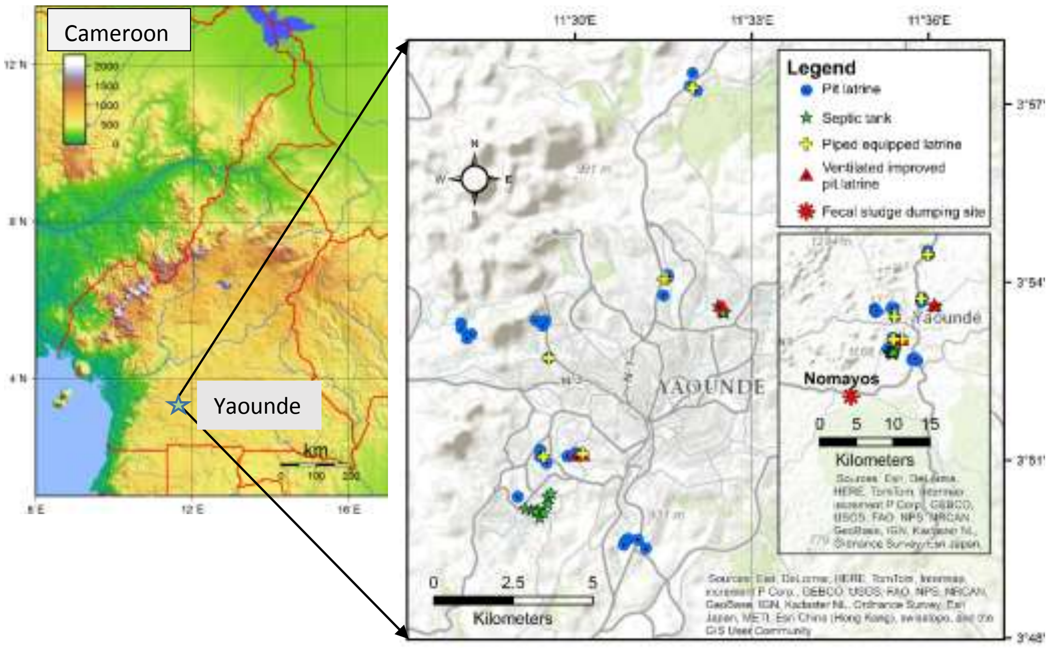


Fig. 22. Map showing the location of Yaounde in Cameroon and the distribution of the different sanitation systems investigated in the study area as well as the FS discharge site of Nomayos.

Yaounde has an equatorial climate with four seasons comprising two dry seasons (December-February, July- August) and two rainy seasons (March-June, September-November) (Kengne, 2008). The average annual rainfall is 1,600 mm with an average temperature of 23 °C. On-site sanitation systems for excreta collection are widespread with the predominance of pit latrines (> 59 %). The city has no FS treatment station and it was estimated that about 700 to 1,300 m^3 of FS are discharged weekly into the environment of peri-urban areas (Berteigne, 2012).

II.2. Methods

II.2.1. Assessment of the existing faecal sludge management practices at household level

To assess the faecal sludge management practices in households, a heterogeneous stratified sampling method was applied in different urban settlements previously identified in the study area. Therefore, a total of 22 settlements were selectively chosen in the study area according to the heterogeneity of urban settlements of Yaounde and represented by peri-urban interfaces, planned urban area, informal settlements, middle and high income areas according to the methodology described by Lüthi and Parkinson (2011). For these authors, every city is a patchwork of different domains and physical environments, each of which presents their own challenges and opportunities. The distribution of the quarters investigated is shown in Table IX.

Table IX. Different urban settings and the names of settlements investigated in the study area (adapted from Lüthi and Parkinson, 2011).

Different urban settings	Names of settlements investigated in the study area
Peri-urban interfaces (which represents 18.18 % of the quarters investigated)	Olembe; Ekounou; Oyom-Abang; Nkolbissong.
Planned and high income (which represents 18.18 % of the quarters investigated)	Bastos; Nkondengui; Mballa II; Nfandena
Informal settlements (which represents 40.90 % of the quarters investigated)	Ngoa-Ekele; Etam-Bafia; Ngousso; Emana; Briquetterie; Carriere; Melen; Nsam; Mvan.
Middle and high income areas (22.72 %)	Mendong; Biyem-Assi; Tsinga; Essos; Damas.

The size "n" of the households investigated as a function of the total population "N" was estimated using the margin of error formula for defined population (Barlett et *al*., 2001):

$$n = \frac{N}{1 + Ne^2}$$

With “N” the size of the total population of Yaounde (estimated at about 2.4 million inhabitants (BUCREP, 2012), “n” the sample size, “e” the marginal error set to 5 % in the case of this study. The size of sample obtained after the above calculation formula showed a total of 402 households. To limit errors and to increase the viability of results, the sample size was adjusted to 602 households which were chosen as sampling and analysis unit, while on-site sanitation facilities were organized and managed as property according the sampling methodology described by Jenkins et *al.* (2014).

II.2.1.1. Household survey

This survey consisted of a 602 semi- structured questionnaire administered verbally in French or English to the property owners or the oldest tenants in the absence of owners. The survey was designed to characterise and describe the sanitation facilities (below and above ground design), to determine the age of the facilities, to document latrine use, to assess operating and maintenance practices. The survey also assessed facility design, emptying preferences and the perceptions of sanitation conditions and problems. At each property, GPS coordinates and respondent socio-economic characteristics (including sex, educational level, number of people living in the households and reported monthly income) were collected. This study draws on a sub-set of the survey data related to the facility design, management and functionality, safety and sustainability assessment of on-site sanitation systems in the studied settlements.

II.2.1.2. Toilet facilities observation

'Flushing out' is a method of partial emptying of pits which involves inserting a drain or an opening into an exposed or elevated portion of the latrine pit wall, below the slab to release faecal sludge into open environment to be washed away by storm water during rains. In some cases, the rising of water tables during rain events and excess flooding may increase pit sludge levels to the level of the opening, where it is divulged or 'vomited' out. In the light of growing concerns over this unsanitary pit-emptying practices, surveyors were trained to look for and record the presence of a 'flushing out' pit waste drain pipe during structured on-site observations of each facility. The functional state of the facilities in terms of slab structural conditions, fullness of the waste pit/tank, and aspect of the superstructure were observed. Pit fullness was judged by observing the height of the vacuum space between the slab or cover and the surface of the sludge. To understand barriers to safe emptying, physical accessibility of the property to small car or tanker vehicles was also observed.

II.2.1.3. Indicators of improved, safe and sustainable sanitation

The eight proposed indicators of hygiene safety, sustainable and functionality of the systems in relation to the Sustainable Development Goal (SDG) of 'improved' sanitation definition were assessed. The first three indicators (1-3) assessed the technical design of the facility, the next two (4 and 5) assessed availability and access to safe faecal waste management services and the last three (6-8) assessed the functionality of the facility at the time of survey. Inclusion of the pit lining as safe and sustainable design indicator (indicator 3) accounted for two considerations (see Table II above). First, lining is structurally necessary to prevent pit collapse in areas with flooding, poor drainage or high water table, conditions widely present in poor neighbourhoods in urban areas of developing countries (Jenkins et *al*., 2014). Second, lining could facilitate emptying of full pits while unlined pits of most part cannot be emptied using hygienic mechanised suction methods and risk damages or a collapsing event when manual emptying are used (Koné and Strauss, 2004). Access to vacuum tanker services (indicator 4 and 5) is then necessary for hygiene emptying and sanitary disposal of pit wastes in the study area.

II.2.2. Determination of the diversity and prevalence of helminth eggs as well as the assessment of health risks related to excreta disposal in households

II.2.2.1. Faecal sludge collection method

Prior to the collection of raw sludge samples in pits of the investigated latrines, a survey of 602 households were conducted in different settlements identified around the town to assess the household's on-site sanitation facilities typology as well as their excreta management. During survey, agreements were made with the latrine owners to collect FS samples in their pits. According to the agreements obtained, only 53 out of the 602 investigated households issued a favourable response for the sampling of their pits among which 30 were traditional latrines, 13 were septic tanks, 6 were ventilated improved pit latrines and 4 were piped equipped latrines (latrines having a pipe for the release of excreta during flooding events). The sampling material was composed of a metal bar of 1.5 m of length, with 3 cm of diameter (Fig. 23). The metal bar was linked to a metallic box (10 cm in diameter and 20 cm in height) welded at its lower end for collecting the sludge, the upper end was connected to a 15-m graduated rope. The use of the rope allowed the sampling team to sample deep latrines found in the study area. The mass of the metal bar allowed the easy entrance of the sampling equipment into the pit sludge substrate. Information regarding the age of the sludge (duration between the date of the first use of latrine/the last emptying period and the date of sampling) as well as the age of the pit were collected.

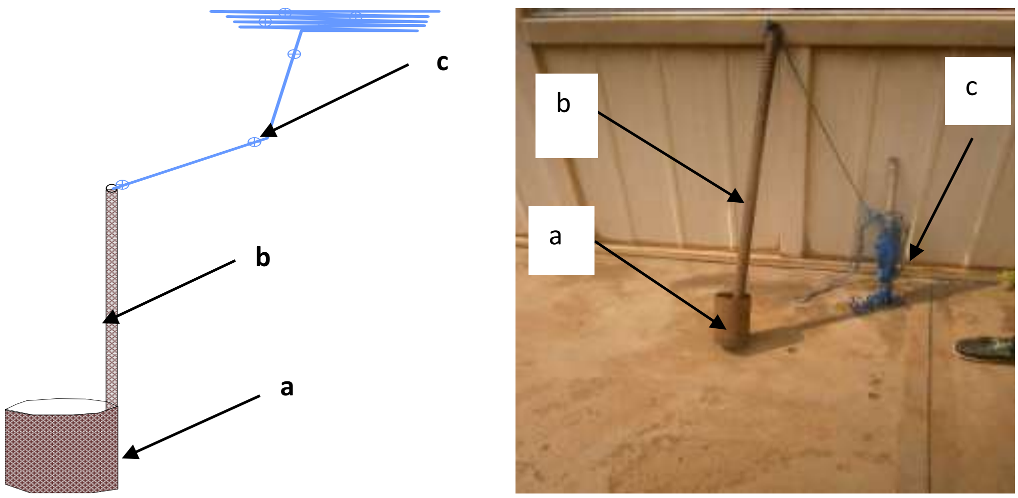


Fig. 23. Faecal sludge sampling equipment needed to be adapted for this study (a: the metallic box, b: the metal bar, c: the graduated rope).

The sampling method took into consideration a non-destructive operation: removal of the sludge through the hole of the slab of latrines and an easy cleaning after the sampling operations. Sampling was performed in the first 2 meters of the sludge layer after their vigorous stirring in the pit with the device. The sampling protocol aimed at the introduction of the sampling equipment through the hole of the latrine slab, stirring (2 to 5 minutes) the sampling zone, extraction of two or three fraction of sample (about 0.5 L), pouring into a 5 L bucket, stirring, transferring into a sterilised plastic box and transportation of samples to the laboratory in a refrigerated thermic box. Additionally, the depth of the pits (height between the surface of the sludge layer and the slab of latrine) were measured as well as the information about the size of the pits, the number of persons using the latrines and the presence of other materials in the pits.

II.2.2.2. Laboratory analysis of samples

Parasites are usually encountered in raw faecal sludge, but the type and the concentration may vary according to the level of infection among the targeted populations as well as environmental factors prevailing in the on-site sanitation devices. The enumeration of parasites was carried out by the determination of helminth eggs in the 53 samples of raw sludge. These parasites were chosen because they are more resistant and easy to detect (Feachem et *al.*, 1983).

The characterization of samples was performed by the determination of the prevalence and diversity of helminth eggs following the protocol described by Schwartzbrod et *al.* (2003). This method is based on the separation and concentration of the sludge solid fraction in an interphase of ethyl acetate solution and flotation with zinc sulphate solution of a relative density of 1.18. The observation of samples was made and the identification of the different species of helminth eggs was done using the key for identification of intestinal parasites of the World Health Organization (WHO, 2006). The preparations in the Mc Master Chambers were examined with the gradual objectives of 20 X and 40 X in a photonic microscope with a systematic way of exploring the whole preparation. The number of eggs was calculated using following formula:

$$N = \frac{YxM}{CxV} \text{ x } 1000 \text{ (Schwartzbrod et al., 2003)}$$

With: N = number of eggs per litre of sample;
Y = mean number of helminth eggs counted per Mc Master Slide;
C = volume of the Mc Master slide (0.3 mL);
V = volume of sample (mL);
M = volume of final product (mL).

The results were expressed in number of eggs/g of dry matter (DM) and number of eggs/L of sludge.

II.2.2.3. Assessment of health risks related to excreta disposal in households

Safe disposal of excreta is critical because agents of a large number of infectious diseases are passed from the body through excreta (Stenström et *al.*, 2011). These excreta infection agents fall into four main groups: viruses, bacteria, protozoa, and worms (helminths). Excreta, unless properly isolated, can also provide a breeding biotope for insects, which may act as either direct or indirect transmitters of diseases. Therefore, the health risks related to different on-site sanitation technologies used in the study area were additionally assessed by investigating the health status of the users. The health risks assessment related to excreta disposal attempts to collect some information about the prevalence and the diversity of excreta-related diseases in the past six months (cholera, amoebiasis, typhoid fever, helminthiasis, etc…) in households investigated and the climatic seasons of occurrences.

II.3. Determination of the physico-chemical and heavy metals composition of sludge samples

The determination of the physico-chemical composition took into consideration parameters such as temperature (Temp), electrical conductivities (EC), salinity, biological oxygen demand for five days (BOD_5), chemical oxygen demand (COD), the total Kjeldahl nitrogen (TKN), nitrogen ammonia (NH_4^+), total volatile solids (TVS), total solids (TS), total suspended solids (TSS), and water content. The heavy metals that have been included in the analysis were iron (Fe), Copper (Cu), Manganese (Mn), Lead (Pb), Cadmium (Cd), Zinc (Zn), Chromium (Cr) and their determination was done in the whole samples including each group of latrines. These parameters were measured following methods outlined in Standard Methods for the examination of Water and Wastewater (APHA/AWWA/WEF, 2005).

II.3.1. Methods for the determination of the physico-chemical composition

II.3.1.1. Measurement of the temperature and pH

pH is the logarithm of the reciprocal of hydrogen-ion concentration in gram atoms per litre; it provides a measure on a scale from 0 to 14 of the acidity or alkalinity of a solution. It has great influence on the development of microorganisms as well as some chemical processes. The pH as well as the temperature were evaluated using calibrated portable HACH pH-meter (HQ11d). The electrode responds to the hydrogen ion concentration by developing an electrical potential at the glass-liquid interface as well as the temperature of the samples. Approximately 100 mL of raw excreta samples were poured into a clean glass beaker and the electronic probe of the pH-meter introduced into the solution for the measurements. The apparatus displayedboth values of pH and temperature on the digital screen.

II.3.1.2. Measurement of the electrical conductivity

This test was performed to have an idea of the ion contents of the raw sludge. Electric conductivity is the capacity of ions in solution to carry electrical current; it is the reciprocal of the solution resistivity (APHA/AWWA/WEF, 2005). Current is carried by inorganic dissolved solids and cations. Voltage is applied between the two electrodes immersed in the solution and the voltage drop caused by the resistance of the solution is used to calculate conductivity per cm. Approximately 100 mL of raw excreta samples were poured into a clean glass beakers and the electronic probe of the HACH conductimeter (HQ14d) introduced into the solution for measurements. The apparatus displayed the values of the conductivity on the digital screen and the results expressed in mS/cm or µS/cm.

II.3.1.3. Measurement of the Chemical Oxygen Demand (COD)

COD concentration is relatively important to estimate the amount of organic matter in the different sludge samples. This parameter is used as a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant (APHA/AWWA/WEF, 2005). The amount of 0.2 mL of diluted raw sludge samples were heated for two hours at 150 °C in COD tubes containing potassium dichromate, a strong oxidising agent. Oxidizable compounds react thereby reducing the dichromate ion ($Cr_2O_7^{2-}$) to green chromic ion (Cr^{3+}). The intensity of the colour is proportional to the amount of organic content in the sample. Then, the COD tubes were cooled at ambient temperature and put into the cell holder of the DR 3900 Spectrophotometer. The value of COD concentration was read under the 420-nm wavelength and results expressed in mg/L.

II.3.1.4. Measurement of the Biological Oxygen Demand for five days (BOD_5)

The determination of the biochemical oxygen demand for five days (BOD_5) was done using the "manometric method" with the aid of BOD_5 HACH apparatus (model 2173B). The quantity of the samples was measured and introduced in the BOD_5 bottles (their volume varid depending on the presumed ranges of organic concentration). Inhibitors of nitrification was added to the samples and was incubated for 5 consecutive days at 20 °C. During the incubation period, the bacteria communities present in the samples used the oxygen present in the upper section of the bottle to oxidize organic matter present in the solution and gave out CO_2. This is fixed by crystals of lithium hydroxide (present in the capsule placed at the top of the bottle). Thereafter, there is an air depression in the bottle, creating a rise in the column of mercury in manometers. The value of BOD_5 is directly read on the digital screen at the front of the BOD_5 apparatus.

II.3.1.5. Measurement of the total Kjeldahl nitrogen (TKN)

Total Kjeldahl Nitrogen (TKN) includes the determination of ammonia in addition to organic nitrogen (Kadlec and Wallace, 2008). Total Kjeldahl Nitrogen was determined in this study using the Kjeldahl method. In a quantity of diluted samples not containing more than 0.5 g of solids (mL=40/C with C the % of solids) was added 3 mL of concentrated sulphuric acid (H_2SO_4) and 10 mL of oxygenised water. The mixture was heated till the reflux of the sulphuric acid using the HACH Digesdhal mineralisator apparatus (model 23130-20, -21). In the presence of sulphuric acid, potassium sulphate and cupric sulphate catalyst, amino nitrogen and ammonia present in the sludge samples are converted to ammonium. After addition of the base (NaOH), the ammonia is distilled from an alkaline medium and absorbed in boric acid in a BÜCHI distillation unit apparatus, model K-350. The concentration of TKN in the samples was determined after back-titration using H_2SO_4 0.01 N. The results were expressed in g/L of TKN.

II.3.1.6. Measurement of the ammoniacal nitrogen (NH_4^+)

Ammonia found in raw faecal sludge comes mainly from urine (Strande et *al*., 2014). It was determined using the Nessler method. Approximately 250 mL of filtered raw excreta samples were distillated and nitrogen ammonia released in a strong NaOH solution using the BÜCHI distillation unit apparatus, model K-350. After the distillation, a 25 mL of distillate was poured into a mixing graduated cylinder as well as the blank (deionized water). Three drops of mineral stabilizer were added to each cylinder as well as 1 mL of Nessler reagent. In the presence of mineral stabilizer, the hardness in the samples is complexed and polyvinyl alcohol dispersing agent aids the colour formation in the reaction of Nessler reagent with the ammonium ions. The yellow colour formed is proportional to the ammonia concentration found in sample. The nitrogen ammonia in samples was determinate in a DR 3900 Spectrophotometer under the programme 380 and 420 nm wavelength. The results were expressed in mg/L of ammonia nitrogen (NH_3-N).

II.3.1.7. Measurement of solid contents and water content

Analysis of the solid content is important in understanding the consistence of the sludge samples. The various forms of solids considered were the total solids (TS) and the total volatile solids (TVS). Their levels represent a serious technical difficulty for the safe collection and disposal of sludge. The TS was determined after evaporation of moisture from samples and its subsequent drying in an oven at 105 °C while the total volatile solids (TVS) represent the weight loss upon ignition of dried solids. For total solids, replicates consisting of 50 mL of well mixed samples of raw excreta were evaporated in a weighed dish and dried to constant weight in an oven at 103 to 105 °C. Total solids of samples were determined using the following formula:

$$\text{TS}\ (\%) = \frac{(\text{A} - \text{B})\text{x}100}{(\text{C} - \text{B})}$$

With:

- A= weight of dried residue + dish (g);
- B= weight of dish (g);
- C=weight of wet sample + dish (g).

The total volatile solids were determinate by transferring the dried residues above (heated at 103-105 °C) for ignition at 550 °C for 1 hour. Thereafter, allow to cool in a desiccator and the remaining residues weighed using a precision balance. TVS calculation was done using the following formula:

$$\text{TVS}\ (\%) = \frac{(\text{A} - \text{B})\text{x}100}{(\text{A} - \text{C})}$$

With:

- A= weight of dried residue + dish (g);
- B= weight of residue + dish after ignition (g);
- C the weight of dish (g).

The water content of samples (expressed in %) was deducted from the TS as the second parameter is inversely proportional to the first.

II.3.2. Methods for the determination of heavy metal contents

II.3.2.1. Measurement of iron (Fe)

The determination of iron concentration in the sludge samples was done using TPTZ method after the digestion of samples in concentrated sulphuric acid (H_2SO_4). After the digestion of diluted samples not containing more than 0.5 g of solids (mL=40/C with C the % of solids) with 3 mL of concentrated sulphuric acid (H_2SO_4) and 10 mL of oxygenised water, the stored program number (270) as well as the wavelength dial (590 nm) for iron (Fe) TPTZ was entered in a HACH DR 3900 Spectrophotometer. The glassware used for this analysis were rinsed with a 1:1 Hydrochloric acid solution and deionized water to remove iron deposits which can cause the modification of results. The 25-mL sample cell was filled with a digested sample and another one with deionized water. In each sample cell, the content of TPTZ Iron Reagent Powder Pillow was added. The cells were covered and homogenized for 30 seconds. The blue colour developed when iron was present in the samples and the intensity of the coloration was proportional to the concentration of Iron. The value of Iron in the solution of the samples is displayed on the HACH DR 3900 Spectrophotometer screen after the insertion of the blank into a cell holder. The results were expressed in mg/L.

II.3.2.2. Measurement of copper (Cu)

The determination of copper in sludge samples was done using the Bicinchoninate Method after the digestion of samples with concentrated sulphuric acid (H_2SO_4). After the digestion of diluted samples not containing more than 0.5 g of solids (mL=40/C with C the % of solids) with 3 mL of concentrated sulphuric acid (H_2SO_4) and 10 mL of oxygenised water (H_2O_2), the stored program number (135) as well as the wavelength dial (560 nm) for copper (Cu) was entered in a HACH DR 3900 Spectrophotometer. A 25-mL sample cell was filled with the sample and the content of one CuVer 1 Copper Reagent Powder Pillow added. After two minutes ‘of the reaction period, a second sample cell was filled with 25 mL of sample. The concentration of Copper in samples was read in the Spectrophotometer in the presence of a blank and the values expressed in mg/L of Cu.

II.3.2.3. Measurement of lead (Pb)

The determination of lead (Pb) in samples was done using the Dithizone Method after the digestion of samples with concentrated sulphuric acid (H_2SO_4). After the digestion of diluted samples not containing more than 0.5 g of solids (mL=40/C with C the % of solids) with 3 mL of concentrated sulphuric acid (H_2SO_4) and 10 mL of oxygenised water, the stored program number (280) as well as the wavelength dial (515 nm) for lead was entered in a HACH DR 3900 Spectrophotometer. Before analysis, all glassware was cleaned with a 1:1 Nitric Acid solution and rinsed with deionized water. A 250-mL graduated cylinder was filled to the 250- mL mark with sample and the sample transferred to 500 mL separatory funnel. The contents of one Buffer Powder Pillow, Citrate type for heavy metals was added into the 500-mL separating funnel and shaken for dissolution. The amount of 50 mL chloroform was added in a 50-mL graduated cylinder and the content of one Dithiver Metals Reagent Powder Pillow added and diluted for the formation of the Dithizone solution. 30 mL of the Dithizone solution was added into a 500 mL separatory funnel additionally to 5 mL of Sodium Hydroxide 5.0 N standard solution. Two heaping of 1.0 g scoop of potassium cyanide was added to the funnel and shaken vigorously until the potassium cyanide was all dissolved. The value of lead in sample was determined after reading on the Spectrophotometer in the presence of the blank (Chloroform).

II.3.2.4. Measurement chromium (Cr^{6+})

The determination of Chromium (Cr^{6+}) in samples was done using 1.5-Diphenylcarbohydrazide Method. The stored program number (90) as well as the wavelength dial (540 nm) for chromium hexavalent was entered in a HACH DR 3900 Spectrophotometer. A sample cell was filled with 25 mL of sample and the content of ChromaVer 3 Reagent Powder Pillow added (to the prepared samples) and mixed. A purple colour will be formed if hexavalent chromium is present. At high chromium level (formation of precipitate), the samples were diluted using successive decimal dilution technique. After a five minutes' reaction period, another sample cell was filled with 25 mL sample (the blank). The value of chromium in sample was determine after reading on a Spectrophotometer DR 3900 in the presence of the blank and expressed in mg/L of Cr^{6+}.

II.3.2.5. Measurement of cadmium (Cd)

The determination of Cadmium (Cd) in samples was done using Dithizone Method after the digestion of samples with concentrated sulphuric acid (H_2SO_4). The stored program number (60) as well as the wavelength dial (515 nm) for cadmium was entered in a HACH Spectrophotometer DR 3900. A 250-mL graduated cylinder was filled to the 250- mL mark with sample and the sample transferred to 500 mL separatory funnel. The contents of one Buffer Powder Pillow, Citrate type for heavy metals was added into the 500-mL separating funnel and shaken for dissolution. A content of 30 mL of chloroform was add to a 50-mL graduated cylinder and the content of one Dithiver Metals Reagent Powder Pillow added and diluted for the formation of the Dithizone solution. 20 mL of Sodium Hydroxide 50 % standard solution. Two heaping of 1.0 g scoop of potassium cyanide was added to the funnel and shake vigorously until the potassium cyanide is all dissolved. 30 mL of the Dithizone solution was also added into the 500 mL separatory funnel. The bottom layer (Chloroform) will be pink if cadmium is present. The value of cadmium in the sample was determined after read in HACH Spectrophotometer DR 3900 in the presence of the blank (Chloroform) and the results expressed µg/L of Cd.

II.3.2.6. Measurement of manganese (Mn)

After the digestion of diluted samples not containing more than 0.5 g of solids (mL=40/C with C the % of solids) with 3 mL of concentrated sulphuric acid (H_2SO_4) and 10 mL of oxygenised water, 25- mL of digestate was measured and poured in a mixing graduated cylinder. For this analysis, all the glassware was rinsed with a Nitric Acid Solution 1:1 and then rinsed with deionized water. A second 25- mL mixing graduated cylinder was filled with deionized water to the 25-mL mark (the reagent blank). The contents of one Ascorbic Acid Powder Pillow was added to each cylinder and inverted to mix. 1 ml of Alkaline Cyanide Reagent Solution was added to each cylinder. The PAN Indicator Solution, 0.1 % was added to each cylinder and mixed. The contents of each cylinder were poured into a 25-mL sample cell and the value of manganese read on HACH DR 3900 Spectrophotometer at the stored program 295 and the wavelength dial to 515 nm. The concentration of manganese in samples was expressed in mg/L of Mn.

II.3.2.7. Measurement of Zinc

The determination of Zinc (Zn) in samples was done using the Zincon Method after the digestion of samples in a strong sulphuric acid (H_2SO_4) solution. After the digestion of diluted samples not containing more than 0.5 g of solids (mL=40/C with C the % of solids) with 3 mL of concentrated sulphuric acid (H_2SO_4) and 10 mL of oxygenised water, the stored program number (780) and the wavelength dial (620 nm) for zinc was entered in a HACH Spectrophotometer DR 3900. A 25-mL graduated cylinder was filled to the 20- mL mark with sample and the contents of the ZincoVer 5 Reagent added. After the dilution of the ZincoVer in the solution of sample, 10 mL was poured in a 10-mL sample cell (the blank) and it was added to the rest of the 10 mL of sample of the graduated cylinder 0.5 mL solution of Cyclohexanone. The graduated cylinder was covered and thoroughly shaken for the homogenization. The blue coloration indicated the presence of Zinc in samples with its intensity proportional to the concentration in the solution of the sample. The concentration value of zinc in the sample was displayed on the screen of the Spectrophotometer and expressed in mg/L.

II.4. Assessment of the variability of pit latrine sludge

To assess the variability of sludge in the study area, only the sludge from pit latrines were assessed as the high number of samples was collected (n=30). The principal component analysis and the hierarchical clustering were used according to the methodologies described by Singh et *al*. (2013) and Anderberg (2014) using the software XLStat 2007. The preference map which summarises the principal component analysis and hierarchical clustering was showed to present the relation between the tested parameters, the factors scored as well as the clusters. The number of components kept was based on the Kaiser criterion (Kaiser, 1958), for which only components with eigenvalues greater than 1 were retained.

II.5. Assessment of the effect of retention times on the removal of intestinal helminth eggs by planted drying beds

II.5.1. Experimental design and operational conditions

The experiment was conducted in pilot-scale planted drying beds located at the University of Yaounde I (Cameroon). Three triplicated (9 units) pilot-scales setup consisted of 1 x 1 x 1 m (length, width, height) polyethylene skid containers (metal-caged, liquid-storage, pallet-sized containers), each representing 1 m^2 of planted sludge drying bed (Fig. 24). All the containers were filled with three layers of filter media, increasing in grain size from top to bottom. The layers consisted of 15 cm of 0.3-2 mm diameter sand, 20 cm of 5-15 mm diameter semi-coarse gravel and 30 cm of 15-25 mm diameter coarse gravel. The uniformity coefficient from the sand, semi-coarse gravel and coarse gravel layers were 3.55, 1.67 and 1.37 (Kengne et *al.*, 2008).

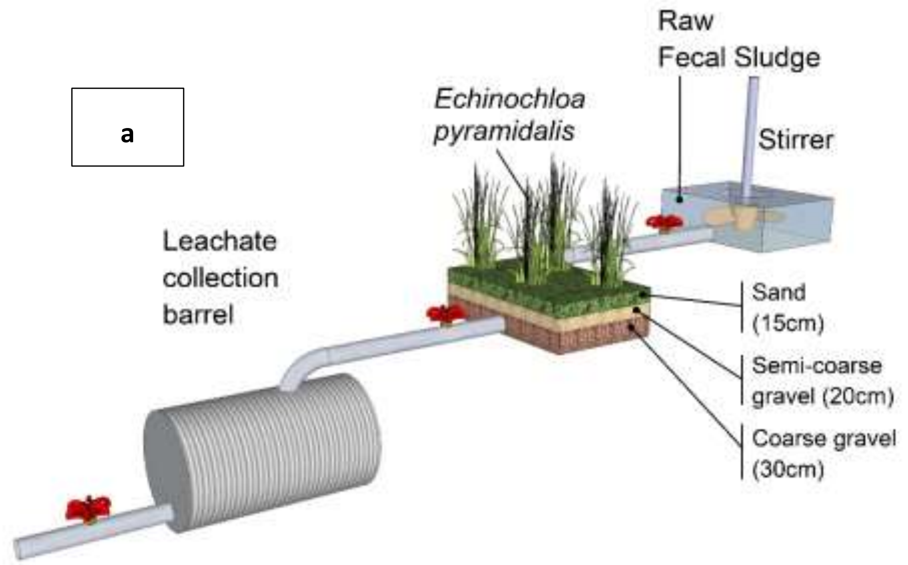


Fig. 24. Schematic diagram (a) an experimental view (b) of the planted bed units used for faecal sludge dewatering (Adapted from Kengne et *al*., 2008).

The experiment ran for 9 months (from December 2013 to August 2014) corresponding to one vegetative cycle of *Echinochloa pyramidalis* including one month of plant acclimatization. The different wetlands were distinguished in the field with the numbers 1, 2 and 3 while the triplicated wetlands were distinguished by the letters A, B and C. The letter A, B, and C represented respectively: free flow, 7 days retention time and 14 days retention time. For any given treatment combination, the wetlands were fed in a batch mode in order to allow sufficient oxygenation, based on the finding of Kaiser and Fuchs (2015).

II.5.2. Monitoring of the system performance

II.5.2.1. Assessment of the removal efficiencies of the planted drying beds

The application of the sludge began after acclimatization of the young shoots in the system. The faecal sludge was applied every 14 days for 32 weeks following the nominal load of 200 kg/MS /m^2/year (Kengne et *al*., 2009). These different applications of the sludge were made according to different experimental conditions. The quantities of sludge to be applied to the pilots were each calculated according to the following formula:

$$\text{Hydraulic load} = \frac{1}{f} \times \frac{1}{52} \times \frac{C1}{C2}$$ Wher

- f: Frequency of application of sludge per week;
- C1: annual loading rate (kg TS/m^2/year;
- C2: TS content of each newly raw sludge delivered by the mechanical emptiers.

Before application of faecal sludge on the bed units, the physico-chemical parameters (NH_4^+, DM and pH) known to affect the helminth eggs composition of the sludge were analysed (Pecson et *al.*, 2007; Maya et *al.*, 2012). For each application, raw faecal sludge and leachates from each bed units were collected and analysed as outlined in standard methods for the examination of water and wastewater (APHA/AWWA/WEF, 2005). Parasitological (helminth eggs) parameters were determined in the incoming sludge and outlet leachates as a function of the retention times tested (free flow, 7 days and 14 days). Helminth eggs were determinate according to the modified method of Schwartzbrod et *al.* (2003) (Appendix 6).

II.5.2.2. Assessment of the parasitological quality of biosolids

A month to the end of the experiment, three samples of biosolids accumulated on the surface of each bed were randomly sampled, air dried and sieved before performing hygienic quality. Analysis were performed in approximately 10-50 g of biosolids mixtures collected at three different depths (surface, middle and bottom) in each sample were analysed according to the methodology described by Schwartzbrod et *al*. (2003).

II.5.2.3. Calculation of the removal efficiencies

The system performances were assessed for each parameters tested by comparing average values of inputs (raw sludge) and outputs (effluents) for each retention time (free flow, 7 days and 14 days). Removal efficiencies were expressed in terms of percentage concentration reduction and were calculated taking into consideration the inflow and outflow loads (Kadlec, 2009)**.**

$$\text{Removal (\%)} = \frac{(\textbf{Inlet concentration} - \textbf{outlet concetration})}{\textbf{Inlet concentration}} \text{ x } 100$$

II.6. Data analysis

II.6.1. Survey data

All the data of the questionnaires were entered manually into Microsoft Excel 2013 cross-checked manually with corresponding questions to ensure that the data entered were accurate. Descriptive statistics using percentages (frequency distribution) and Chi-square test were used to establish associations between categorical variables. Missing values (associated to the variation of denominators) were in some case considered during data interpretations. Facility design, waste management and functionality indicators were evaluated and combined to evaluate the SDG indicators safe and sustainable sanitation access across the studied population. Associations between the monthly income, the level of education of householders on the choice and the management of sanitation devices in place were assessed. Tests of association were performed with aid of SPSS software v. 20 using the chi-squared likelihood ratio test for differences in proportions and the chi-squared linear-by-linear association test of trends in proportions. Differences in group means were tested with the analysis of variance *F*-statistic. All observations were done at 95 % of confident interval. Monetary values were adjusted to 2017 values and presented in US dollars.

II.6.2. Analysis of the hygienic quality and the physico-chemical characteristics of raw excreta samples collected from various on-site sanitation systems.

Data obtained after laboratory analyses where explored using the softwares R statistic v. 3.22, SPSS v. 20 and XLstat 2007. The descriptive statistics of the samples was done and the minimum, maximum, mean, standard errors, standard deviation, interquartile range (IQR), and variances considered to express the parameters dispersion. The Spearman rank correlation test, the Pearson correlation test, the principal component analysis, the hierarchical cluster analysis was performed to describe the data dispersion as well as the relationships between physicochemical parameters and helminth eggs concentration found in sludge. The level of significance was set to 0.05.

Spearman rank correlation analyses between the prevalence of parasites species were conducted using the pathogen abundance in samples according to the methodology described by

Cheng et *al*. (2012). The cross-correlation matrix (using the Pearson test) between some physico-chemical parameters (BOD_5, COD, NH_4^+ and TKN) known to affect the helminth eggs survival in the natural environment was also computed to show the variation in the distribution of parameters as function of the type of latrines investigated.

II.6.3. Application of multivariate statistical methods for the assessment of the variability of samples

II.6.3.1. Hierarchical cluster analysis (HCA)

HCA is an unsupervised pattern recognition technique that uncovers intrinsic structure or underlying behaviour of a data set without making a prior assumption about the data, in order to classify the objects of the system into categories or clusters based on their nearness or similarity (Anderberg, 2014). Hierarchical clustering is the most common approach in which clusters are formed sequentially, by starting with the most similar pair of objects and forming higher clusters step by step. The Euclidean distance usually gives the similarities or dissimilarities between two samples and a distance can be represented by the difference between analytical values from both samples (Patras et *al*., 2011). HCA was performed in this study by using the Ward's method: The Euclidean distances between centroids objects of classes was used to measure the similarities between classes of FS. This method uses the analysis of variance approach to evaluate the distances between clusters, attempting to minimize the sum of squares of any two clusters that can be formed at each step (Singh et *al*., 2013 ; Shrestha and Kazama, 2007). The linkage distance between classes (Height) is represented on *y*-axis.

II.6.3.2. Principal component analysis (PCA)

PCA techniques extract the eigenvalues and eigenvectors from the covariance matrix of original variables. The PCs are the uncorrelated (orthogonal) variables, obtained by multiplying the original correlated variables with the eigenvector, which is a list of coefficients (loadings or weightings). Thus, the PCs are weighted linear combinations of the original variables. PC provides information on the most meaningful parameters, which describe whole data set affording data reduction with minimum loss of original information (Liu et *al*., 2015). It is a powerful technique for pattern recognition that attempts to explain the variance of a large set of inter-correlated variables and transforming into a smaller set of independent (uncorrelated) variables (principal components). The principal component can be expressed as:

$$z_{ij} = a_{i1}x_{1j} + a_{i2}x_{2j} + a_{i3}x_{3j} + \ldots + a_{im}x_{mj}$$

Where *z* is the component score, *a* the component loading, *x* the measured value of variable, *i* the component number, *j* the variable and m the total number of variables. PCA of the FS data set was performed to extract significant PCs and to further reduce the contribution of variables with minor significance; these PCs were subjected to Varimax rotation (raw) generating varifactors (VFs) (Shrestha and Kazama, 2007). Thus, a small number of factors will usually account for approximately the same amount of information as do the much larger set of original observation.

II.6.4. Analysis of the data on the effect of retention times on the removal of intestinal helminth eggs by planted drying beds

The analysis of the data obtained was carried out using the Microsoft Office Excel 2013 program. The mean, standard deviation, maximum, minimum were used to express the dispersion between the parameter values. The removal efficiencies between the hydraulic retention times tested were compared using the ANOVA test at the significance level of 5%. In addition, the Pearson correlation coefficient (r) was calculated to verify the correlation between physicochemical and parasitic parameters using SPSS 20.0 software.

CHAPTER III. RESULTS AND DISCUSSION

III.1. Current faecal sludge management practices in households investigated

III.1.1. Demography of respondent

The demographic profiles of the investigated populations are presented in the Table X. The table show the variation (in frequency) of the gender of householder, the age group, the educational level, the monthly income as well as the number of person living in household. Globally, householders were dominated by males (77.7 % of respondents, n=602) mostly between the ages of 46 to 55 years (26.4 %) and majority from secondary school (45.2 %, n=589). Looking at the monthly incomes, only 13.5 % of respondents had income above 400 USD (n=364). According to the number of persons living in the investigated households, 32.2 % of respondent mentioned that their household were occupied by more than 6 persons (n=559).

Table X. Sociodemographic characteristics of study respondents.

Parameters	Variable	Frequency	Percent	*
Gender	Female	134	22.30	49.75 %
	Male	468	77.70	50.25 %
	Total	602	100.0	100
Age group (years)	18 to 25	140	23.30	Under 15 to more than 60.
	26 to 35	67	11.10	
	36 to 45	122	20.30	
	46 to 55	159	26.40	
	Over 56	114	18.90	
Educational level	No response	13	2.20	/
	Never went to school	57	9.50	14.30 %
	Primary school	148	24.60	35.50 %
	Secondary school	272	45.20	30.80 %
	Higher education	112	18.60	17.40 %
	Total	602	100.0	100
Monthly income	No response	237	39.40	Under 80 USD to more than 450 USD
	Under 100 USD	80	13.30	
	100 to 200 USD	71	11.80	
	200 to 300 USD	96	15.90	
	300 to 400 USD	37	6.10	
	Over 400 USD	81	13.50	
	Total	602	100.0	
Number of person living in households	No response	43	7.10	One person to more than 6 persons (with about 40 % of households of more than 6 persons).
	One person	87	14.50	
	2 to 4 persons	140	23.30	
	4 to 6 persons	137	22.80	
	More than 6 persons	194	32.20	
	Total	602	100.0	

*Population and housing census of Cameroon, 2015

However, the education level of some respondents was low (24.6 % of respondent coming from primary school and 9.5 % of respondent didn't go to school). This situation may affect the capacity to understand many issues regarding the management of on-site sanitation systems. These observations are similar to those obtained by the population and housing census of Cameroon, 2015 (Table IX). According to the findings of Bakare et *al*. (2015) working on the effect of modified pit-latrines on the sustainable environmental protection addressed the low education to be the main reason for low-paying jobs performed by householders with an implication of inadequate financial resources for daily subsistence and investment into good excreta disposal facilities.

III.1.2. Typology of excreta disposal

The variation of the current defecation practices was observed in the different urban settings investigated that constitutes the study area (Fig. 25). Assessment of the variation in diversity of on-site sanitation systems in the study area revealed that traditional pit latrines and septic tanks are the most widespread sanitation technologies in use in different households. The prevalence of the distribution recorded were 7.30 %, 10.31 %, 3.98 %, 20.26 % for septic tanks and 22.75 %, 13.95 %, 4.15 % and 9.13 % for traditional pit latrines respectively in the informal settlements, middle and high income area, peri-urban interface and planned urban areas.

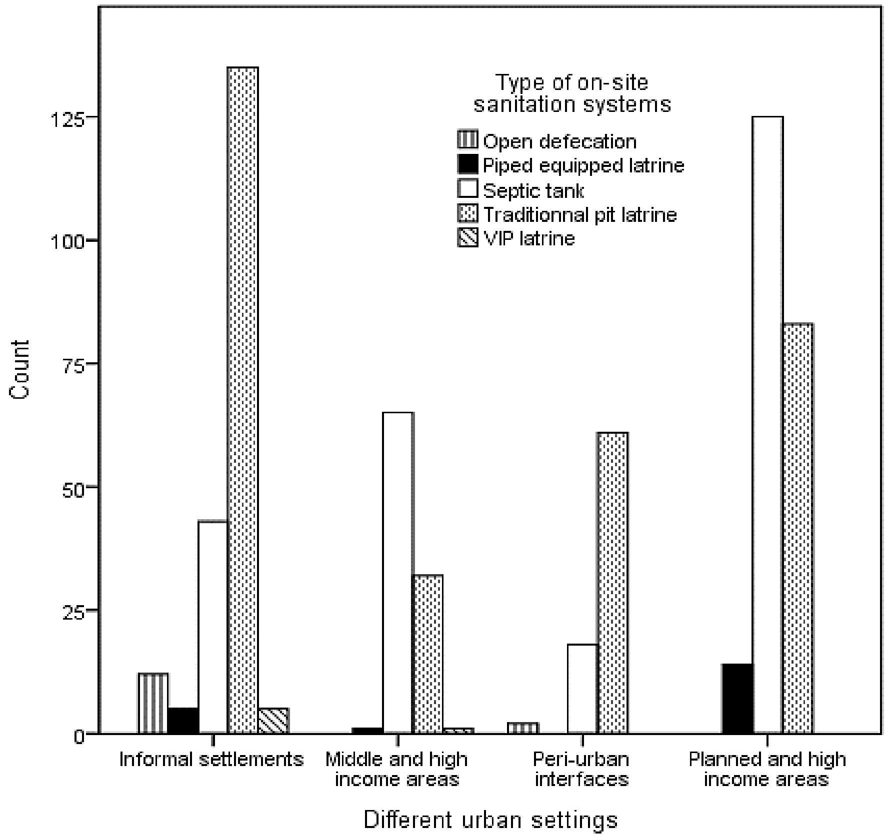


Fig. 25. Distribution of the different toilet facilities found in the investigated urban settings as well as the prevalence of open defecation (n= 602).

However, the traditional pit latrines were most prevalent in the informal settlements, in the middle, high income areas and peri-urban interface while the septic tanks were mostly prevalent in planed urban area. The “piped equipped latrines” systems were found to be used in the investigated households. The “piped equipped latrine” is one of the latrine found in the study area principally located in the lowland areas which the top of the pit is related to a PVC pipe allowing the exit of faecal sludge in case of flooding conditions. The prevalence recorded for this type of technology were 0.5 %, 2.5 % and 0.5 % respectively for the informal settlements, middle and high income area and the planned and high income urban settlements.

One of the main results of the survey is that some households didn’t have any on-site sanitation technologies and thereby practicing open defecation into the natural environment. This practice may occur mostly in households from informal settlement. This practices of open air defecation constitute a sanitary and environmental risk as it exposes surface and groundwater resources to faecal contamination. The 3 % of investigated households that practiced open defecation was found to be mostly located in the shallow areas of the town. It is important to mention that the open defecation practice didn’t constitute a type of sanitation system. It was considered as a variant of excreta management (current defecation practices) found at the household level. The finding of this study corroborate with those of Stenström et *al*. (2011) who assessed microbial exposure and health assessments in sanitation technologies and systems in tropical area. The authors pointed out the practice of open defecation to be widespread among billions of people mainly in developing countries and the most significant environmental factor involved in the transmission of excreta-related diseases. Additionally, the inquisitive eyes that may occur during open defecation, as reported in this study is found to be particularly disadvantageous to women who are prone to sexual abuse while finding places of convenience and to children who are mostly affected by diseases associated with it (Bartram and Cairncross, 2010).

III.1.2.1. Relation between the on-site sanitation systems and the level of education of households

To assess the effect of the educational level of households in the distribution of the current sanitation systems in use in the households, the Pearson Chi-Square correlation test was computed at the 2-sided test. There was a significant correlation between the educational level of householders and the type of on-site sanitation systems in place in households investigated (X^2 =79.34 and p<0.001). The technologies septic tanks which can be assimilate to improve sanitation systems were widespread in households where the head attended the higher education, secondary school and primary school (Fig. 26). The frequency of the distribution of the septic tank systems which are the most improved sanitation technologies found in the study area were 11.71 %, 1.52 %, 8.65 % and

19.35 % respectively for households where the householders attended higher education, never went to school, attended primary school and secondary school. The traditional latrines were mostly represented in households were the head attended respectively the secondary school (25.29 %),primary school (13.75 %), never went to school (6.28 %) and higher education (6.62 %). According to the VIP latrines, the frequencies of the distribution of these on-site sanitation technologies in the households are 0.50 %, 0.17 % and 0.34 % respectively for households which the head attended higher education, primary school and primary school. Looking at the piped equipped latrines, the households with these type of latrines were mostly attended the primary school (1.35 %), the secondary school (0.50 %) and who never attended to school (1.52 %). The open defecation practice were found in the whole of educational level and it is mostly represented in households who attended primary school (1.18 %) and secondary school (0.67 %).

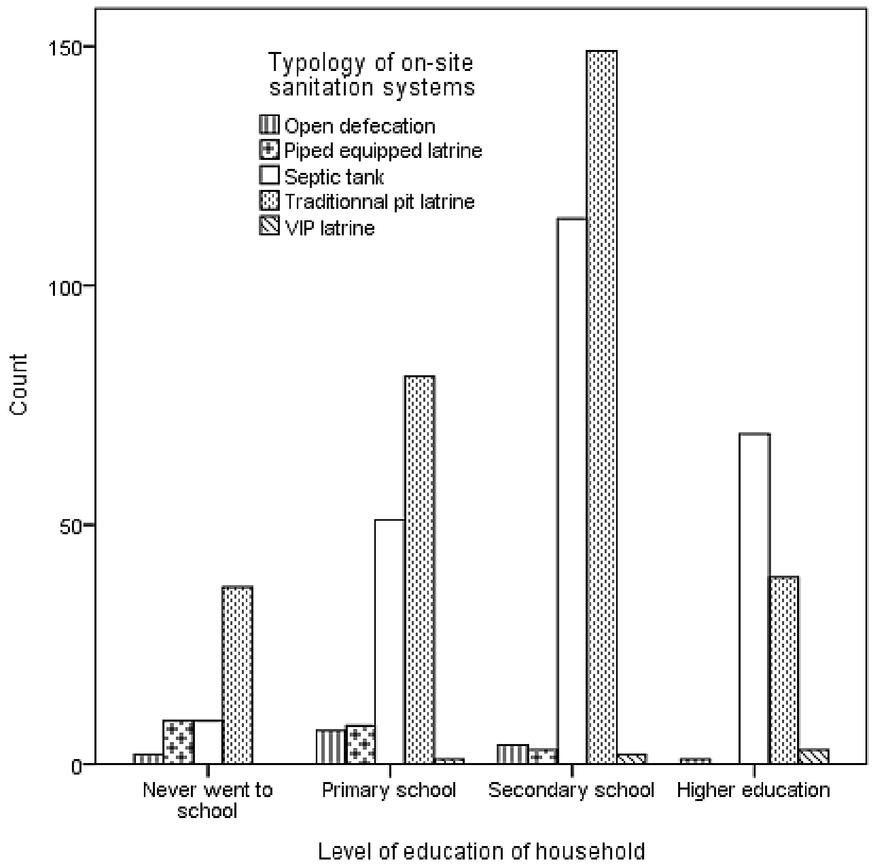


Fig 26. On-site sanitation variation systems in used in the investigated households in relation to the level of education of the households (n=589).

The findings of this study are similar to those of Jenkins et *al*. (2014) who revealed the sustainable sanitation to be strongly affected by the level of education of householders when assessing excreta disposal in Tanzania. According to these authors, well-educated households often know more information on adequate emptying frequency, choosing qualified mechanical emptying services and ensuring environmental and health safety for the surrounding population. Additionally, Brown et *al.* (2015) pointed the difficulty to achieve a change in excreta disposal practices as they are part of the basic behavioural pattern of a community. As unsafe practices, the open defection found in the study area constitutes a significant health risk to populations through contamination of ground and surface water resources. Indeed, Bartram and Cairncross (2010) stated that about 2.4 million deaths (4.2 % of all deaths) could be prevented annually if everyone practised appropriate hygiene and had good and reliable sanitation technologies at household levels.

III.1.2.2. Relation between the on-site sanitation systems and the monthly income of households

To assess the effect of monthly income of households on the distribution of the current defecation practices at the household level, the Pearson Chi-Square correlation test was computed at the 2-sided test. The monthly income has significant effects on the distribution of sanitation systems in household investigated (X^2 =83.501 and p<0.001). In general, the unimproved sanitation practices, i.e. the prevalence of open defecation practice and the distribution of pipe latrines in households were found to be widespread in households with low income (under 100 USD, 100 to 200 USD, 200 to 300 USD) while the septic tank systems which represent an improved sanitation practices were mostly represented in household with higher incomes (300 to 400 USD and over 400 USD) (Fig. 27). Looking at the open defecation, this practice were found in the households with low income. The finding of this study could be explained by the fact that the good sanitation practices in the study area may strongly depends on the household income. This is the reason while the number of latrines observed in low income households were half constructed and do not have permanent roofs and doors in some cases. The strong correlation between the household incomes and the type of sanitation systems in use in households was addressed in the literature (Bakare et *al.*, 2015). The authors demonstrated the strong implication of the inadequate financial resources on the weak coverage of improve sanitation technologies in Tanzania and Senegal respectively.

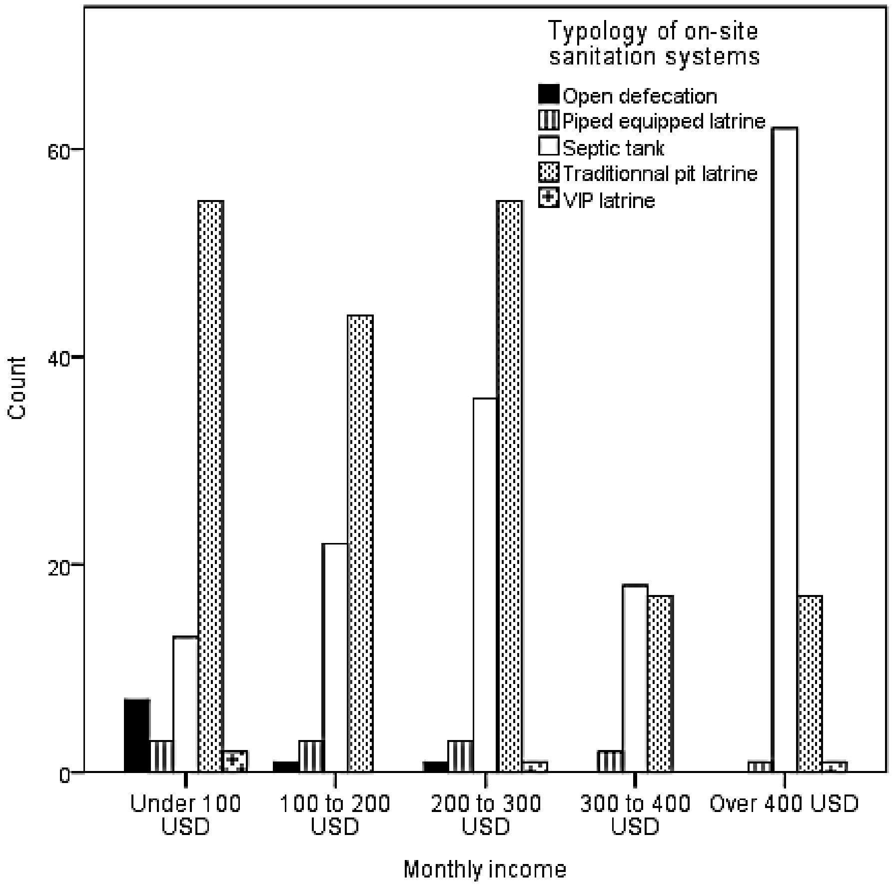


Fig. 27. On-site sanitation variation systems at the household levels in relation to the monthly income of households (n=364).

III.1.3. Latrines characteristics

III.1.3.1. Number of persons using the facilities

An important variation was recorded in the number of persons using the latrines. In general, the number of persons using the latrine depending on the investigated quarters and ranged between one person to more than six people (Fig. 28). However, latrines visited by more than 6 persons were mostly represented in the study area (32.39 %, n=559) while the latrines used by one person were less represented (14.45 %, n=559). The number of persons using the latrines in the households investigated displays with the number of people living in the households. This observation could be explained by the fact that people in the study area didn't share their latrines with other external users as it is contrary observed in other countries where the numbers of users of latrines may be sometimes more than the number of people living in the households. Indeed, Jenkins et *al.* (2014) by assessing the sanitation access in rapidly expanding informal settlement in Tanzania revealed the practices of sharing latrine to be common at mixed landlord-tenant and tenant only residences compared with family occupied residences where this practices is very low or absent. These authors pointed out the economic factors to be the cause of these observations, like the sharing of latrine involve several contributions from multiple users in building, maintaining and operating a shared facility.

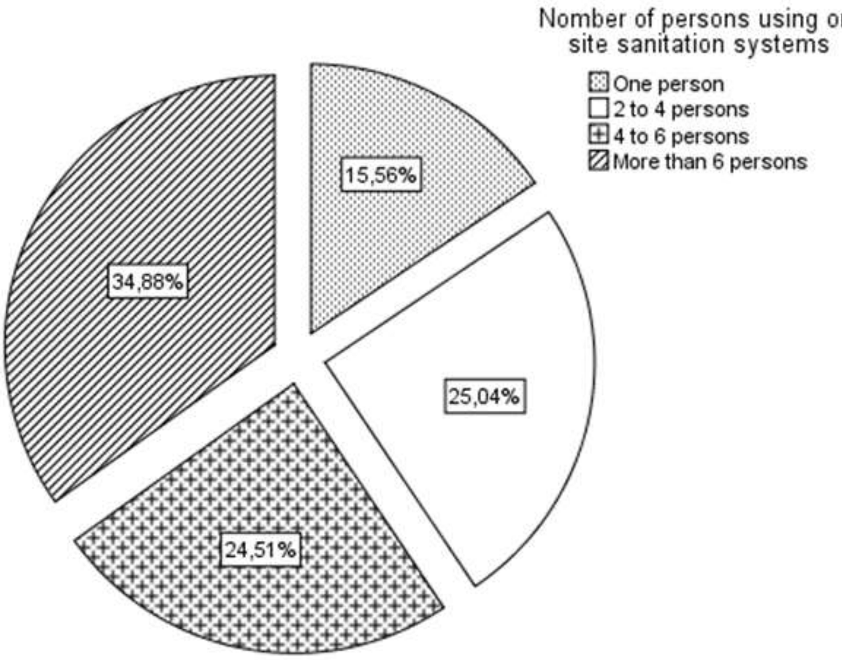


Fig. 28. Representation of the number of persons using the latrines in the investigated households (n=559).

III.1.3.2. Building materials

Based on the field observations, several available building materials were used by households to build their latrines (Fig. 29). Most of the latrines were built with concrete (83.98 %, n=586) while other where built with materials like metal sheets (4.72 %, n=586), beaten earth (2.27 %, n=586), wood (6.75 %, n=586) and plastic materials (2.28 %, n=586). Assessment of the distribution of the latrine building materials in function of the level of education and monthly income of households using the Pearson Chi Square at the 2-sided test revealed 56.7 % and 63.9 % of variations respectively. The latrine building materials used by the surveyed populations was strongly depend on the educational level of householders (X^2 = 64.80; p=0.004 at the 2-sided test) as well as their financial incomes (X^2 = 41.07; p<0.001) (Fig. 30 and Fig. 31). It can be concluded that the sanitation technologies in use in the surveyed populations were strongly depend on the educational level and the monthly income of the population. Similar observations were done by Bakare et *al*. (2012) assessing the excreta disposal in Dar-es-Salaam (Tanzania). The authors mentioned the variation of the latrine building materials to be strongly affected by educational level coupled to the financial resources. For these authors, low education is the main reasons for low-paying jobs performed by householders with an implication on the investment into good excreta disposal facilities.

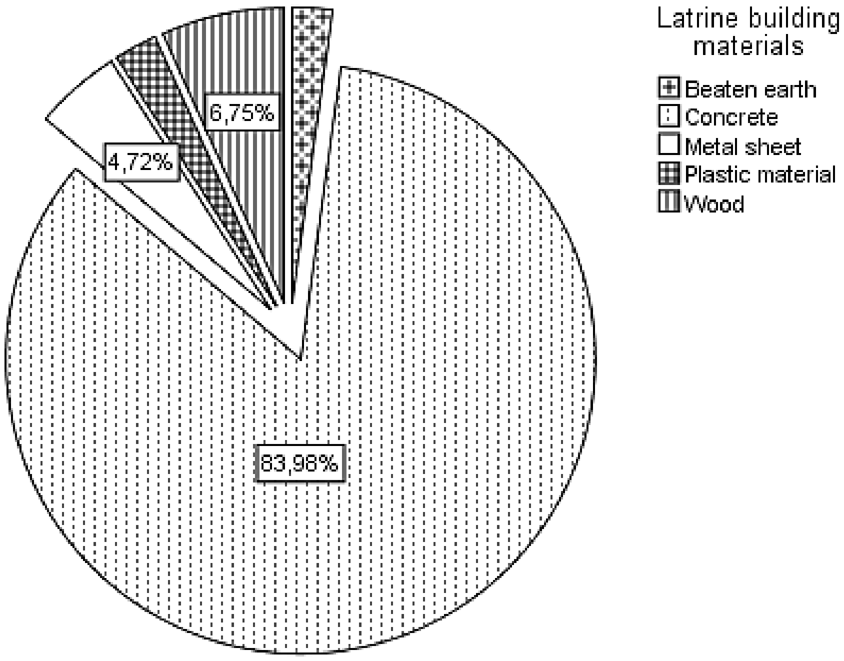


Fig. 29. Representation of the materials used to build latrines in the studied population (n=586).

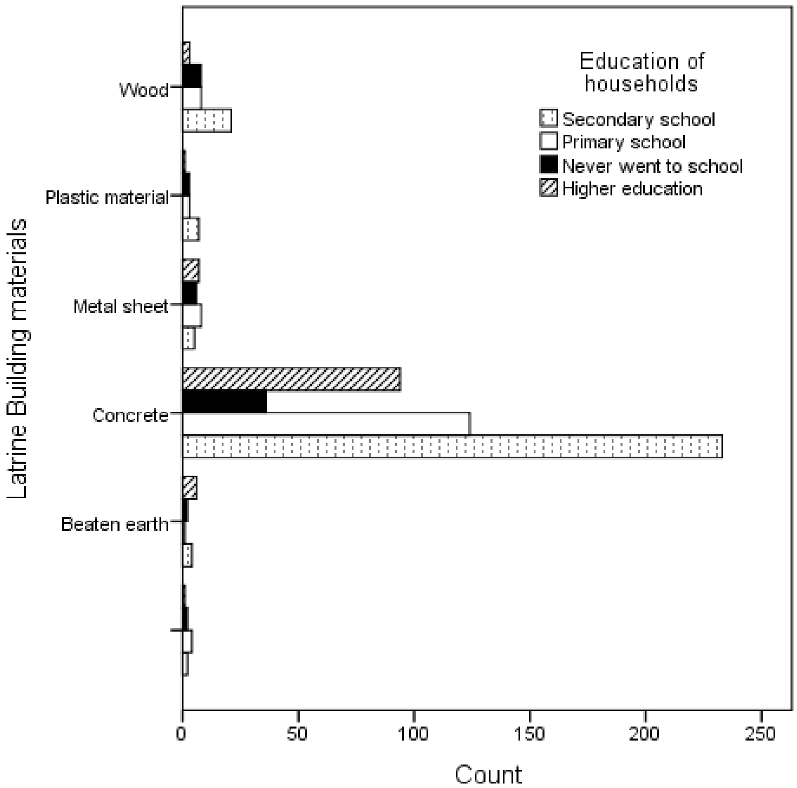


Fig. 30. Variation of the latrine building materials in relation to the level of education of households (n=586).

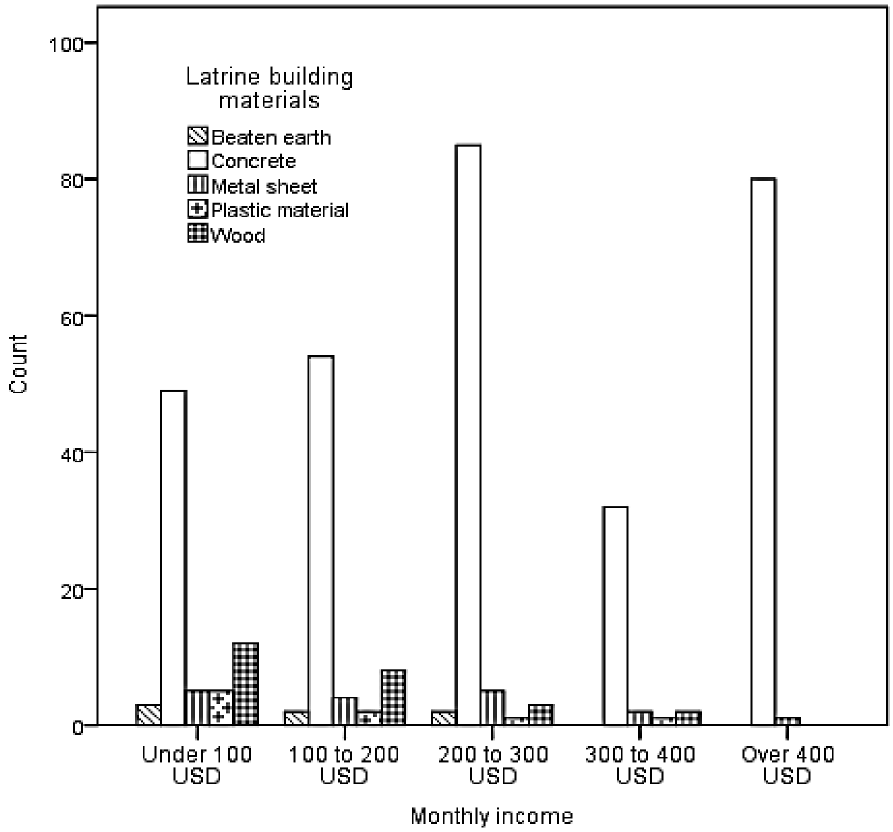


Fig. 31. Variation of the latrine building materials in relation to the monthly income of households (n=364).

III.1.3.3. Desludging periods

Several opinions were collected from the surveyed populations per the action needed to be carried out when the pit of their latrines are full (question 216 of the survey questionnaire) (Fig. 32). Most of respondents mentioned the emptying of their devices (74.10 %, n=583), 21.10 % mentioned the addition of chemical substances (caustic soda, wood ache), and only 4.80 % mentioned the construction of another latrine. The last of the cited options where recorded in households which didn't face space problems. Within the facilities that had been emptied, 50.99 % (n=557) mentioned that they usually empty the pit of their latrines within a period of less than two times/year, 12.39 % (n=557) emptying their latrines two time/year, 18.31 % (n=557) with a period of three times/year, 10.77 % (n=557) of households emptying their latrine four times/year, and 7.54 % (n=557) with a period of more than four times/year.

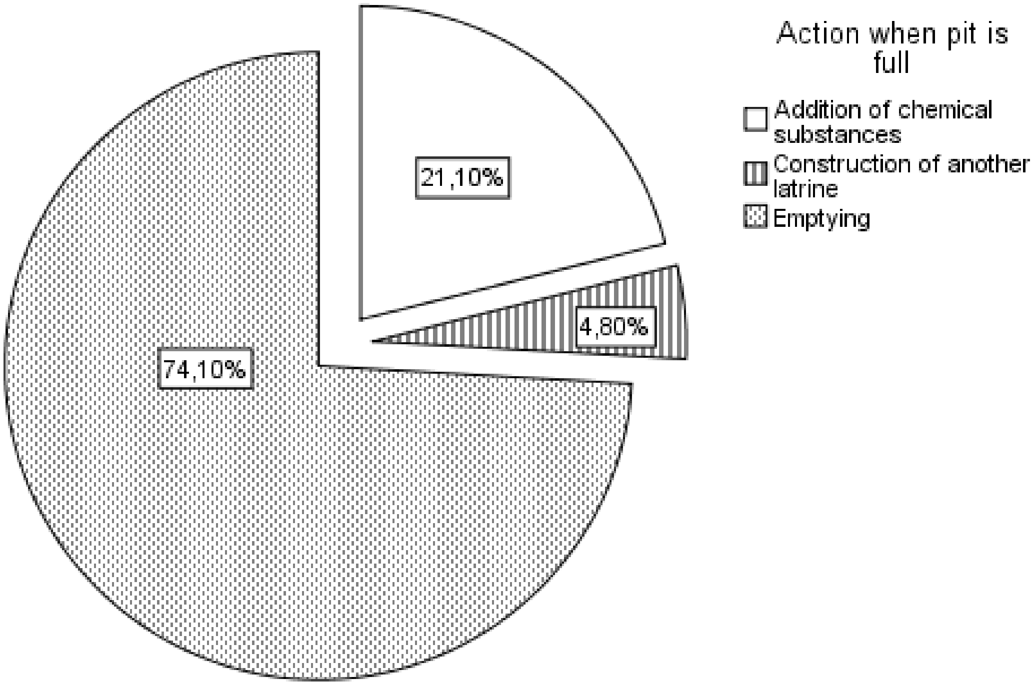


Fig. 32. Distribution of household's opinions per the actions needed to be done when the pits of their latrines are full (n=583).

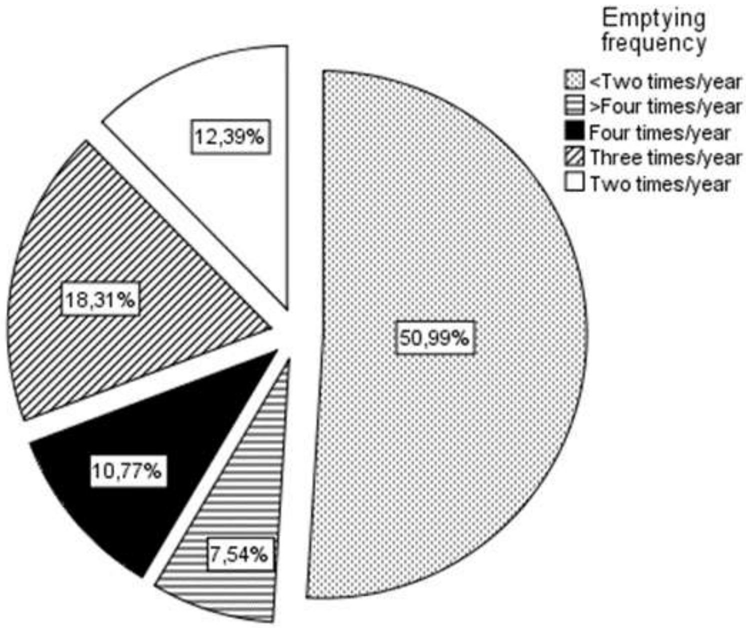


Fig. 33. Representation of the frequency of desludging in surveyed households (n=557).

To assess the relation between the types of sanitation systems and the variation of desludging periods within the surveyed population, the cross correlation using the Pearson Chi-Square tests was computed. The test revealed 53.3 % of the variability of emptying periods within the surveyed population with a strong significant effects of the types of sanitation systems (X^2 = 371.30; p<0.001)

(Fig. 33). The variation recorded in the distribution of the desludging frequency may be due to the variation of the number of latrine users, the dimension of the pits, the available space in household as well as the socioeconomic status of households. Looking at the septic tank facilities, the frequencies of the desludging periods recorded in the study area were 49.79 %, 14.97 %, 23.07 %, 6.48 % and 5.67 % respectively for the desludging frequencies less than two times per year, two times per year, three times per year, four times per year and more than four times per year (n=247) (Fig. 34). For the traditional pit latrines, the frequencies of the desludging periods recorded were in order of 56.09 %, 4.18 %, 14.98 %, 13.58 % and 4.18 % respectively for the desludging frequencies less than two times per year, two times per year, three times per year, four times per year and more than four times per year (n=287). According to the piped equipped latrine, the desludging period frequencies recorded were 84.21 % and 15.79 % respectively four times per year and more than four times per year (n=19).

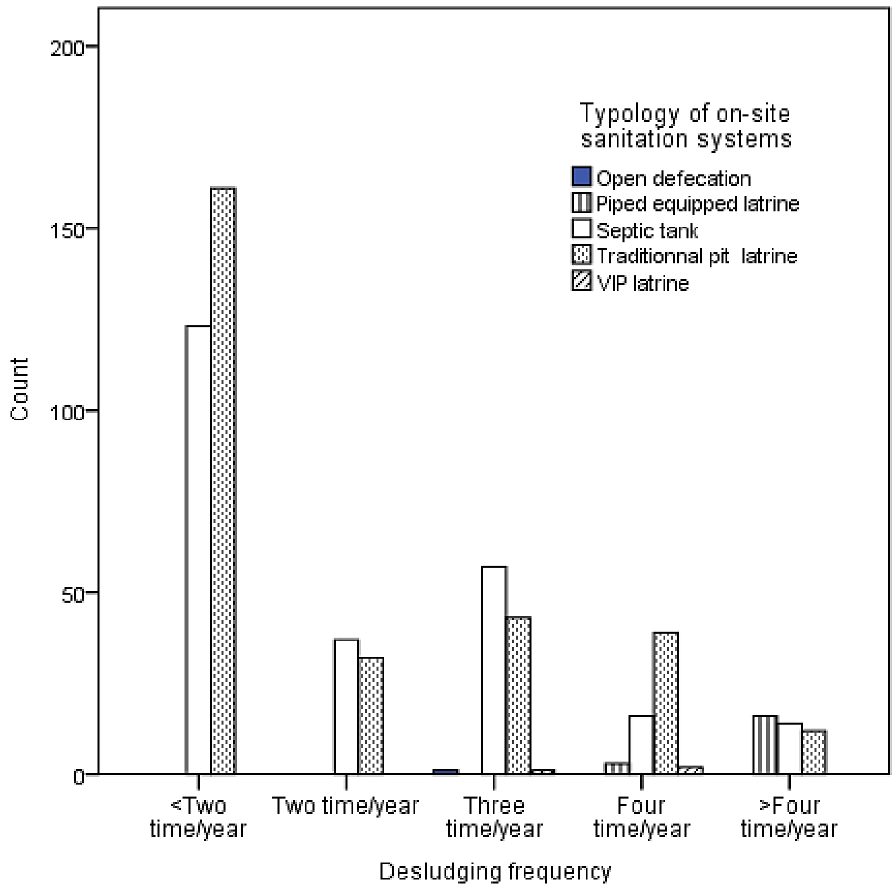


Fig. 34. On-site sanitation variation systems typologies in relation to the desludging frequencies (n=589).

Indeed, the findings of Nakagiri et *al.* (2016) working on the characterisation of pit latrines sludge in urban areas of Sub-Saharan Africa mentioned the high variation in the depth of the latrine pits and the number of latrine users as principal factor which may affect the pit filling rate.

Additionally, Bakare et *al*. (2012) demonstrated the high-water table to be the main causes of the pit's filling rate. The pipe equipped latrines identified during this study and which is usually located near the water table showed a higher desludging period of more than four times per year (Fig. 38). According to the literature, the number of users of latrines could strongly affect the rate of faecal sludge accumulation in the pits of latrines as the excreta production rate per person was estimated at about 0.12 to 0.40 litre of faeces and 0.6 to 1.5 litre of urine per day (Bakare et *al*., 2012).

III.1.3.4. Comfort of use

On the base of the survey information collected coupled with the field observations, the significant variation of opinions looking at the problems related to the comfort of facilities was observed (X^2=204.408, p<0.001, n=368). The spread of bad odours was observed in most of the facilities investigated with the higher prevalence recorded in the 'piped equipped latrines' (> 80 %, n=20) (Fig. 35). The case of insecurity was observed in households practicing open defecation (71.42 %, n=14) and those who used the traditional pit latrines (11.25 %, n=244). Exposure was observed in some of the septic tanks (15.78 %, n=90) and traditional pit latrines facilities (17.21 %, n=244). The views of some unsafe facilities with discomfort are presented (Fig. 36).

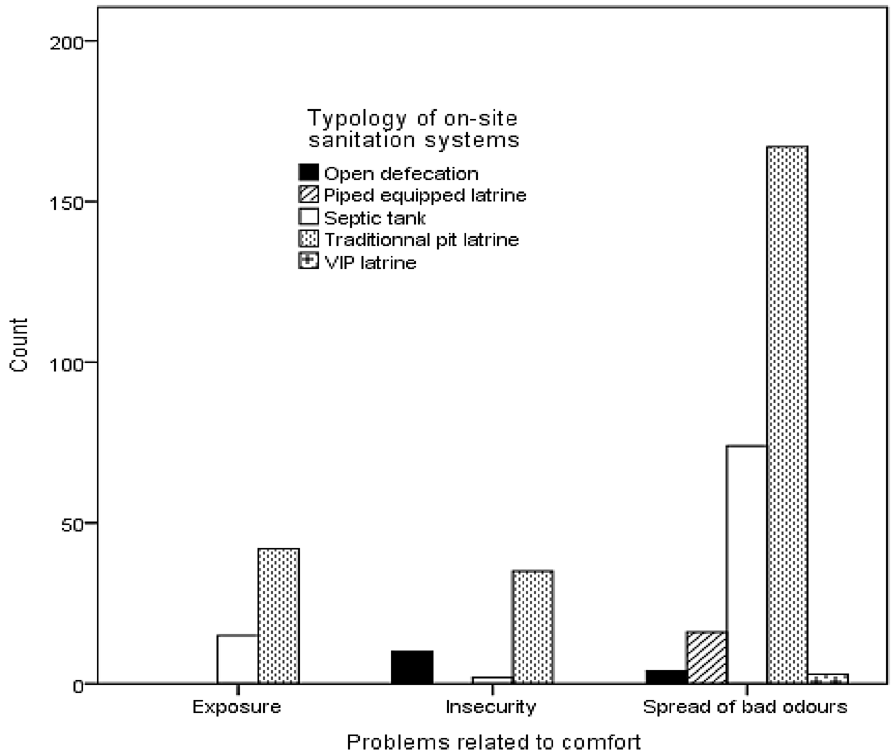


Fig. 35. Distribution of problems facing household in relation to the type of on-site sanitation systems (n=602).

Fig. 36. Photos showing some unsafe latrines with discomfort found in the study area (a: dirty latrine built with metal sheet located in a flooding area; b: latrine with unfinished superstructure showing weak maintenance; c: unsafe latrine with a wood slab partially built and full pit continuously in used; d: dirty latrine with partially built superstructure) (Photos: Letah Nzouebet).

III.1.4. Indicators of improved, safe and sustainable sanitation systems

To classify the on-site sanitation systems investigated (septic tanks, traditional pit latrines and VIP latrines) as improved, hygienically safe, sustainable and functioning, the WHO/UNICEF JMP indicators was applied. Looking at the facility design, 85.36 % (n=568) of latrines with slab (indicator 1) build with concrete, brick, rock or other hard material (Fig. 37). In 68.79 % (n=568) of the facilities investigated, wastes were contained into the pit/tanks of latrines without overflow to the surrounding areas (indicator 2) and 62.85 % (n=568) of latrines had below ground pit/tank lined allowing the safe waste emptying and the protection of shallow groundwater (indicator 3). Looking the waste management practice, 58.97 % (n=568) of households were accessible by the vacuum tanker services for the extraction of faecal sludge in the pit of latrines (indicator 4), 52.62 % (n=568) of pits were accessible to hygienic emptying service vehicles (tanker or tug) (indicator 5).

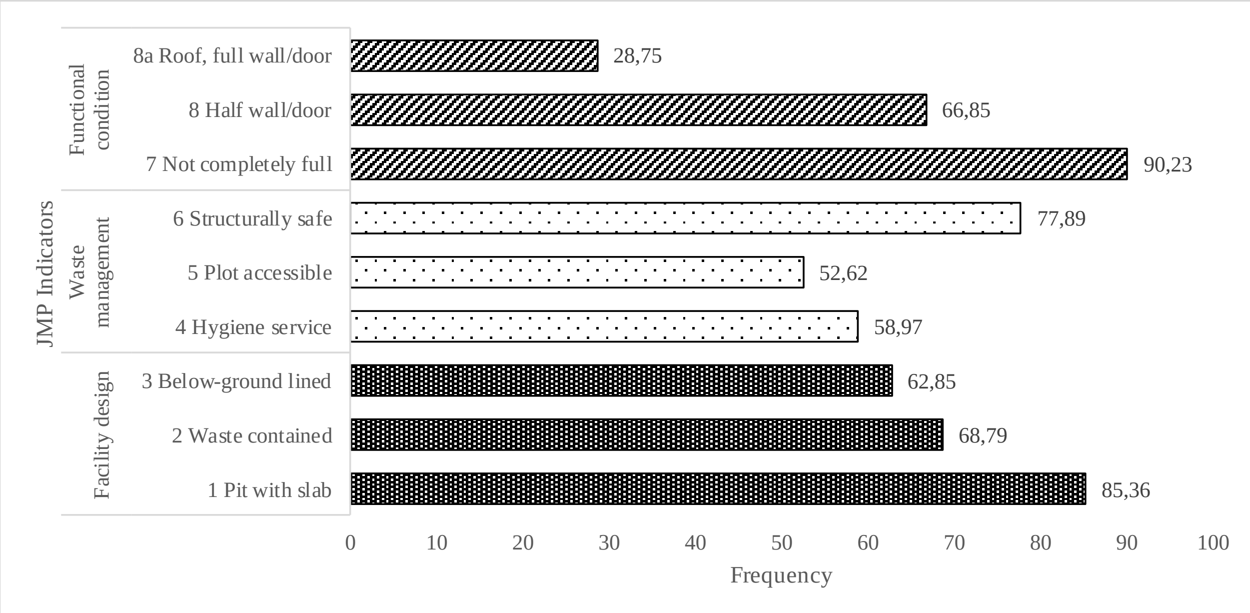


Fig. 37. Indicators prevalence of improved, safe and sustainable sanitation systems (n=568).

The functional conditions of the facilities were also investigated and 90.23 % (n=568) of the latrines investigated was not completely full (indicator 7), 66.85 % (n=568) had half wall/door (indicator 8) and only 28.75 % (n=568) of the facility has a cabin containing full height walls, a full height door and a roof (indicator 8a). The variation of the WHO/UNICEF JMP indicators observed in the study area may be explained by the differences observed in the monthly incomes, level of education of householders as well as the willingness of householders to pay for access to an improve and sustainable sanitation system. Indeed, Taweesan et *al.* (2015) by assessing accelerating uptake of in-house toilets of a rural community in Ghana pointed out the financial limitation to constructing improved in-house latrines.

III.1.5. Physical appearance of faecal sludge samples

It is important to point out that the sampling team were faced with many problems during collaboration with latrine owners and some of them perceived the management of FS to be a taboo. In general, three types of sludge colour were recorded (n=53) namely greenish (28 %), yellowish, colour (32 %), and grey (40 %). These different colours of raw sludge sampled may provide guidance on the degree of mineralization of excreta in the pit. Out of all the collected sludge samples 72 %, were pasty in appearance against 28 % which had a liquid appearance (Fig.38). The predominance of pasty sludge appearance could inform about the dry matter concentration in samples and the type of system in place for the collection of excreta. Indeed, some devices operated as wet systems i.e. require water for faecal matter flushing. The quantity of water added into the pits during faecal matter flushing may affect the concentration of sludge parameters especially the water content, dry matter content and the dilution of organic and bacteriological parameters.

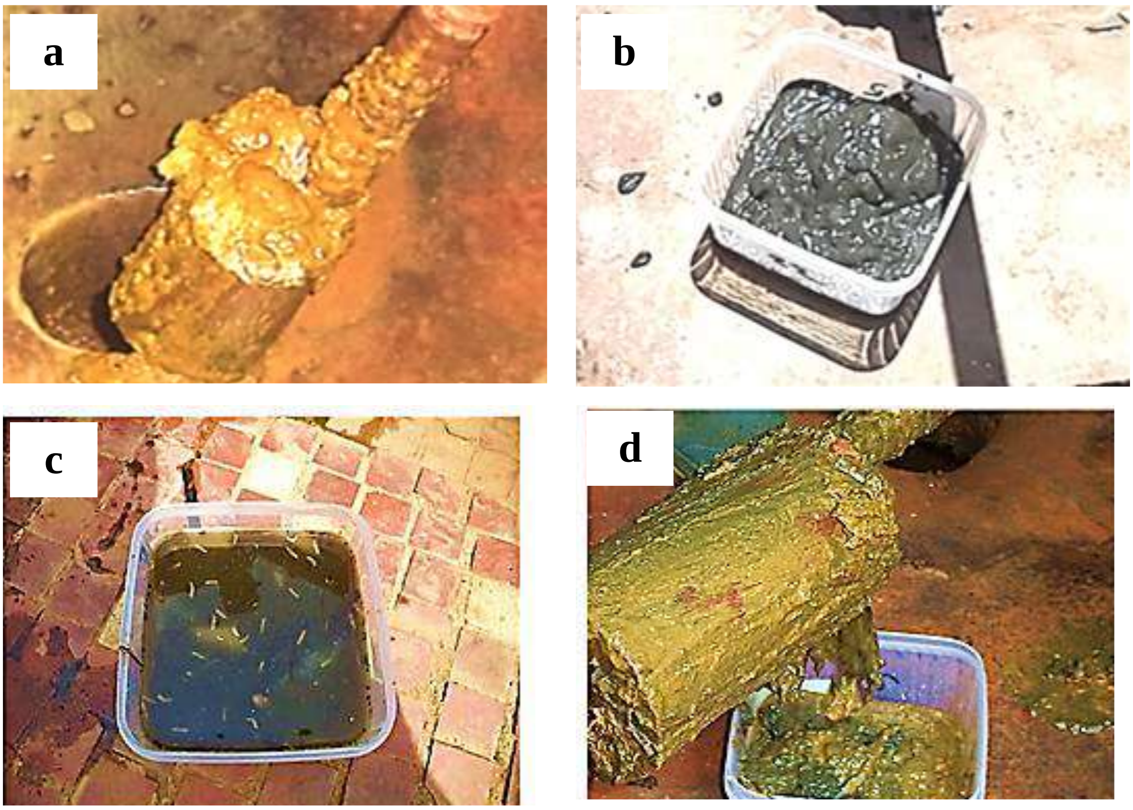


Fig. 38. Photos showing visual aspects of sludge sampled (a: pasty sludge with yellow colour; b: pasty sludge with grey colour; c: liquid sludge with black colour. d: pasty sludge with mixed yellow and black colour) (Photos: Letah Nzouebet).

Observations done in the field during sampling showed that all the pits investigated were still being loaded with fresh faeces and all of them were simultaneously used for bathing. In addition to the visual characteristics, the sludge samples were also characterized by the presence of trash elements (household solid wastes) (Fig. 39). The type of solid wastes found in the pits of the latrines during sampling events varied widely and consisted of plastic materials, broken glasses, bottles, clothes, metals, hair, stones, newspapers, menstrual hygiene products and anal cleansing materials. The presence of household wastes in the pit need to be considered during pit emptying operations because household wastes may cause clogging of pipes during mechanical emptying. The results of this study corroborate with literature (Nakagiri et *al*., 2016; Bakare et *al.*, 2015). The authors pointed out the presence of household solid wastes in the pit depending on the habits of the users, the demography of the households and the type of cleansing material used. For Still and Foxon (2012), the consistency of the sludge in the pit is affected by the amount of water added to the pit (by flushing, disposal of grey water or water used for anal cleansing), the ability of water to leave or enter the pit (determined by pit design, permeability of soil and level of water table relative to the pit), the type of anal cleansing material used, presence of other solid or liquid waste in the pit and diet.

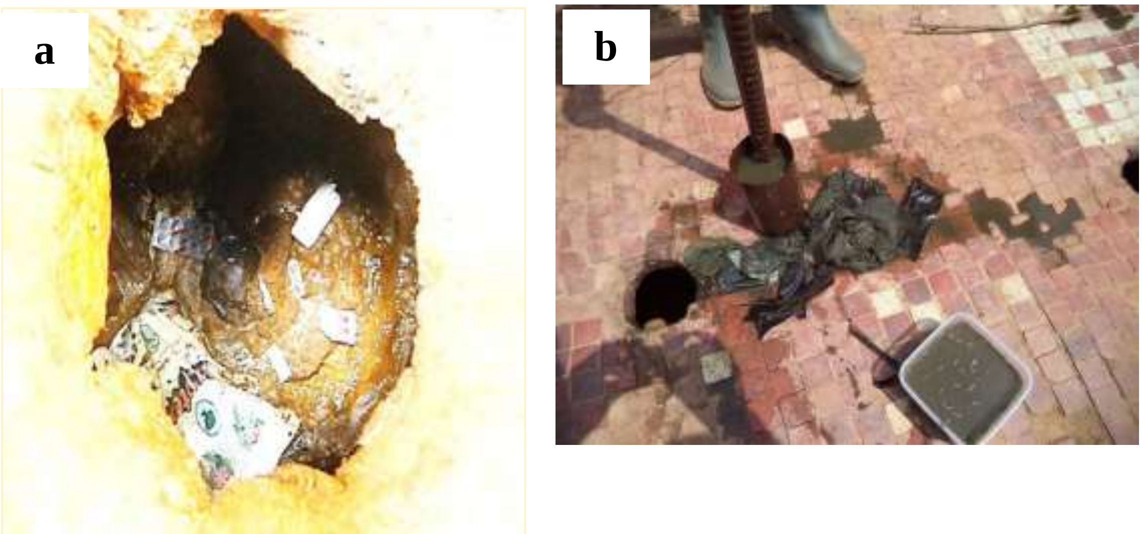


Fig. 39. Photos showing solid waste refuses found in the pit of latrines during sampling (a: pit with a mixture of solid wastes; b: clothes removed in the pit during sampling) (Photos: Letah Nzouebet).

III.2. Hygienic quality of sludge samples as well as the sanitary and environmental risks associated with the current defecation practices in surveyed population

III.2.1. Distribution of helminth eggs diversity and the total helminth eggs

Helminth eggs in sludge may pose significant health risks to exposed populations through direct or indirect contact. Helminth eggs were detected in 100 % of pit latrine sludge tested corroborating the study of Yen-Phi et *al.* (2010) in Vietnam and the study of Amoah et *al.* (2018) in sewage sludge from South Africa and Senegal. The detection frequencies among individual helminth species strongly varied. *Ascaris lumbricoides* was detected in over 64 % of all samples which is in line with the results of previous studies (Koné et *al*., 2007; Yen-Phi et *al.*, 2010) indicating a high prevalence of Ascariasis in the population (Fig. 40). In general, the prevalence of helminth eggs diversity recorded in the 53 samples were *A. lumbricoides* (64.15 %), *Taenia* sp. (32.07 %), *E. vermicularis* (32.07 %), *S. stercoralis* (30.18 %), *T. trichiura* (26.41 %), *S. mansoni* (20.75 %), *H. nana* (20.75 %), *F. hepatica* (20.75 %) and *A. duodenale* (20.75 %). The parasite *A. duodenale* had the lowest detection frequencies (see Table X).

The mean values of the prevalence recorded were 35.02 eggs/g DM (*F. hepatica*), 40.17 eggs/g DM (*A. lumbricoides*), 35.08 eggs/g DM (*A. duodenale*), 33.03 eggs/g DM (*T. trichiura*), 32.99 eggs/g DM (*Teania* sp.), 35.14 eggs/g DM (*S. stercoralis*), 32.49 eggs/g DM (*E. vermicularis*), 24.21 eggs/g DM (*H. nana*), 30.12 eggs/g DM (*S. mansoni*) and 90.23 eggs/g DM (Total helminth eggs) (Table XI).

Table XI. Descriptive statistics of the helminth eggs data (number of eggs/g DM).

Helminth eggs diversity	N	Mean	Sd. Dev.	Min	Max	Percentiles		
						25th	50th (Median)	75th
Schistosoma mansoni	11	30.12	21.87	8.58	79.70	12.96	23.97	48.83
Ascaris lumbricoides	34	40.17	27.03	1.94	90.30	14.92	33.07	58.96
Taenia sp.	17	32.99	21.38	1.74	87.52	17.29	28.61	44.85
Strongyloides stercoralis	16	35.14	25.50	8.49	107.20	19.53	27.06	40.61
Trichuris trichiura	14	33.03	19.53	8.70	67.06	15.27	30.46	47.85
Enterobius vermicularis	17	32.49	26.67	7.17	100.48	10.26	25.68	51.43
Hymenolepis nana	11	24.21	15.16	6.63	48.83	11.73	18.68	40.14
Fasciola hepatica	11	35.02	23.45	2.81	80.16	14.17	34.93	47.50
Ankylostoma duodenale	11	35.08	24.25	6.91	81.00	14.57	31.09	54.17
Total helminth eggs	53	90.23	64.75	8.5	264.51	30.38	77.41	137.39

(N: number of positive samples; Sd. Dev.: standard deviation; Min: minimum, Max: maximum)

To assess the variability of each helminth species in samples, the non-parametric test of independent samples revealed a significant difference ($p<0.05$) in the distribution of the median values of helminth eggs prevalence between samples. The most significant variation recorded were

0.632, 0.666, 0.584, 0.520, 0.974 respectively for *S. mansoni*, *A. lumbricoides*, *S. stercoralis*, *A. duodenale* and the total helminth eggs. Similar observations were obtained by Kumwenda et *al*. (2017) in Malawi. The authors assessed the variability of the difference between the prevalence and the mean concentration of helminth eggs in two types of latrines respectively and obtained a significant correlation in the prevalence of helminth eggs between households using ecological sanitation and those using traditional pit latrines.

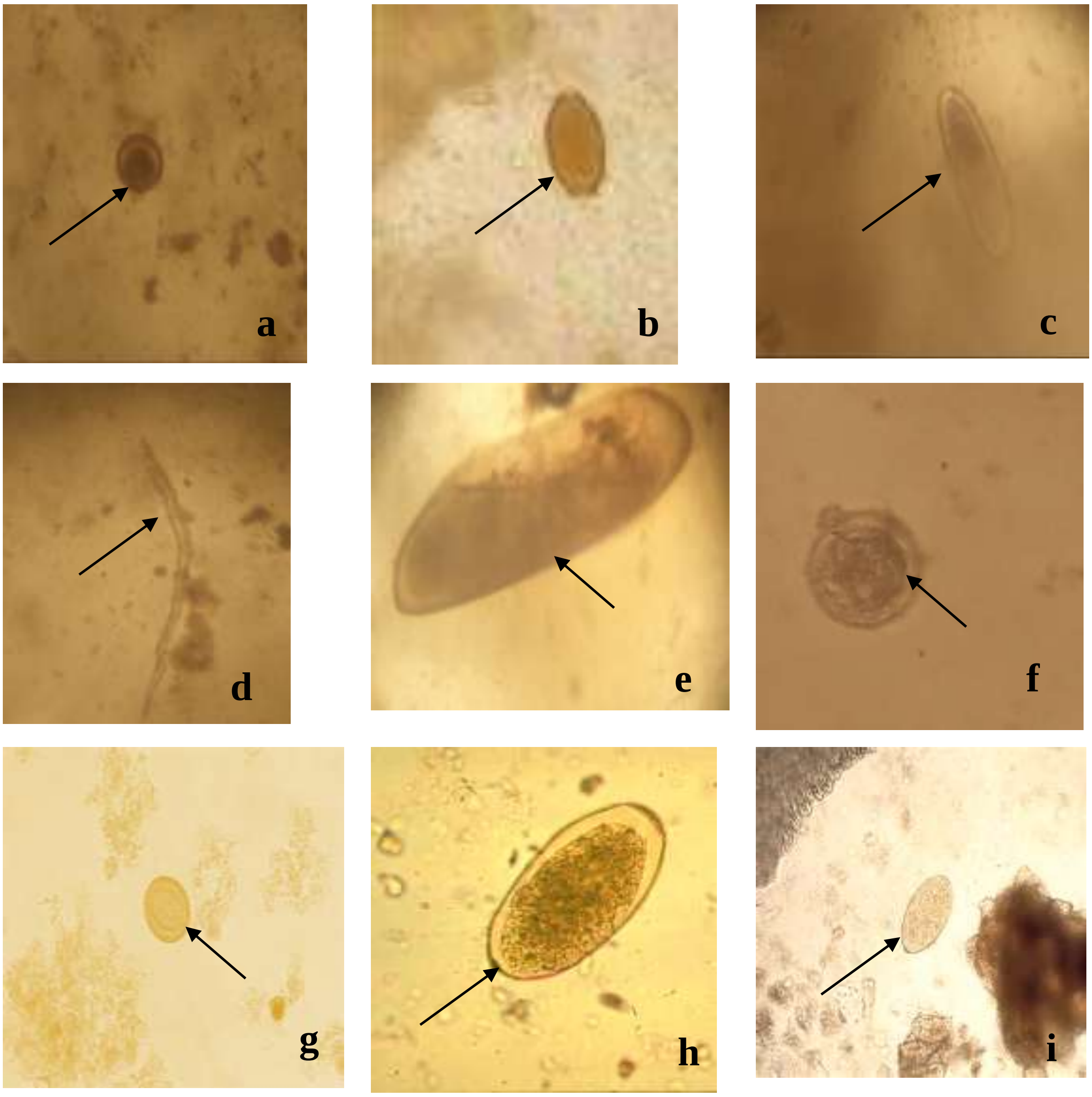


Fig. 40. Views of helminth eggs found in sludge using photonic microscope observation [20 X objective] (Photos: Letah Nzouebet).

(a: *Ascaris lumbricoides*, b: *Trichuris trichiura*, c *Enterobius vermicularis*, d: *Strongyloides stercolaris*, e: *Schistosoma mansoni*, f: *Hymenolepis nana*, g: *Taenia* sp., h: *Ankylostoma duodenale*; i: *Fasciola hepatica*).

III.2.2. Distribution in relation to the latrine types

Assessment of the distribution of helminth eggs species (per g of DM) in relation to the latrine groups was computed. There was a significant difference (p<0.05 confidence level) in the concentration of the helminth eggs species between the types of latrines (p<0.038). The higher differences (One-way ANOVA test) were recorded for the species *F. hepatica*, *E. vermicularis*, *A. duodenale* and the total helminth eggs (Table XII). The visualization in the distribution of the helminth eggs species per type of latrines is represent in the figure 41 below.

Table XII. Variance of the diversity of helminth eggs in relation to the types of latrines (number of eggs/g DM).

Type of Latrine	TPL (n=30)	ST (n=12)	VIPL (n=4)	PEL (n=7)
Schistosoma mansoni	32.33±18.87^{b} [8.58-79.69] 8/30 (26.66 %)	nd	5.99±0.00^{a} [23.96-23.96] 1/4 (25 %)	6.96±6.35^{a} [17.99-30.69] 2/7 (28.57 %)
Ascaris lumbricoides	42.06±27.05^{b} [1.94-90.30] 21/30 (70 %)	39.34±31.08^{b} [4.50-89.6] 7/12 (58.33 %)	21.98±23.41^{a} [30.63-57.30] 2/4 (50 %)	17.05±16.55^{a} [9.54-58.35] 4/7 (57.14 %)
Taenia sp.	30.46±18.34^{b} [1.74-64.25] 11/30 (36.66 %)	45.03±25.39^{b} [17.41-87.52] 4/12 (36.36 %)	nd	6.54±5.72^{a} [17.17-28.61] 2/7 (28.57 %)
Strongyloides stercoralis	34.13±24.28^{b} [8.49-107.20] 13/30 (43.33 %)	nd	10.32± 0.00^{a} [41.29-41.29] 1/4 (25 %)	11.04±6.75^{a} [21.88-55.41] 2/7 (28.57 %)
Trichuris trichiura	35.01±16.80^{b} [9.29-67.06] 6/30 (20 %)	32.03±18.74^{b} [8.70-65.24] 4/12 (33.33 %)	20.46±5.40^{b} [35.52-46.32] 2/4 (50 %)	6.07±8.70^{a} [12.53-29.94] 2/7 (28.57 %)
Enterobius vermicularis	25.46±16.76^{ac} [7.17-61.10] 11/30 (36.66 %)	83.99±30.98^{bd} [67.50-100.48] 2/12 (16.66 %)	9.41±0.00^{a} [37.64-37.64] 1/4 (25 %)	9.52±7.62^{a} [10.07-44.27] 3/7 (42.85 %)
Hymenolepis nana	17.48±9.80^{a} [6.62-48.83] 7/30 (23.33 %)	nd	15.63±6.89^{a} [24.35-38.15] 2/4 (50 %)	11.64± 0.60^{a} [40.14-41.36] 2/7 (28.57 %)
Fasciola hepatica	31.38±16.09^{bc} [2.81-66.84] 7/30 (23.33 %)	63.83±23.90^{bd} [47.50-80.16] 2/12 (16.66 %)	nd	5.41±4.75^{a} [8.63-29.23] 2/7 (28.57 %)
Ankylostoma duodenale	38.39±16.70^{bc} [9.44-81.00] 4/30 (13.33 %)	40.84±19.81^{bd} [14.56-64.41] 3/12 (25 %)	21.32±11.53^{a} [31.09-54.17] 2/4 (50 %)	3.51± 2.36^{a} [6.91-17.63] 2/7 (28.57 %)
Total helminth eggs	286.70±164.69^{bc} [122.01-451.39] 30/30 (100 %)	305.06±149.90^{a} [155.16-454.96] 9/12 (75 %)	105.12±47.23^{bd} [57.89-152.35] 2/4 (50 %)	77.74± 59.40^{a} [18.34-137.14] 7/7 (100 %)

(PEL: piped equipped latrines; ST: septic tank; TPL: traditional pit latrine; VIPL: ventilated improved pit latrine; n=number of sample; nd: not determined; values followed by the same letter are not significantly different from each other following one-way ANOVA test, p<0.05; Interval values in hook show the minimum and the maximum, fractions are the number of positive tests out of the total number of tests performed followed by the values in parenthesis which express the percentage of positive samples).

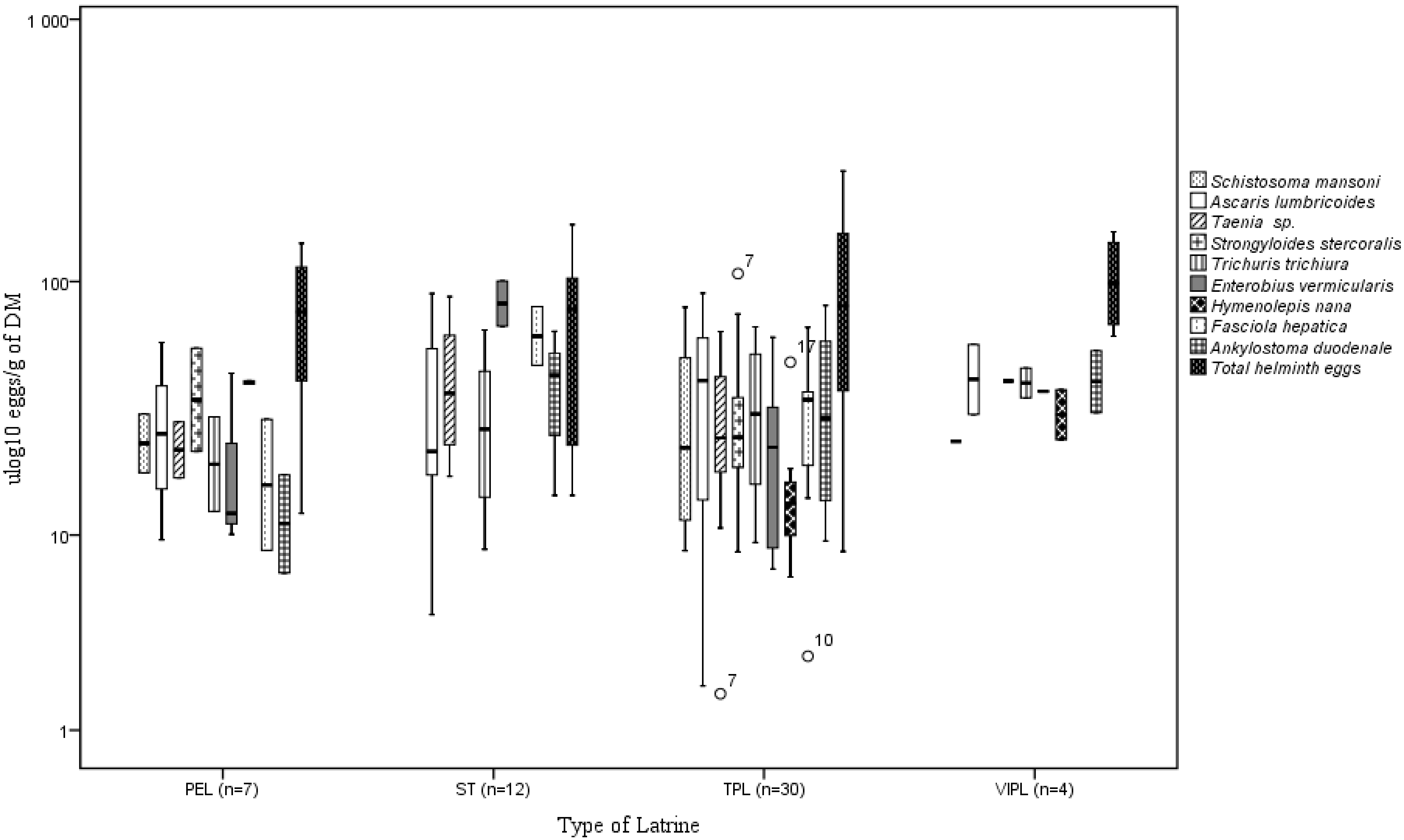


Fig. 41. Box-plot showing the distribution of the prevalence and diversity of helminth eggs species per group of latrines (PEL: piped equipped latrines; ST: septic tank; TPL: traditional pit latrine; VIPL: ventilated improved pit latrine).

The most prevalent helminth eggs found among the 9 species identified is *A. lumbricoides* which, in accordance with data reported in the literature states that Ascariasis is generally one of the most frequent cause of helminthic infections (Pecson et *al*., 2007). Furthermore, *Ascaris* eggs are also characterized by their high resistance to environmental conditions, such as pH, temperature, desiccation, etc. (Koné et *al*., 2007; Ingallinella et *al.*, 2002; Cofie et *al*., 2006). The predominance of *Ascaris* eggs in the sludge samples could also be explained by its high egg production (200,000 eggs/day) and its durable eggs (Feachem et *al.*, 1983). Indeed, observations done by Nkengazong et *al*. (2010), assessing the prevalence of geohelminths in 420 Cameroonian pupils revealed a high prevalence of *Ascaris* eggs. The diversity of helminth species found in the samples is in accordance with Jimenez et *al.* (2000) who characterized wastewater sludge in Mexico and Yen-Phi et *al*. (2010) who characterized faecal sludge in Vietnam. The high variability in terms of number and diversity of helminth eggs could be attributed to the health status of pit latrine users, the epidemiological conditions of the populations in the study area as well as the storage condition in the pit of the latrines. By assessing pathogens in septage in Vietnam, Yen-Phi et *al.* (2010) recorded a correlation between helminth ova concentration and retention time of faecal sludge. In Vietnam, in order to reduce human health risks associated with excreta use in agriculture, the Vietnamese Ministry of Health has stipulated the time for human excreta storage in latrines to be at least six months before application as fertilizer (Jensen et *al.*, 2008). Strauss et *al.* (1997) mentioned the effect of storage duration on faecal sludge stabilization. The effects of retention time couldn't be applied to explain the prevalence and diversity of helminth eggs recorded in this study as pits of latrines were still in used.

As the observed parasite egg concentrations in samples were higher than the limit recommended in the WHO (2006) guidelines for safe use of excreta in agriculture (<1 egg/g of DM), the need for proper health and environmental protection measures has to be stressed, in order to avoid helminthic diseases transmission through untreated sludge discharge into the environment or direct agricultural application. Mara and Sleigh (2010) pointed out that the persistence of helminth eggs in the environment is the most important risk factor for disease transmission. To prevent disease transmission, it is necessary to apply interventions for safe disposal and storage of excreta.

The number of species found varied from 1 to 9 per samples with more than 75 % of the sample containing more than one species. The lower diversity was found in the samples from septic tanks (6 species identified) and the ventilated improve pit latrines (7 species identified). The difference in the number of helminth species found could be explained by the different transmission routes of helminth eggs and the latrine user's specific risks factors (Stenström et *al*., 2011). Traub et *al.* (2004) demonstrated that the transmission of helminth eggs is influenced by several factors like micro-climate, sanitation, hygiene and environmental contaminations with human excreta. In addition, Berteigne (2012) estimated that about 900 to 1,350 m^3 of untreated faecal sludge are discharged weekly into peri-urban areas of Yaounde (Cameroon). Thus, treatment is necessary to minimize risk of helminthic infections by excreta. This study revealed heterogeneity in the distribution of helminth species and the total helminth eggs found in different on-site sanitation systems.

III.2.3. Sanitary and environmental risks associated with the current defecation practices in surveyed urban areas

Based on the survey results, 38.29 % (n=598) of the investigated population have suffered from several cases of faecal-oral diseases (amoebiasis, cholera, helminthiasis, thyphoid fever) within the past six months (Fig. 42) with the difference of prevalence between current defection practices in households (Fig. 43). It appears that the faecal-oral diseases were less prevalent in households with septic tanks as toilet facility (only 31.07 % (n=251) of diseases prevalence recorded) in comparison to the households with traditional pit latrines as toilet facility (58.84 % (n=311) of diseases prevalence recorded). The VIP latrines users didn’t mention the prevalence of faecal-oral diseases contrary to the households practicing open defection. The significant correlation between the prevalence of faecal-oral diseases and the type of on-site sanitation was found (X^2= 163.03, p<0.001, n=598) as well as the distribution of the type of faecal-oral diseases recorded in the households (60 % of variation, X^2= 170.29, p<0.002, n=293) (Fig. 44). A maximum rate of prevalence was recorded in households using traditional latrines as toilet facility and no disease was recorded in households using VIP latrines. According to the variation of the type of faecal-oral diseases recorded in relation to the toilet facilities in use in households, typhoid fever were the most prevalent diseases. The prevalence distributions recorded were in the order of 38.58 %, 26.69 % and 55 % respectively for traditional pit latrine, septic tank and piped equipped latrine. The prevalence recorded with amoebiasis which is the second disease after the typhoid fever recorded in the study area were in the order of 11.57 %, 1.59 %, 30 % and 35.71 % respectively for traditional pit latrine, septic tank, piped equipped latrine and open defecation. We mentioned that open defecation in this study is considered as current defecation practices found in households who didn’t have on-site sanitation technology. The prevalence of helminthiasis in the study households were in the order of 6.10 %, 2.39 %, 10 % and 10 % respectively for the traditional pit latrine, septic tank, piped equipped latrine and open defecation. For the cholera disease, the prevalence recorded were in the order of 2.25 %, 0.32 % and 0.32 % respectively for the traditional pit latrine, septic tank and open defecation.

The prevalence of the faecal-oral diseases in the study area may be due to the weak maintenance as well as the sanitation and hygiene conditions during the management of the toilet facilities in households. Indeed, the empirical evidence provided by Tumwebaze et *al.* (2013) suggests that toilets facilities end up in a deteriorated state and pose health risks since users fail to adequately maintain them. Additionally, Taweesan et *al.* (2015) revealed adequate sanitation as one of the fundamental key factors for good health and socioeconomic development. Also, the improvement of sanitation technologies can substantially reduce the rate of morbidity and severity of various diseases affecting the quality of life particularly for children (Mara et *al*., 2010; Stenström et *al*., 2011; Cairncross et *al.*, 2010). Additionally, lack of hand washing may be the cause of the prevalence of faecal-oral diseases found in the study area. According to the findings of Wolf et *al*. (2018) working on the impact of drinking water, sanitation and hand washing with soap on childhood diarrhoeal disease, the authors reported the association between improved household sanitation facilities and diarrhoea compared to unimproved sanitation and two observations respectively of sewer connection compared to unimproved and improved sanitation facilities. For Mathew et *al.* (2017) working on the systematic review and meta-analysis of the impact of sanitation on infectious diseases and nutritional status showed the positive impacts of sanitation on the aspects of health.

However, the role of the health sector in improving sanitation is fundamental for the promotion of sanitation in environmental health planning at the local and national level. Thus, behaviours should be changed to increase householders' demand for sustained use of excreta disposal facility. According to Tumwebaze et *al.* (2013), the enforcement role of the health sector is particularly important in urban areas where high- living density increases the risks of faecal contamination in the environment and where one person's lack of sanitation can affect the health of many other people.

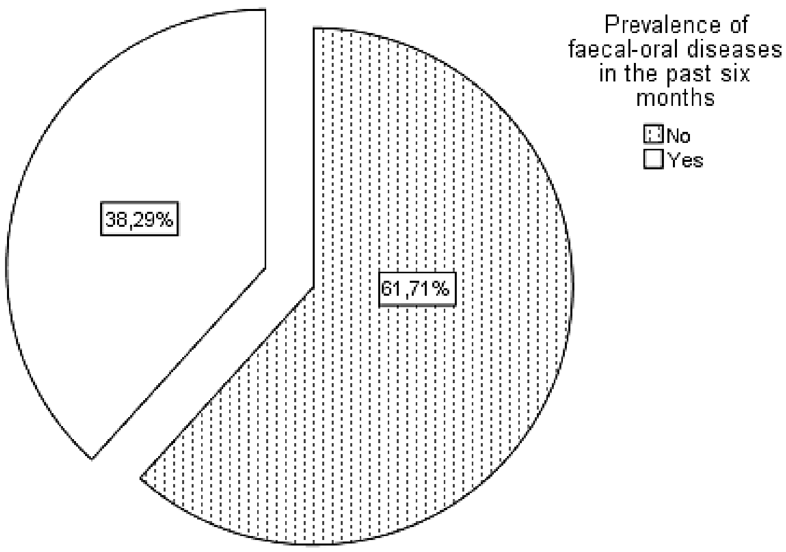


Fig. 42. Prevalence of faecal-oral diseases in the surveyed population (n=598).

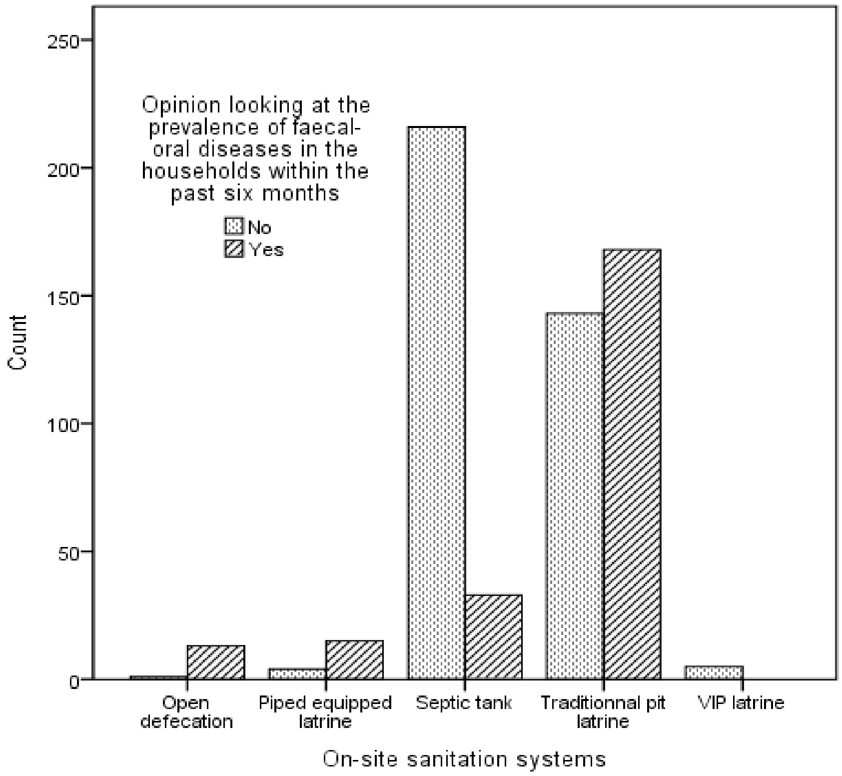


Fig. 43. Prevalence variation of faecal-oral diseases in relation to the toilet facilities in used in households (n=598).

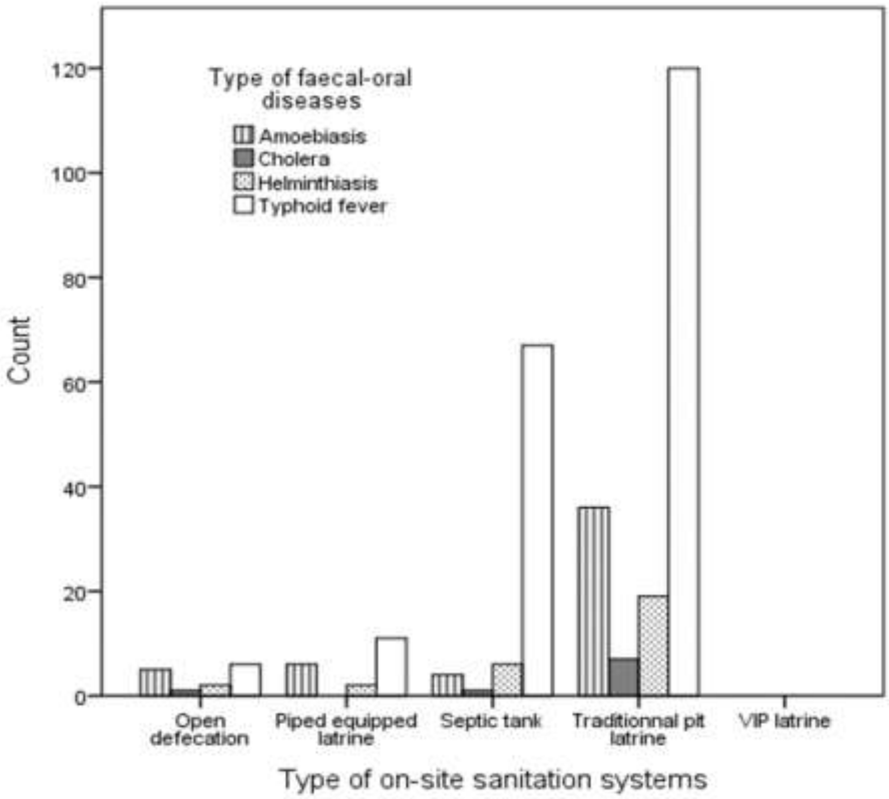


Fig. 44. Variation of the type of faecal-oral diseases recorded in relation to the toilet facilities in used in households (n=293).

III.3. Physico-chemical and heavy metal characteristics of faecal sludge samples

III.3.1. Physico-chemical characteristics

III.3.1.1. Variation of pH

The variation was observed within the samples belongings to the same group and between the samples of different groups of latrines (Fig. 45). The distribution of pH range values in function of the type of latrines were 5.90 - 8.94, 6.76 - 7.21, 6.60 - 7.21 and 6.18 - 7.66 respectively for traditional pit latrines, septic tanks, ventilated improved pit latrines and pipe equipped latrines. Assessment of the variance of the pH values between the groups of latrines using the one-way ANOVA test (α=0.05) revealed that there was significant difference between the samples of the pipe equipped latrine and the others types of latrines sampled ($p<0.038$).

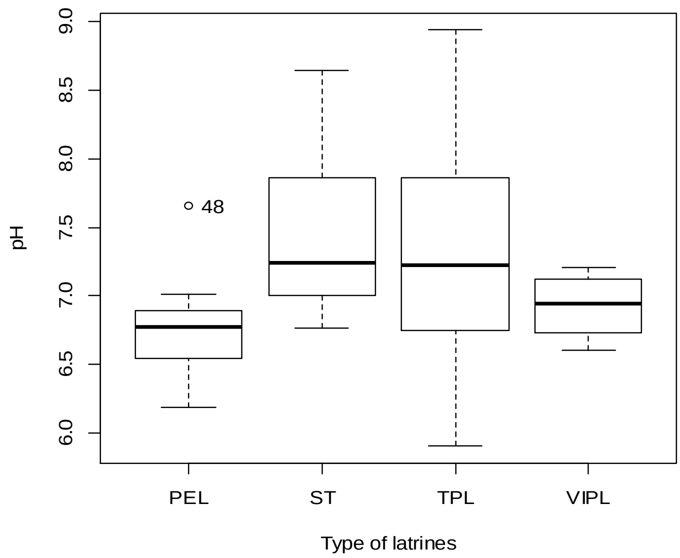


Fig. 45. Box plot showing the variation of the pH in faecal sludge samples in relation to the type of latrines (PEL: piped equipped latrine; ST: septic tank; TPL: traditional pit latrine; VIP: ventilated improved pit latrine).

The variability of pH between samples could depend on the variation of environmental conditions (temperature, humidity, availability of oxygen), the type and the rate of biological processes occurring in FS storage technologies. The variability of faecal sludge pH was also recorded by several authors (Ingallinella et *al*., 2002; Cofie et *al*., 2006; Kengne et *al*., 2008). Strande et *al*. (2014) describe the pH as an essential parameter for the understanding of FS chemistry processes such as acid-base chemistry and biological processes. In addition, Maya et *al*. (2012) mentioned that the optimal pH for biological activities to be ranged between 6.5 and 8 as anaerobic microorganisms, especially methanogens exhibit a characteristic sensitivity to the extreme pH.

III.3.1.2. Variation of the electrical conductivity

The distribution of electrical conductivity in samples vary widely. In general, the samples from septic tanks (ST) were less concentrated with regards to those issuing from traditional pit latrines, ventilated improved pit latrines and piped equipped latrines. The distribution of median values in relation to the types of latrines were 4.40 mS/cm, 2.89 mS/cm, 4.35 mS/cm, 5.67 mS/cm respectively for traditional pit latrines, septic tanks, ventilated improved pit latrines and piped equipped latrines (Fig. 46).

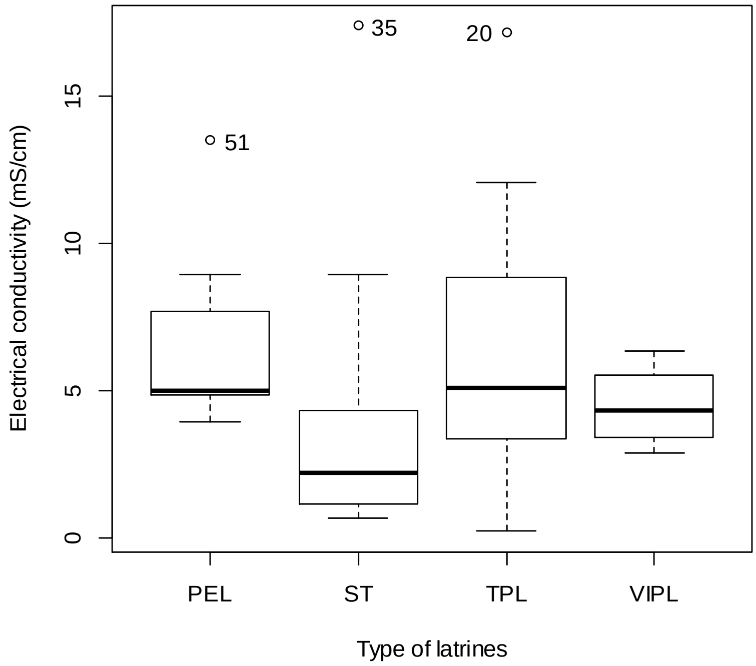


Fig. 46. Box plot showing the variation of electrical conductivity in faecal sludge samples in relation to the types of latrines (PEL: piped equipped latrine; ST: septic tank; TPL: traditional pit latrine; VIP: ventilated improved pit latrine).

Assessment of the variation of the electrical conductivity values between the type of latrines using the one-way ANOVA test (α=0.05) revealed that there was no significant difference (p=0.342). The lower values of EC recorded for samples from septic tanks could be explained by the high mineralization of faecal matters that may occur in septic tank systems (Montangero and Belevi. 2007). Thus, the septic tank systems could be more favourable for the better stabilization/mineralization of FS during storage and stabilization depending on the pH which is slightly basic with septic tank systems thereby favourable for microorganism activities.

III.3.1.3. Variation of COD and BOD_5

The distribution of organic matter contents represented by COD and BOD_5 vary within the samples of the same group and between the groups of latrines. The samples were characterized by very high COD content with respective median values of 34 g O_2/L, 6.51 g O_2/L, 70.38 gO_2/L, and 31.81 gO_2/L respectively for the samples from traditional pit latrines, septic tanks, ventilated improved pit latrines and piped equipped latrines (Fig. 47). In general, the samples from traditional pit latrines and those of ventilated pit latrines exhibited very high concentration of COD. Assessment of the variation of the COD values between the type of latrines using the one-way ANOVA test (α=0.05) revealed that there was a significant difference (p<0.04).

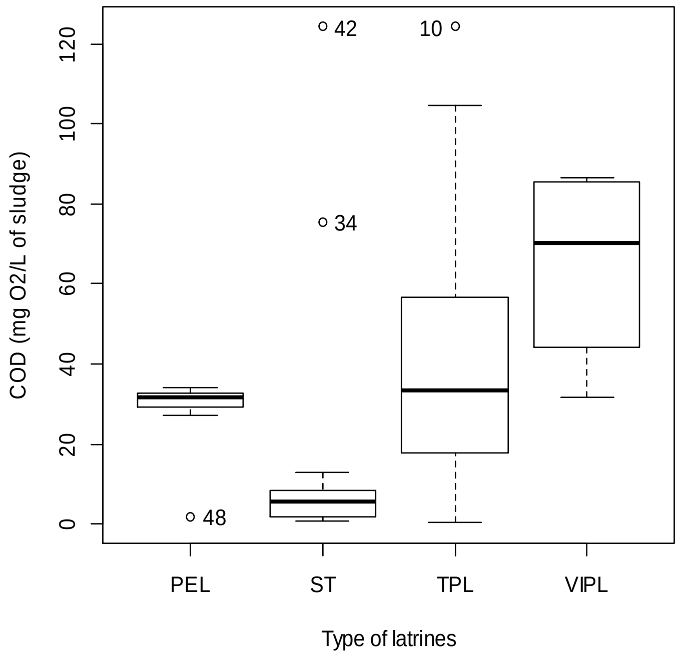


Fig. 47. Box plot showing the variation of COD in faecal sludge samples in relation to of the types of latrines (PEL: piped equipped latrine; ST: septic tank; TPL: traditional pit latrine; VIP: ventilated improved pit latrine).

In comparison to the concentration of COD in samples, the BOD_5 values were very low with the median distributed of 3.20 g/L, 1.53 g/L, 6.50 g/L, and 3.40 g/L respectively for the samples of piped equipped latrines, septic tank, traditional latrine, ventilated improved pit latrine (Fig. 48).

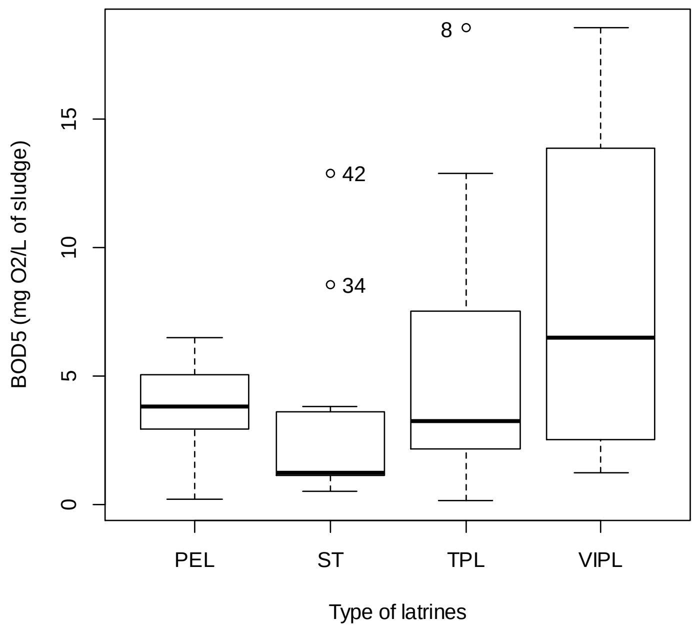


Fig. 48. Box plot showing the variation of BOD_5 in faecal sludge samples in relation to the types of latrines (PEL: piped equipped latrine; ST: septic tank; TPL: traditional pit latrine; VIP: ventilated improved pit latrine).

In addition, the median values of COD/BOD_5 mass ratio have varied between 1.15 and 70.08 in FS samples. Thus, the COD/BOD_5 mass ratio greater than 3 was observed and distributed as 7.54, 7.89, and 8.88 respectively for the samples from traditional pit latrines, ventilated improved pit latrines and piped equipped latrines. Assessment of the variation of the BOD_5 values between the type of latrines using the one-way ANOVA test (α=0.05) revealed that there was no significant difference (p=0.192). The lower COD/BOD_5 mass ratio (2.87) was recorded in samples from septic tanks. The low COD/BOD_5 mass ratio <3 recorded in samples from septic tanks could explain the high bio degradability of faecal sludge in these systems. COD/BOD_5 mass ratio >3 could be the result of the poor activities of microorganisms involved in the mineralization process in faecal sludge matrix into the pit of sanitation technologies (Bassan et *al.*, 2013). The low microbial biodegradability could also depend to the modes of latrine usage. Indeed, Still et *al.* (2012) mentioned the negative effects of disinfectants containing sodium hypochlorite added by people into the latrine pits to reduce odours. The authors pointed out the effects of disinfectants in the inhibition of the metabolism of heterotrophic bacteria activities in faecal sludge degradation. In addition, many of the latrines investigated in this study, particularly traditional pit latrines contained household solid waste refuses (anal cleansing material, plastic wastes, menstrual hygiene material …) that could negatively affect the biodegradability of faecal sludge by reducing the surface contact between microorganisms and faeces. In a similar observation, Bakare et *al.* (2012) working on the variation of VIP latrine sludge contents also found the quality of faecal sludge to be dependent on the household habits combined with local environmental conditions.

III.3.1.4. Variation of the TKN and NH_4^+

The variation of TKN and NH_4^+ parameters followed similar patterns like the above described parameters. The median values recorded for TKN in relation to the latrine types were 0.96 g/L, 0.21 g/L, 1.69 g/L and 2.81 g/L respectively for samples from piped equipped latrines, septic tanks, traditional pit latrines and ventilated improved pit latrines (Fig. 49). Assessment of the variation of TKN values between the type of latrines using the one-way ANOVA test (α=0.05) revealed that there were significant differences (p<0.033). Looking at the variation of ammoniacal nitrogen, the median values recorded in relation to the latrine types were 0.33 g/L, 0.13 g/L, 0.21 g/L and 0.23 g/L respectively for the samples from piped equipped latrines, septic tanks, traditional pit latrines and ventilated improved pit latrines (Fig. 50). Assessment of the variation of NH_4^+ values between the type of latrines using the one-way ANOVA test (α=0.05) revealed that there were no significant differences (p=0.71).

In general, the septic tank samples exhibited a lower concentration of TKN and NH_4^+. This could be explained by the better mineralisation of the organic matters that takes place in septic tanks systems. Indeed, Fidjeland et *al.* (2013) demonstrated that nitrogen ammonia (NH_3) in faecal sludge is produced by deamination of organic nitrogen and hydrolysis of urea ($CO(NH_2)_2$) in urine by urease in faecal sludge storage systems.

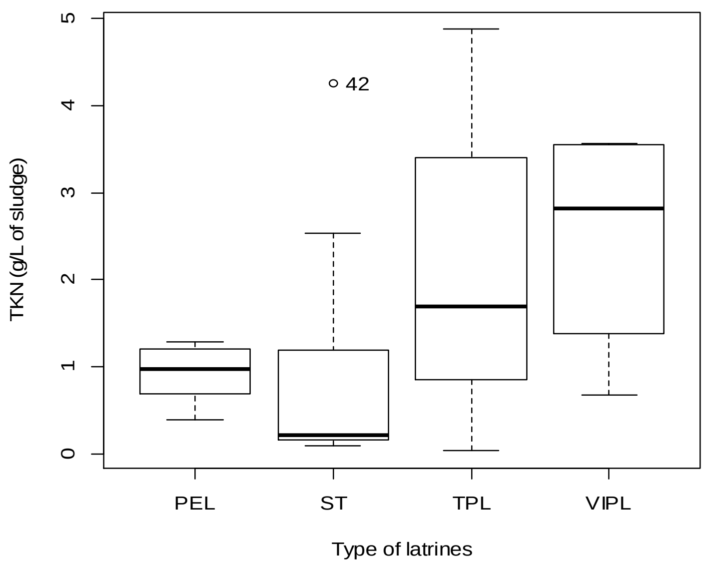


Fig. 49. Box plot showing the variation of the TKN in faecal sludge samples in relation to the type of latrines (PEL: piped equipped latrine; ST: septic tank; TPL: traditional pit latrine; VIP: ventilated improved pit latrine).

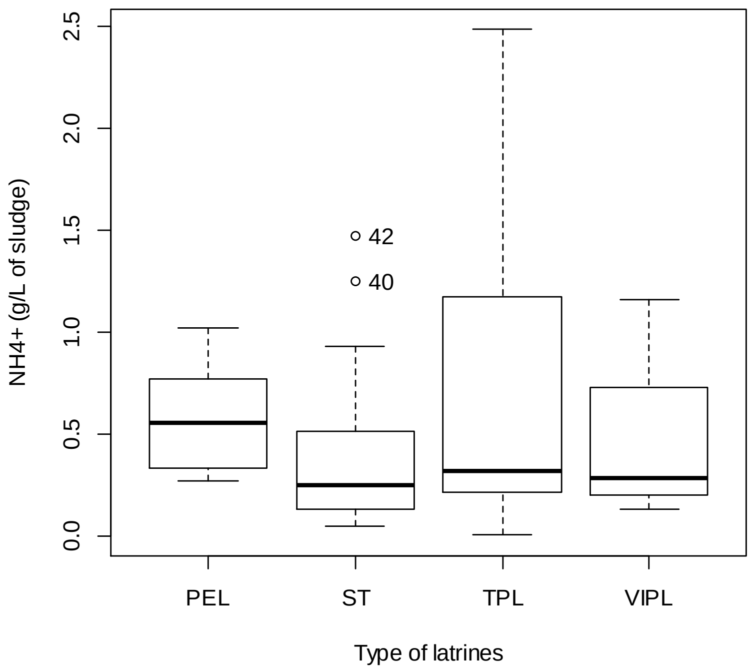


Fig. 50. Box plot showing the variation of the NH_4^+ in faecal sludge samples in relation to the type of latrines (PEL: piped equipped latrine; ST: septic tank; TPL: traditional pit latrine; VIP: ventilated improved pit latrine).

In addition, the majority of ammonia in raw faecal sludge comes from the urine (Jönsson et *al.*, 2005). According to the denitrification which is a biological reduction of nitrate (NO_3^-) and nitrite (NO_2^-) to gaseous N which was found to be the main cause of nitrogen loss in the on-site sanitation systems. Indeed, the on-site sanitation systems particularly traditional pit latrines and ventilated improve pit latrines are functioning as open systems because the gaseous N is released via the hole of the slab of these types of sanitation technologies.

III.3.1.5. Variation of dry matters and water content

Dry matters and water content in faecal sludge are widely varied between samples belonging to the same group of latrine and between samples of different groups. Looking at the dry matter contents, the median values recorded were 44.26 %, 37.89 %, 44.79 %, 47.20 % respectively for samples from piped equipped latrines, septic tanks, traditional pit latrines and ventilated improved pit latrines (Fig. 51). Assessment of the variation between the groups of latrines using the one-way ANOVA test (α=0.05) revealed that there was a strong significant difference (p<0.00043) with the samples from septic tank systems.

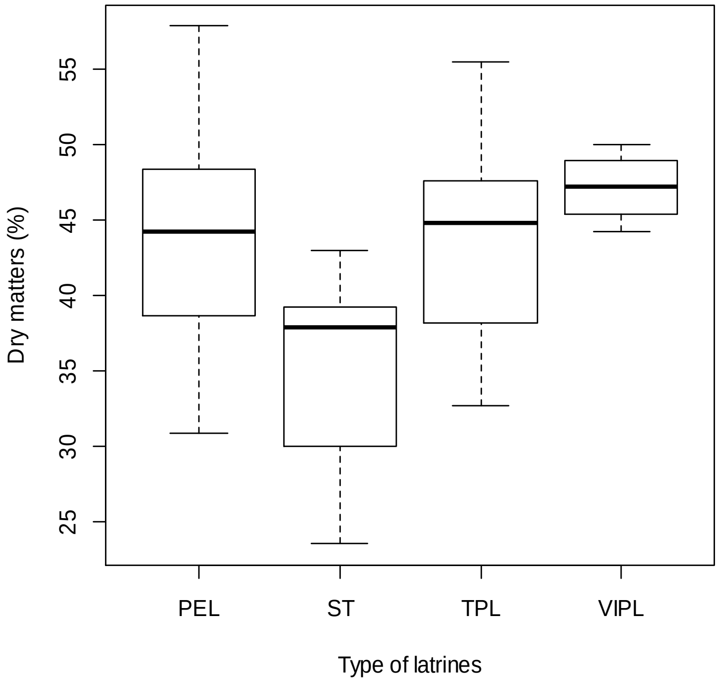


Fig. 51. Box plot showing the variation of the dry matters content in faecal sludge samples in relation the type of latrines (PEL: piped equipped latrine; ST: septic tank; TPL: traditional pit latrine; VIP: ventilated improved pit latrine).

The heterogeneity in the distribution of dry matters in samples can be explained by the difference in the modes of latrine usage, the septic tanks and piped equipped latrines operates as wet systems and requires time to time water for flushing urine and faecal matters into the pit thereby contributing to the dilution of the concentration of faecal sludge total solids recorded in these systems. The concentration of dry matters in the faecal sludge samples was found to be inversely proportional to the water content. The distribution of median values recorded for water content were 55.73 %, 62.10 %, 55.20 % and 52.79 % respectively for samples from piped equipped latrines, septic tanks, traditional pit latrines and ventilated improved pit latrines. The variability of FS moisture content was observed by Radford and Sugden (2014) working on the experimental characterization and fluidization of synthetic pit latrines sludge and Bakare et *al*. (2015) working of the characterisation of VIP latrine sludge content in South African Republic.

III.3.1.6. Assessment of the correlations between some physico-chemical parameters of samples

Analysis of the relationship between the parameters taking into consideration the 53 samples and the type of latrines using the Pearson correlation test (at 95 % of confidence level) revealed that there was a significant positive correlation between some physico-chemical parameters analysed. The correlation factors recorded were 0.618, 0.203, 0.516, 0.516, 0.782, 0.737 respectively for the relation between BOD_5 and COD, BOD_5 and NH_4^+, BOD_5 and TKN, COD and NH_4^+, COD and TKN, NH_4^+ and TKN (Fig. 52).

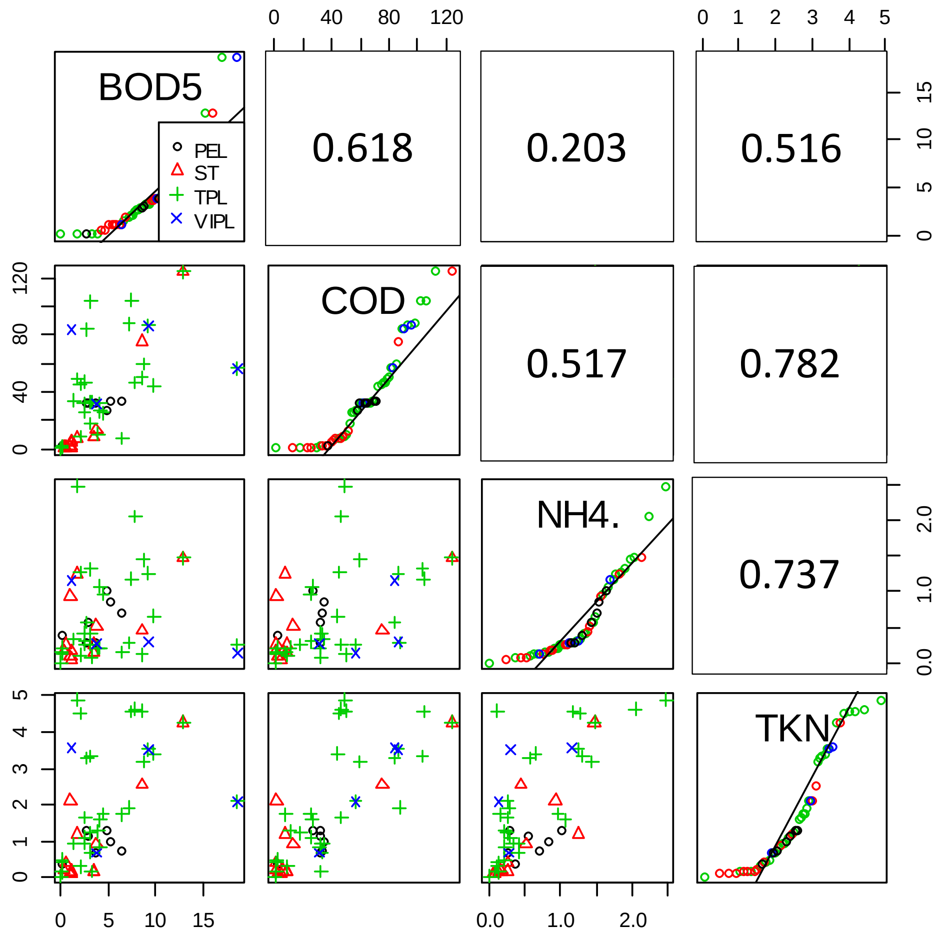


Fig. 52. Cross correlation matrix (Pearson test, 95 % confidence level) showing relationship between BOD_5, COD, NH_4^+ and TKN of faecal sludge samples (PEL: piped equipped latrines; ST: septic tank; TL: traditional pit latrine; VIP: ventilated improved pit latrine) (n=53).

III.3.1.7. Physico-chemical composition of faecal sludge recorded in this study in comparison to literature data

The comparison between the physico-chemical parameters of the sludge sampled (median values considered) and the results of the literature was done (Table XII). In general, apart from the dry matters concentration, the findings of this study corroborate to those obtained by Kengne et *al.* (2008) who characterized 44 sludge samples provided by vacuum trucks in an experimental faecal sludge treatment plant of Yaounde (Cameroon). Except for parameters COD and BOD_5 which were found to be lower, similar observations were made by Berteigne (2012) who assessed the quantification and characterization of faecal sludge in the two big cities of Cameroon, Yaounde and Douala. In general the quality of faecal sludge obtained by the author were lower due to the dilution effect, as the amount of water enter the on-site sanitation technologies due to the intrusion of groundwater. In fact, the author has made the characterisation of faecal sludge during rainy season in comparison to this study were the investigations were made during dry season. In addition, the FS sampled in this study ranged from 'low strength' (samples from septic tanks) to 'high strength' (samples from traditional latrines, ventilated improved pit latrines and piped equipped latrines) with regards to the classification of Heinss et *al*. (1998). The values of COD and BOD_5 recorded by Bassan et *al.* (2013) who characterised FS produced in Ouagadougou (Burkina Faso) were lower than those obtained in this study (Table XIII). This difference may be due to the effect of the factors affecting the quality of faecal sludge in on-site sanitation technologies. Indeed the study of Strauss et *al.* (1997) revealed the quality of faecal sludge to be influence by several variables such as the storage duration, temperature, intrusion of groundwater, mixture with solid wastes and the tank emptying technology.

Table XIII. Comparison between the physico-chemical characteristics of sludge sampled during this study and the results of the literature.

Origin of faecal sludge		pH	EC (mS/cm)	COD (g O_2/L)	BOD_5 (g O_2/L)	NH_4^+ (g/L)	TKN (g/L)	DM (%)	Moisture content (%)
Traditional pit latrines (n=30)		7.24	4.83	34.00	3.20	0.33	1.73	44.79	55.20
Septic tanks (n=12)		7.24	2.21	5.80	1.2	0.25	0.21	37.89	62.10
Piped equipped latrines (n=7)		6.77	5.02	31.75	3.8	0.55	0.96	44.26	55.73
Ventilated improved pit latrines (n=4)		6.94	4.34	70.38	6.50	0.28	2.81	47.20	52.79
Literature data	Kengne et *al*. (2008)	6.55-9.34	2.10	30.50	-	0.40	0.90	2.90	-
	[a]Berteigne (2012)	8.29	1.30	2.01	0.64	0.08	0.14	31	69
	[b]Berteigne (2012)	7.84	3.47	5.22	2.34	0.52	1.04	54.97	45.02
	*Heinss et *al*. (1998)	-	-	<10	7.6	1	-	<3	-
	**Heinss et *al*. (1998)	-	-	20-50	-	2-5	-	≥ 3.5	-
	Bassan et *al*. (2013)			12.44	2.13	-	-	-	-
	Bakare et *al*. (2012)	-	-	-	-	-	-	-	60 %

(*low strength faecal sludge; **High strength faecal sludge; [a&b]Faecal sludge characteristics obtained in Yaounde and Douala (Cameroon))

The obtained concentrations of moisture content in samples were in accordance to the results obtained by Bakare et *al*. (2012). These authors revealed the sludge variation from on-site sanitation systems to be attributed to household habits and local environmental conditions. Differences observed between the concentration of DM recorded in this study and the results of Kengne et *al*. (2008) could be explained by the fact that faecal sludge collected directly from on-site sanitation systems (the case of this study) didn't have the same quality with faecal sludge being discharged at experimental treatment plants, because water is frequently added into the pit to dilute faecal sludge during mechanical emptying.

III.3.2. Heavy metals content in sludge samples

In general, the measured concentration of heavy metals in samples were variable within the same group of latrines and between the groups of latrines. The median concentration of cadmium and lead in samples were 0.20 mg/L, 0.1 mg/L, 0.25 mg/L, 0.14 mg/L and 0.41 mg/L, 0.08 mg/L, 0.84 mg/L, 0.30 mg/L respectively for faecal sludge from traditional pit latrines, septic tanks, ventilated improved pit latrines and piped equipped latrines (Fig. 53). The higher concentration of cadmium was recorded in samples from ventilated improved pit latrines. The one-way ANOVA test (α=0.05) revealed a strong significant difference ($p< 0.00517$) in the distribution of lead between the type of latrines. Looking the distribution of copper and zinc in samples, the values recorded were in the order of 1.65 mg/L, 0.59 mg/L, 1.29 mg/L and 5.78 mg/L, 1.7 mg/L, 3 mg/L and 4.9 mg/L respectively for faecal sludge from traditional pit latrines, septic tanks, ventilated improved pit latrines and piped equipped latrines. There was no significant difference in the distribution of copper and zinc in samples. The one-way ANOVA test (α=0.05) revealed a strong significant difference ($p< 0.00413$) in the distribution of zinc between the type of latrines.

The distribution of the median values of iron and manganese in sludge samples were 7.50 mg/L, 1.37 mg/L, 11.00 mg/L, 7.50 mg/L for iron, 16.75 mg/L, 6.5 mg/L, 22.75 mg/L, 11.50 mg/L and 0.165 mg/L, 0.16 mg/L, 0.29 mg/L, 0.165 mg/L for chromium respectively for sludge from traditional pit latrines, septic tanks, ventilated improved pit latrines and piped equipped latrines (Fig. 57). The one-way ANOVA test (α=0.05) revealed a strong significant difference ($p< 0.000648$) in the distribution of iron between the type of latrines. In general, the samples from septic tanks exhibited low concentration of heavy metal parameters in comparison with other types of latrines sampled in this study. This could result from the higher dilution process that may occur in septic tanks as they required water when functioning.

The presence of heavy metal concentrations in faecal sludge was elucidated by several authors (Bassan et *al.,* 2013; Appiah-Effah et *al*., 2015; Zhao et *al*., 2012). The prevalence of cadmium and lead in faecal sludge could be a result of the disposal of unapproved materials such as lead acid batteries, rubber and plastics which are disposed into toilet pits. Indeed, many studies carried out in the field of faecal sludge characterisation in the sub-Saharan Africa region revealed the use of on-site sanitation systems for the disposal of solid wastes (Bakare et *al*., 2012; Appiah-Effah et *al*., 2015). Additionally, the presence of lead in sludge may also be due to leachate from the dump sites usually located close to toilets, where used motor oils and discarded electronic gadgets including televisions, calculators and stereos are disposed.

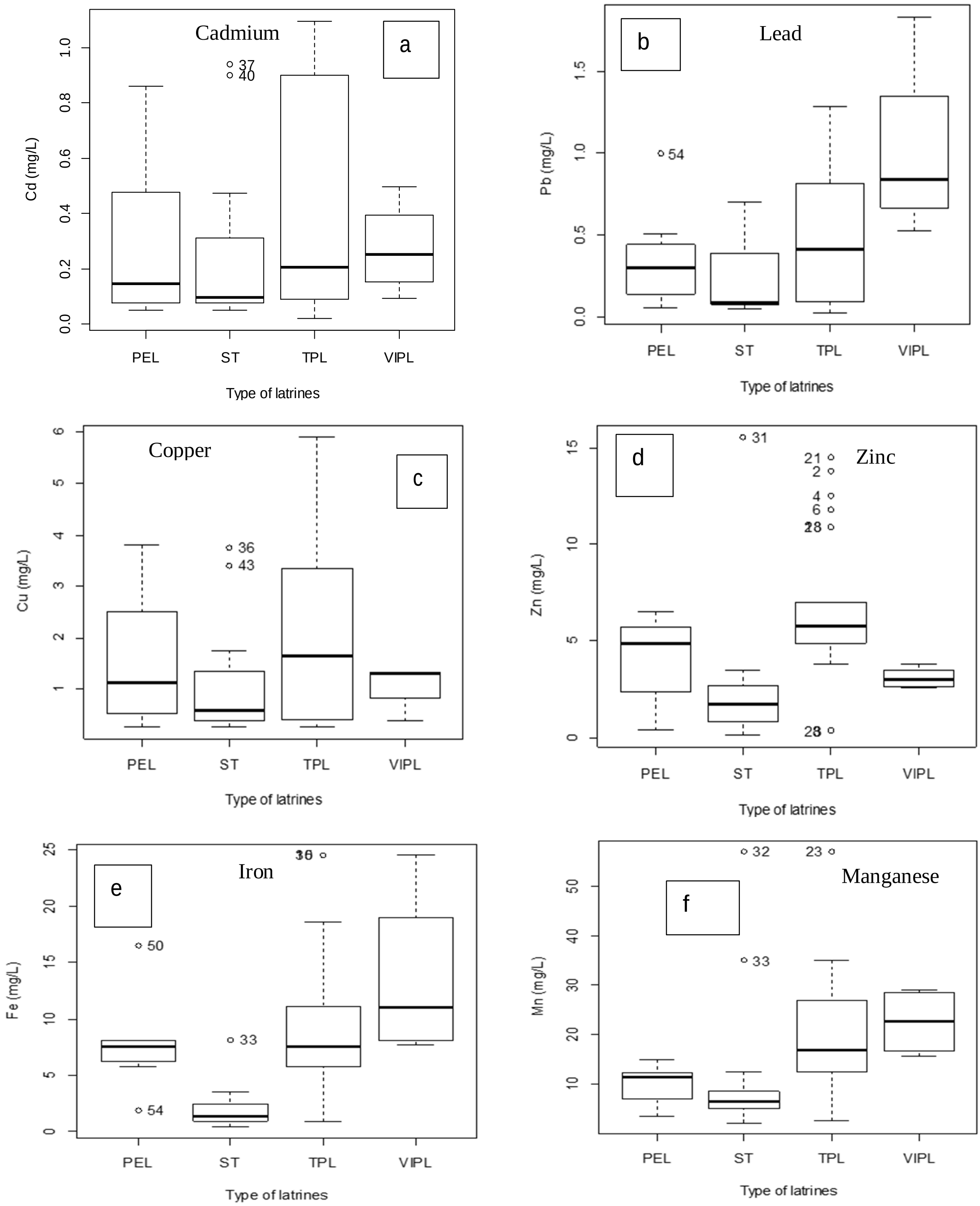


Fig. 53. Variation of heavy metal concentrations in sludge samples (a: Cd; b: Pb; c: Cu; d: Zn; e: Fe; f: Mn) (PEL: piped equipped latrine; ST: septic tank; TL: traditional pit latrine; VIP: ventilated improved pit latrine).

The higher concentration of zinc was found in samples from traditional pit latrines with the values of 6.56 mg/L. The presence of zinc in faecal sludge may be due to leaching of zinc residue contained in wastes from deodorants and cosmetics disposed into latrine pits. The concentration of iron in sludge could be a result of infiltration as rainfall leaches through the soil and dissolves ion in the earth's surface and carries it into the pits. In addition, the feral soil of the study area may affect the concentration of the total iron found in samples.

The comparison of heavy metal concentrations recorded in this study with the literature data is shown in the Table XIV below. In general, the concentrations of lead obtained in this study (mean values of 0.40 mg/L) was lower than those obtained by Bassan et *al.* (2013) (1.37 mg/L) and higher than the results of Appiah-Effah et *al.* (2015) (0.16 mg/L). Considering the concentration of copper, the faecal sludge samples from Ghana (Appiah-Effah et *al.*, 2015) were more concentrated than those of Ouagadougou (Bassan et *al.*, 2013) as well as the faecal sludge sampled in this study. The faecal sludge sampled were less concentrated than those of Ouagadougou with regards to the concentration of zinc and iron. The concentration values of cadmium, copper, zinc, manganese and chromium recorded in samples from each type of latrines were above the concentration limits prescribed by Ayers and Westcot (1985) for the irrigation of water bodies. Thus, the increasing discharge of untreated faecal sludge into the environment as observed in Yaounde could constitute sanitary and environmental risks due to the contamination of water resources and the accumulation of heavy metals into the environment.

Table XIV. Variation of heavy metal concentration in sludge samples in comparison to the literature data. (PEL: piped equipped latrine; ST: septic tank; TL: traditional pit latrine; VIP: ventilated improved pit latrine).

Type of latrine	TPL	ST	VIPL	PEL	Bassan et *al.* (2013)	Appiah-Effah et *al.* (2015)	Water quality for irrigational water (Ayers and Westcot, 1985)
Cd (mg/L)	0.40	0.28	0.27	0.30	-	0.045	0.01
Pb (mg/L)	0.47	0.24	1.01	0.36	0.85	0.16	-
Cu (mg/L)	1.99	1.20	1.07	1.60	1.5	3.978	0.2
Zn (mg/L)	6.56	2.59	3.08	3.99	9.05	-	2
Fe (mg/L)	8.83	2.02	13.54	7.79	88	2.492	-
Mn (mg/L)	19.22	12.23	22.55	9.81	-	4.571	0.2
Cr (mg/L)	0.28	0.22	0.30	0.35	-	-	0.1

III.4. Variability of raw faecal sludge

III.4.1. Physico-chemical variability

PCA was applied to the physico-chemical quality data of FS to compare the compositional pattern of the analysed samples and to identify factors that influence each of the samples. As expressed by the PCA, FS of Yaounde were highly influenced by its solids fraction, nutrients and its organic contents (Fig. 54). The data set was brought out into three principal components (PCs) with eigenvalues >1 explaining about 78 % of the total variance. The first component accounted for 49.44 % of the total variance was positively correlated (factor loading > 0.50) with COD (0.812), BOD_5 (0.589), NH_4^+ (0.731), DM (0.870), water content (0.870), TKN (0.866) and the second component accounted for 15.86 % of the total variance was positively correlated only with the pH (0.830). The third, fourth and fifth components accounted for the total variance of 13.32 %. 9.41 % and 6.52 %.

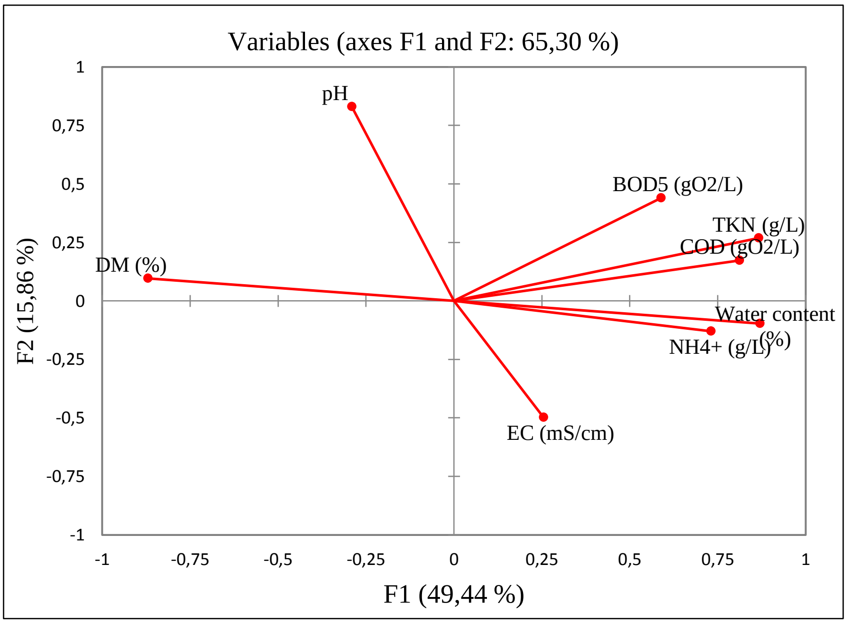


Fig. 54. Representation of factor loadings for the PCA of physico-chemical parameters analysed.

The main results of the HCA performed using the Ward's method divided sludge samples into four clusters and the variance decomposition for the optimal classification within cluster was 136.75 and 1107.08 between the different clusters. The characteristics of each cluster for the eight analysed FS parameters used in the HCA are described (Table XV). Analyses of the variance between clusters showed significant variations for the cluster 1. The samples belongings to cluster 2, cluster 3 and cluster 4 are closed together due to the low distance between their class centroids while the cluster 1 is linked to them with an elevated distance between class centroids (Fig. 55). It can be concluded that the clusters with lower distance between centroid classes are expected to contain FS of similar composition according to the physicochemical parameters analysed.

Table XV. Analysis of variance between clusters.

Cluster	DF	Sum of squares	Mean squares	R^2	F	Pr > F	F-ratio	Pr > F
Cluster 1	5	6.804	1.361	0.972	13.885	0.069	20.125	**0.048**
Cluster 2	2	2.366	1.183	0.338	1.276	0.357		
Cluster 3	2	1.510	0.755	0.216	0.688	0.545		
Cluster 4	2	1.675	0.838	0.239	0.787	0.505		

(DF: degrees of freedom; F: *Fisher*-statistic; Pr: probability value; bold values expressed significant differences)

The outcome of this study indicates the high dissimilarity observed between samples originating from the traditional pit latrines. A simplified approach of FS classification based on the on-site sanitation sources have been proposed by Heinss et *al.* (1998). The authors divided FS into two classes, the low strength faecal sludge which are most stabilized (septage) and the high strength faecal sludge highly concentrate coming from public toilets and bucket latrines. However, this classification of Heinss et *al.* (1998) may be limited in the case where the classification is considering only the origin of samples as well as the variability of FS quality that may occur in samples from a same device. The classification should also take into consideration the whole FS quality data independent of the sample origins. Assessment of the physco-chemical variability of faecal sludge samples using PCA was also performed by Kengne et *al*. (2008) working on the characterization of FS discharge by mechanical trucks at the treatment station. The author mentioned the FS to be influenced by their solids and organic fraction with first component strongly affected by solid contents and the second component by the organic and nutrient contents.

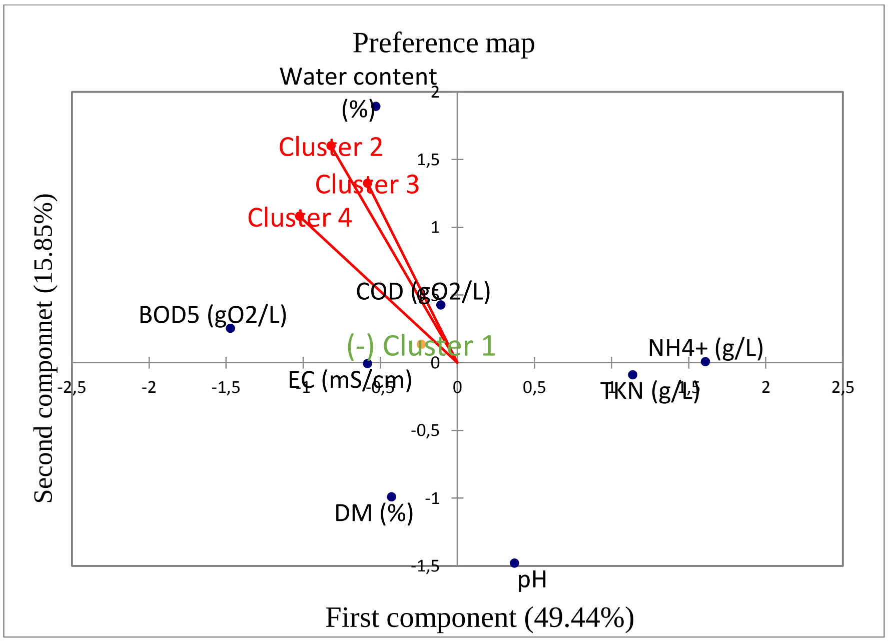


Fig. 55. Preference map showing the distribution of scores and loadings of the first two components of the principal component analysis indicating the relationship between the physico-chemical parameters of the faecal sludge sampled as well as the 4 clusters of faecal sludge.

Table XVI. Preference scores (from 0 to 1) showing the correlation between the obtained clusters and physico-chemical parameters of the 30 faecal sludge samples from traditional pit latrines analysed.

Objects	Cluster 1	Cluster 2	Cluster 3	Cluster 4
pH	0.290	0.000	0.000	0.000
EC (mS/cm)	0.230	0.512*	0.502*	0.562*
COD (gO_2/L)	0.236	0.561*	0.561*	0.558*
BOD_5 (gO_2/L)	0.133	0.699*	0.675*	0.824*
NH_4^+ (g/L)	0.200	0.222	0.250	0.074
DM (%)	0.984*	0.234	0.223	0.295
TKN (g/L)	0.000	0.260	0.280	0.157
Water content (%)	1.000*	1.000*	1.000*	1.000*

(*significant scores > 0.50)

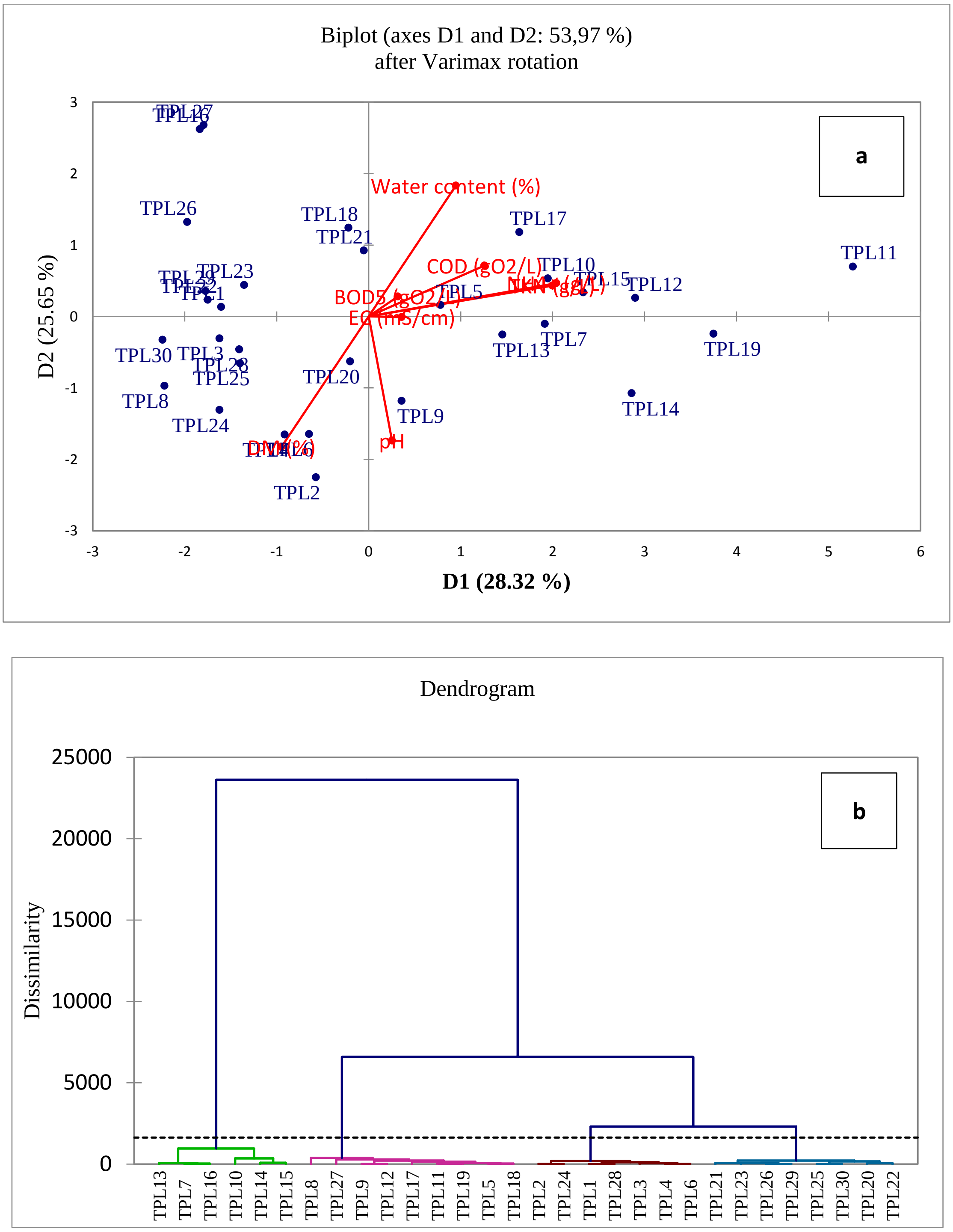


Fig. 56. Summarize graphs of the biplot physico-chemical parameters after Varimax rotation (a) and dendrogram (b) for the physico-chemical parameters.

III.4.2. Hygienic variability

The variability of samples was analysed considering the prevalence and diversity of helminth eggs. PCA of the data set brought out four principal components (PCs) with eigenvalues > 1 explaining about 72.26 % of the total variance in the hygienic quality of the faecal sludge. The first component accounting for 26.40 % of the total variance was positively correlated (factor loading >

0.50) with *Ascaris lumbricoides* (0.564), *Hymenolepis nana* (0.558), *Trichuris trichiura* (0.736), *Schistosoma mansoni* (0.538), *Enterobius vermicularis* (0.613) and the total helminth eggs (0.757) and the second component accounted for 19.17 % of the total variance was positively correlated only with *Ascaris lumbricoides* (0.539) and *Ankylostoma duodenale* (0771) (Fig. 57). The third and fourth components accounted for the total variance of 17.81 % and 11.30 %. The HCA of the helminth egg parameters performed using the Ward's method divided the total samples into three clusters and the variance decomposition for the optimal classification within cluster was 1989.195 and 5113.72 between the different clusters (Fig. 58). However, there was no significant difference between the obtained clusters.

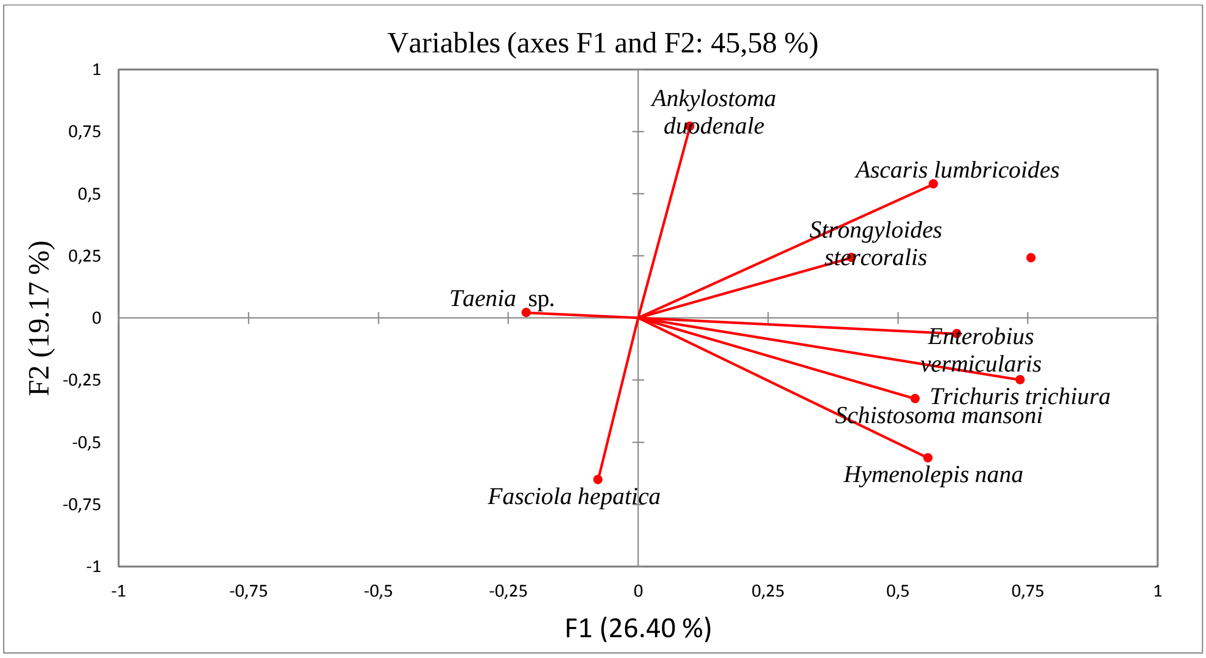
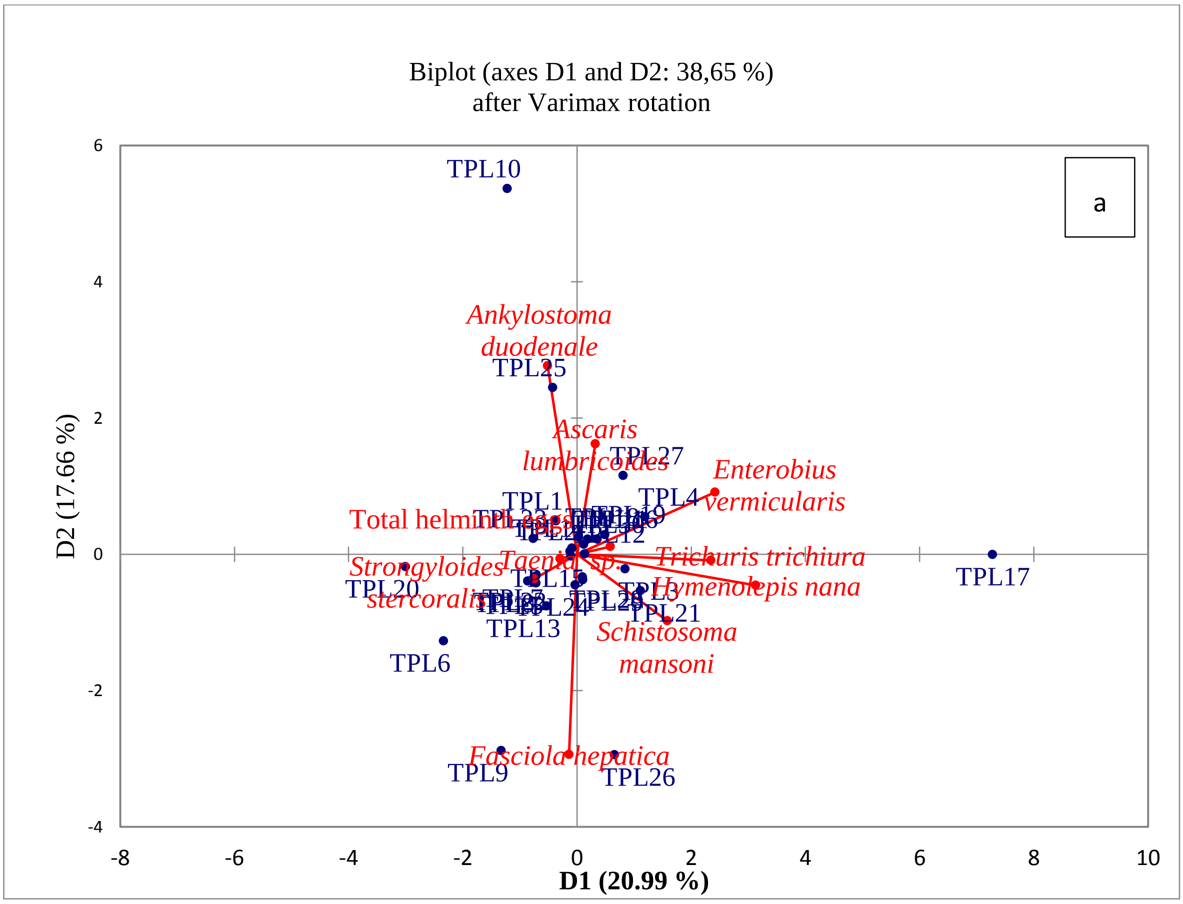


Fig. 57. Representation of factor loadings for the PCA of helminth egg paramaters.



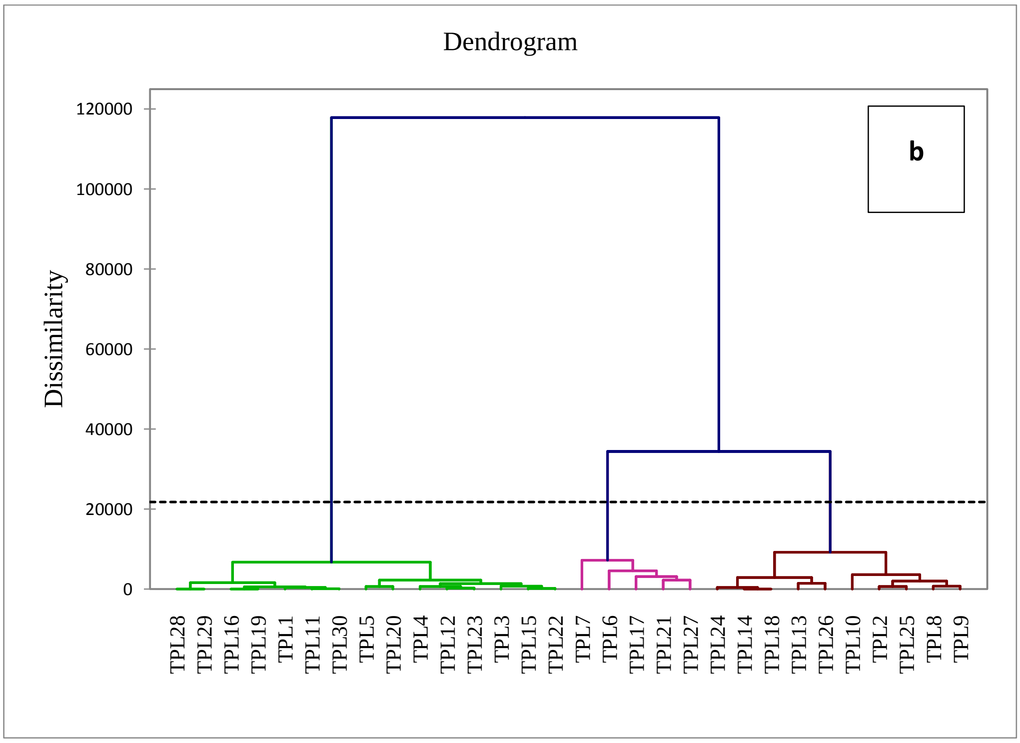


Fig. 58. Summarized graphs for the biplot, showing the distribution of scores and factors for helminth egg parameters after varimax rotation (a) and the dendrogram (b).

III.4.3. Heavy metal content variability

The PCA of the heavy metal quality of the faecal sludge data set brought out four principal components (PCs) with eigenvalues > 1 explaining about 47.89% of the total variance. The first component accounting for 29.05 % of the total variance was positively correlated (factor loading > 0.50) with the parameters Cu (0.55), Mn (0.72), Cr (0.67) and the second component accounting for 18.84 % of variability was positively correlated with Cd (0.82) (Fig. 59). The first component and the second component are negatively correlated with the parameter Zn (Fig. 59).The third and fourth components accounted for the total variance of 18.02 % and 13.12 % and strongly correlated with the parameters Pb (0.68), Cu (0.56) and Fe (0.66) respectively. Assessment of the heavy metal quality of the faecal sludge samples using the HCA and the Ward's method divided the total samples into three clusters without a significant difference between them. The Fig. 60 below summarizes the graphs for the principal component analysis and hierarchical clustering for the heavy metal parameters.

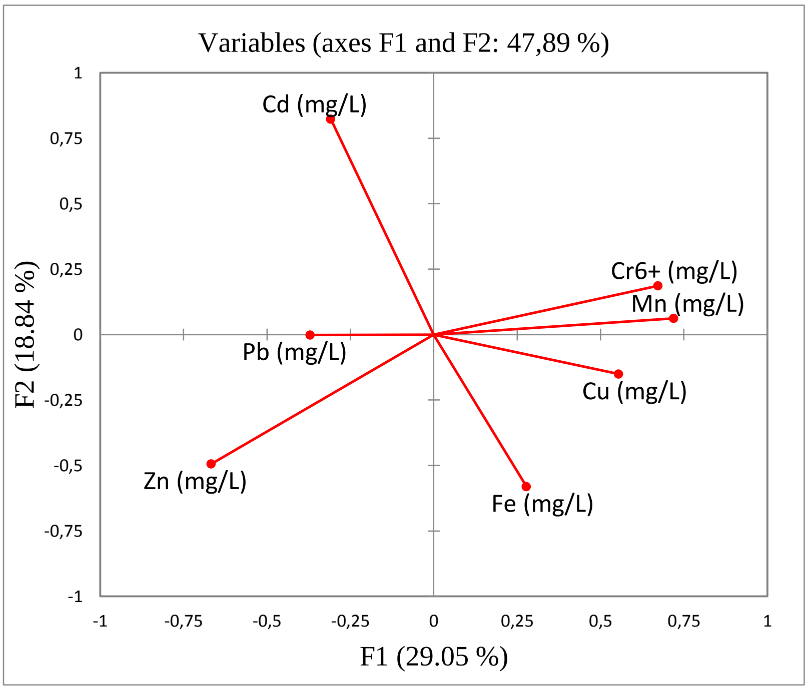


Fig. 59. Representation of factor loadings for heavy metal parameters in the faecal sludge samples.

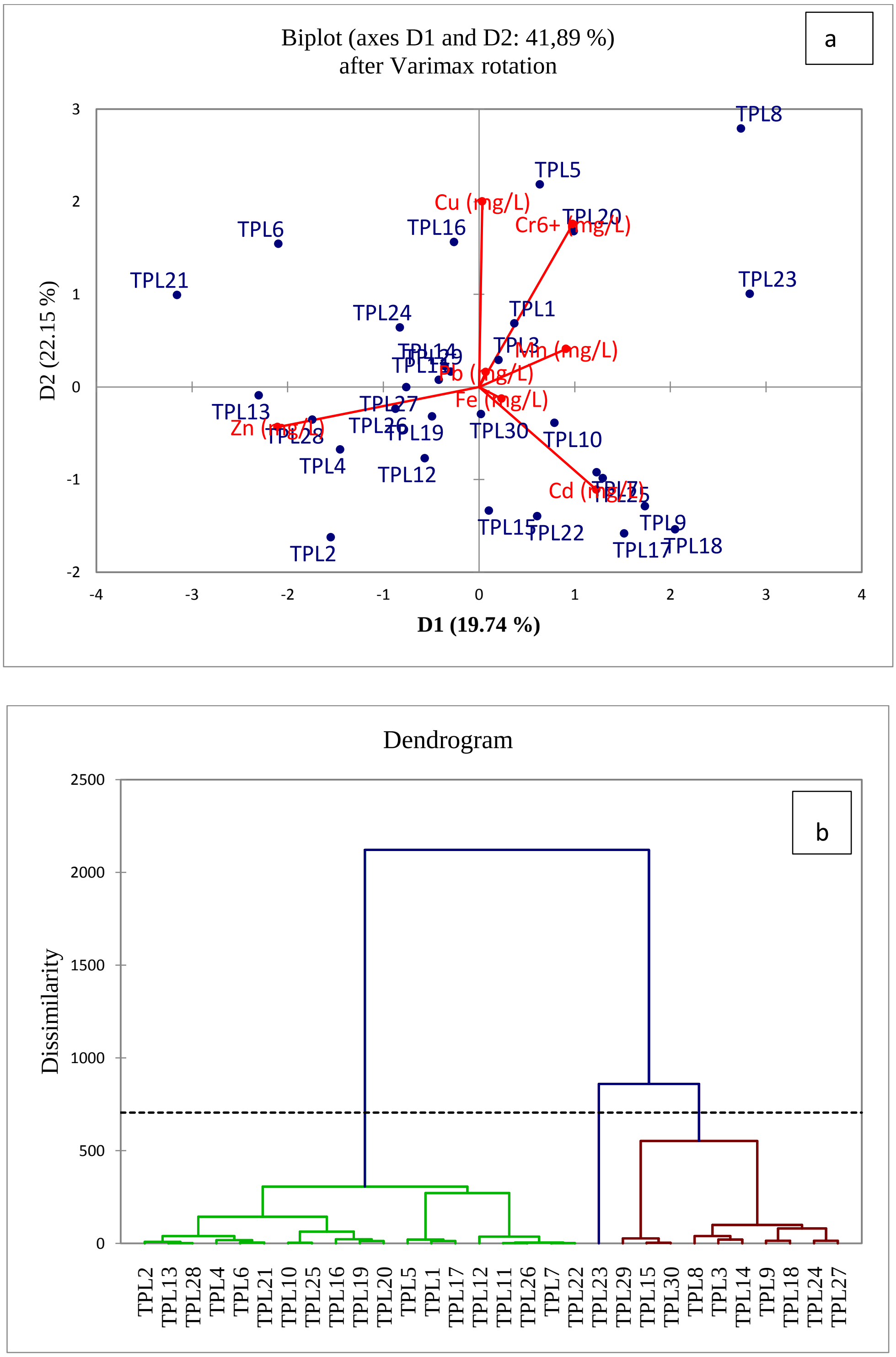


Fig. 60. Summarized graphs of the biplot showing the distribution of scores and factors for heavy metal parameters after Varimax rotation (a) and the dendrogram (b).

III.5. Effects of retention times and plant densities on the removal of helminth eggs by planted drying beds

III.5.1. Quality of faecal sludge applied on the beds

III.5.1.1. Physico-chemical characteristics

The physico-chemical composition of the incoming faecal sludge are reported in the Table XVII. The faecal sludge originating from septic tanks, public latrines, and traditional pit latrines shows a very high variation between the various campaigns. The recorded median concentrations were in the order of 10.30 %, 0.25 g/L and 7.89 respectively for the dry matters (DM), ammoniacal nitrogen (NH_4^+) and pH.

Table XVII. Characteristics of untreated faecal sludge applied to planted drying beds (n=16).

Campaigns	DM (%)	NH_4^+(g/L)	pH
1	1.03	0.12	7.24
2	0.77	0.21	8.48
3	21.11	0.10	7.85
4	10.72	0.14	8.36
5	1.36	0.16	8.65
6	10.70	0.11	8.73
7	32.40	0.21	8.47
8	25.51	1.25	7.86
9	9.91	0.25	7.94
10	2.47	0.25	8.94
11	10.82	1.47	6.8
12	8.80	1.48	6.75
13	10.89	1.26	7.05
14	12.95	0.56	7.92
15	6.33	1.31	7.71
16	2.69	1.17	7.23

(DM: Dry matters; NH_4^+: Ammoniacal nitrogen)

The disparity observed in the physico-chemical quality of sludge could be explained by the origins of the faecal sludge samples. Generally, the faecal sludge sampled in this part of the study were found to be of lower concentrations according to the parameters tested as compared to the manually direct sampling in the on-site sanitation systems. These differences could be explained by the dilution factor. Indeed, a given quantity of water is added in faecal sludge during emptying by mechanical emptiers. According to Strauss et *al*. (1997), the variability of faecal sludge is a consequence of several factors, such as the duration of storage, the intrusion of ground water, and climate. The work carried out by Bassan et *al*. (2013) and Kengne et *al*. (2008) mentioned the influence of the emptying modes as factors responsible for the quality of faecal sludge. For Koné and Strauss (2004), working on faecal sludge treatment options in developing countries and Letah

Nzouebet et *al*. (unpublished paper), have shown that the faecal sludge from traditional pit latrines are very concentrated compared to those from septic tanks.

III.5.1.2. Hygienic quality of faecal sludge

The pathogen analysis of the faecal sludge applied on the beds revealed the presence of high parasitic loads (Table XVIII). Indeed, an average total median number of 62.51 helminth eggs/g of DM were obtained. Among these totals, seven main species of helminth eggs were identified. These species included *Ascaris lumbricoides, Enterobius vermicularis, Strongyloides stercolaris, Trichuris trichiura, Schistosoma mansoni, Hymenolepis nana* and *Fasciola hepatica* with respective concentrations of 28.95 eggs/g of DM, 18.06 eggs/g of DM, 22.68 eggs/g of DM, 16.18 eggs/g of DM, 9.96 eggs/g of DM, 9.59 eggs/g of DM and 35.88 eggs/g of DM.

Table XVIII. Diversity of helminth eggs found in samples (eggs/g of DM) (n=16).

Helminth egg species	n	Mean	Sd	Min	Max	Median
Ascaris lumbricoides	11	31.69	16.91	1.94	62.68	28.95
Enterobius vermicularis	7	19.48	12.48	7.17	38.78	18.06
Fasciola hepatica	6	28.03	16.85	2.81	37.56	35.88
Hymenolepis nana	9	10.09	3.42	6.62	14.56	9.59
Schistosoma mansoni	1	9.96	/	/	/	/
Strongyloides stercoralis	5	28.02	18.80	8.49	75.12	22.68
Trichuris trichiura	4	27.32	21.79	13.34	52.43	16.18
Total helminth eggs	16	66.54	43.29	9.96	143.54	62.51

(Sd: Standard deviation; Min: Minimum; Max: Maximum)

Nevertheless, the number of samples was statistically insufficient to represent the whole city. The total number of eggs comprised between the ranges of 9.96 to 143.54 eggs/g of DM generally found in faecal sludge produced in tropical regions (Heinss et *al*., 1998; Yen-Phi et *al*., 2010; Letah Nzouebet et *al*., 2016). The authors revealed that the helminthic infections are very common in most developing countries. In terms of helminth egg species abundance, the higher predominance of *Ascaris lumbricoides* eggs can be explained by their high resistance to environmental conditions (Pecson et *al*., 2007). As compare to the hygienic quality of faecal sludge obtained in other parts of this study which had as aim characterizing the faecal sludge of 53 samples directly collect from the on-site sanitation systems, the values recorded in this part of the study where generally lower. The lower values recorded in the concentration of helminth egg species may be due to the dilution process occurring during faecal sludge emptying by mechanical emptying services. Usually, a given amount of water added to the sanitation system and this practice may affect the quality of the faecal sludge received at the experimental treatment plant. However, the concentration of helminth egg species in faecal sludge obtained in this part of the study were found to be higher than the limit prescribed by WHO guidelines for reuse in agriculture (<1 egg/g of DM).

III.5.2. Pearson Chi Square correlation test between the analyzed faecal sludge parameters

In order to understand the effects of faecal sludge pathogens variability, the correlation between the physico-chemical parameters and the helminth eggs were analyzed (Fig. 61). The Fig. 65 shows the positive correlation between the dry matters and the total helminth eggs (R^2=0.36), between the pH and the total helminth eggs (R^2=0.34). However, the correlation was not observed between the ammoniacal nitrogen (NH_4^+) and the total helminth eggs (R^2=0.1414). The maximum pH is affected by the dry matter concentrations and the composition of the sludge itself. Chemical and biological reactions within the sludge often decreases the pH levels. The positive correlations were observed between the dry matters and the total helminth eggs. According to the finding of Jimenez et *al*. (2000) working on the pathogen reduction in wastewater sludge, they found that the elimination mechanisms of dry matters in wastewater treatment plants are the same as helminth eggs in wastewater behaves like particles (suspended solids). The measured values of the pH obtained in this study was positively affected the removal of the total helminth eggs in faecal sludge samples (Fig. 65c). It shows that the pH obtained in this study ranges from 6 to 9, favorable for microbial activities. However an increase of the pH basicity was found to inactivate pathogens (Pecson et *al*., 2007). A negative correlation was observed between the NH_4^+ and the total helminth eggs found in the samples. Though ammonia concentration in sludge are rarely reported, its presence could have an important effect on the efficiency of the treatment. Indeed, the uncharged ammonia causes inactivation of *Ascaris* eggs while the inactivation was directly related to the activity of NH_3 (Pecson and Nelson, 2005).

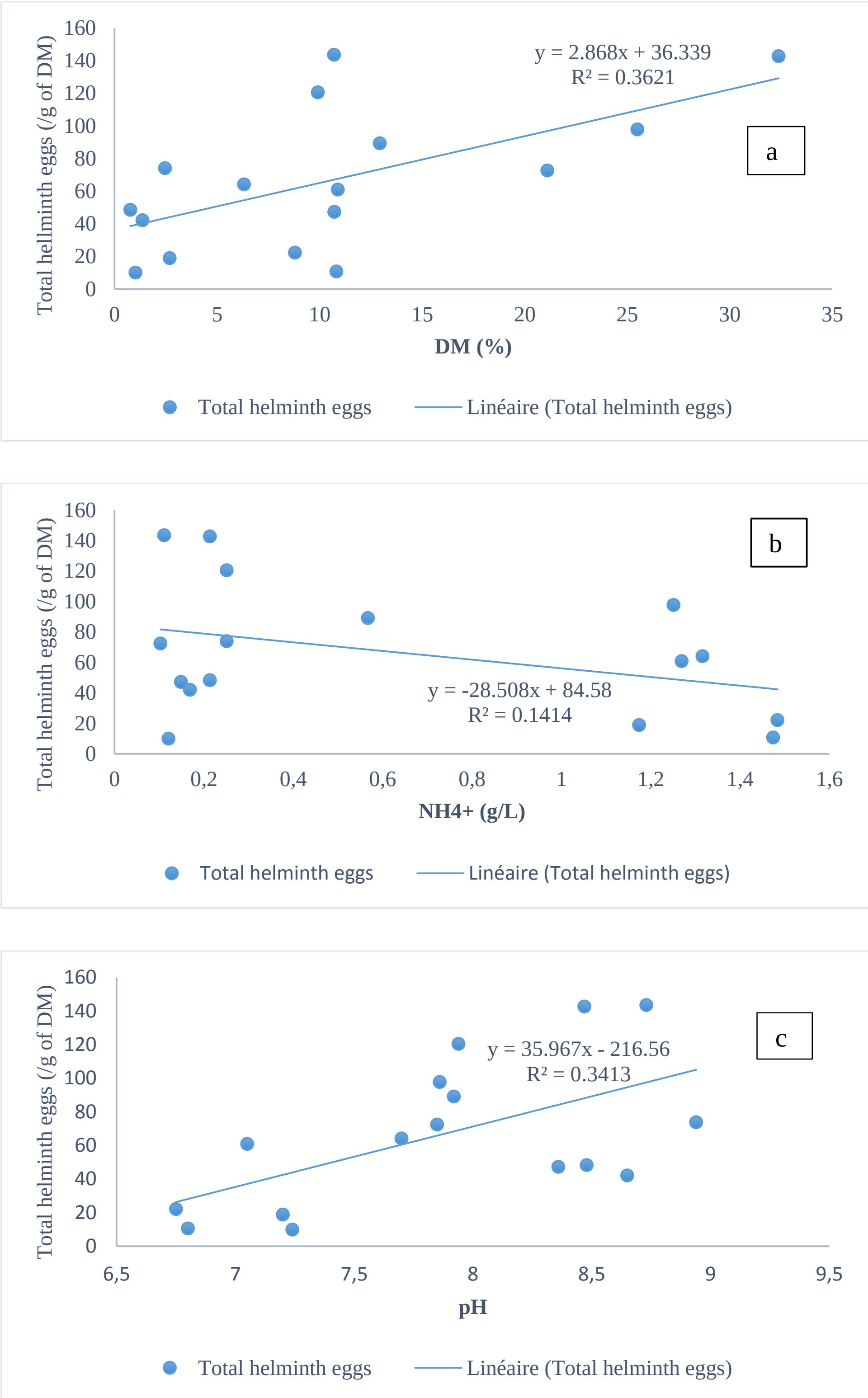


Fig. 61. Correlation test (Pearson) between faecal sludge parameters (a: Total helminth eggs vs DM; b: Total helminth eggs vs NH_4^+; c: Total helminth eggs vs pH).

III.5.3. Quality of the outlet leachates

III.5.3.1. Physico-chemical characteristics

The leachates obtained had an average pH ranging from acid to basic ($6.48 \leq pH \leq 7.51$) (Table XIX). The slight variation of the pH were obtained independent of the hydraulic retention times tested. The values of pH in the leachates were in the order of 7.65±0.52, 7.68±0.57, 7.67±0.51 and 7.59±0.46 respectively for free flow, 7 days retention time, 14 days retention time and unplanted drying bed (control test). On an average basis, a significant reduction of the outflow concentrations of dry matters and NH_4^+ was noted in each bed unit irrespective of the hydraulic retention times and growth of plants ($p<0.05$). Indeed, the concentration of dry matters decreased from 10.53±9.80% to 0.76±0.30% for free flow, to 0.68±0.28% for 7 days retention time, to 0.52±0.22% for 14 days retention time and to 0.93±0.38% for unplanted drying bed (control test). The concentration of NH_4^+ decreased from 0.63±0.57 g/L to 0.08±0.06 g/L for free flow, to 0.09±0.06g/L for 7 days retention time, 0.08±0.06 g/L for 14 days retention time and to 0.09±0.05 for unplanted drying beds ($p<0.05$). The reduction of the faecal sludge physico-chemical parameters tested (dry matters, NH_4^+) could be explained by their retention time in the filter beds. The dry matters removal are the end results of a complex set of internal processes, including the sedimentation and production of transportable solids by wetland biota (Kadlec and Wallace, 2008). In this study, sedimentation on the filter media (layer) seems to be important, because the difference between free flow and retention times for longer periods are low especially for the parameter pH. However, the reduction of NH_4^+ in constructed wetlands is due to many reactions such as chemical reactions and plant uptake (Dan et *al*., 2011; Brix and Arias, 2005). It was shown that an increase of the pH may be favourable to the conversion of NH_4^+ to NH_3, a chemical element which is known to inactivate many pathogenic organisms (Thangarajan et *al.*, 2014). The removal of NH_4^+ in faecal sludge obtained in this study met the Cameroonian guideline for the safe water irrigation in agriculture (<20 mg/L) and the WHO guideline for safe water irrigation in agriculture (<30 mg/l).

Table XIX. Physico-chemical characteristics of the outlet leachates (n=16).

Paramters	Statistics	Free flow	7 days RT	14 days RT	UB
pH	Mean	7.65[a]	7.68[a]	7.67[a]	7.59[a]
	Sd	0.52	0.57	0.51	0.46
	Min	6.85	6.85	6.85	6.69
	Max	8.73	8.44	8.47	8.47
NH_4^+ (g/L)	Mean	0.07[a]	0.08[a]	0.09[b]	0.08[a]
	Sd	0.06	0.06	0.06	0.06
	Min	0.01	0.01	0.01	0.01
	Max	0.18	0.24	0.18	0.18
Dry matters (%)	Mean	0.76[b]	0.67[a]	0.52[a]	0.93[bc]
	Sd	0.30	0.28	0.22	0.38
	Min	0.07	0.07	0.06	0.07
	Max	1.18	0.99	0.91	1.37

(RT : retention time ; UB : unplanted drying beds; Min: minimum; Max: maximum; values followed by the same letter are not significantly different from each other following one-ways ANOVA test, $p<0.05$).

III.5.3.2. Hygienic quality of the leachates

As shown in table XX, the FS dewatering process on the drying beds was not efficient enough to remove all the helminth eggs. The recorded concentrations (mean) were in the order of 3.3 eggs/g of DM, 2.7 eggs/g of DM, 2.25 eggs/g of DM and 3.36 eggs/g of DM respectively for free flow, 7 days retention time, 14 days retention time and unplanted drying bed. However, the observed total helminth eggs recorded in the leachate were during the first four campaigns of this study. Similar results were obtained in unplanted drying beds and planted drying beds operated as free flow ($p<0.05$). The decrease observed in the reduction of the total helminth eggs could be due to the predation, dehydration and retention time which are the main mechanisms in planted drying beds that result in pathogen reduction in faecal sludge, an increase in the pathogen reduction comes with an increase in the retention time (Strande et *al*., 2014). In addition, sedimentation on the filter media and several filtration media (e.g. membrane, granular) are also a common mechanisms for the elimination of helminth eggs present in faecal sludge. It has been show by Tchobanoglous et *al*. (2003) that with slow sand filtration, most of the solids (helminth eggs and dry matters) are trapped on the surface of the filter. Additionally, all the above described mechanisms affecting the pathogens reduction in constructed wetlands, helminth eggs are very resistant to environmental stress (e.g. dehydration and heat) and are an important indicators of sludge quality. Ingallinella et *al*. (2002) summarized various reports and showed that treatment of faecal sludge in a planted drying beds reduced the concentration of helminth eggs between 600-6000 helminth eggs/L of FS to 170 eggs/g of DM. Other researches showed that planted drying bed were able to achieve a complete elimination of helminth eggs in the leachate (Koné et *al.*, 2007; Seck et *al.*, 2015).

Table XX. Variation of the total helminth eggs in the outlet leachates (n=16).

Statistics	Unit	Free flow	7 days RT	14 days RT	UB
Mean	Number of eggs/g of DM	3.3^b	2.7^a	2.25^a	3.36^b
Sd		2.2	1.03	1.83	2.24
Min		1	1	1	1
Max		8	4	6	8

(Values followed by the same letter are not significantly different from each other following one-ways ANOVA test, $p<0.05$)

III.5.4. Hygienic quality of the biosolids accumulated on the beds

Biosolids removed on the beds revealed high concentration of helminth eggs (Fig. 62). In general, almost all the helminth egg species belong to the class Nemotoda (*Ascaris, Trichuris, Enterobius, Strongyloides*). With more than 80% of the total count, *Ascaris lumbrides* was the most common amongst the heminth species investigated. The high concentration of *Ascaris* eggs in the dewatered sludge follows their pattern in the raw sludge. The Nematode species has an extremely high prevalence in developing countries (Nelson and Darby, 2001; Yen-Phi et *al.*, 2010). The concentration of helminth eggs in biosolids are largely dependent on the prevalence and intensity of infection in the population from where the faecal sludge were collected (Ingallinella et *al.*, 2002). Most of the helminth eggs in wastewater are expected to be concentrated in sludge due to their high settling velocities (Nelson et *al.*, 2004; Wafo et *al.*, 2016). Sedimentation has been reported to be effective in removing helminth eggs in planted drying beds (Jimenez et *al.*, 2000; Kengne and Tilley, 2014). However, these concentrations are not in accordance with the WHO standards guidelines (<1 egg/g of DM) for safe agricultural practices (WHO, 2006). The increase in hydraulic retention times allowed a reduction in the pathogen indicators of faecal sludge (Fig. 66). In addition to natural deaths, the elimination of some helminth eggs in the layer of biosolids accumulated on the surface of the beds could be the result of many biological processes occurring on the surface of the planted filters such as dehydration, mineralization and predation (Sanguinetti et *al.*, 2005; Koné et *al.*, 2007).

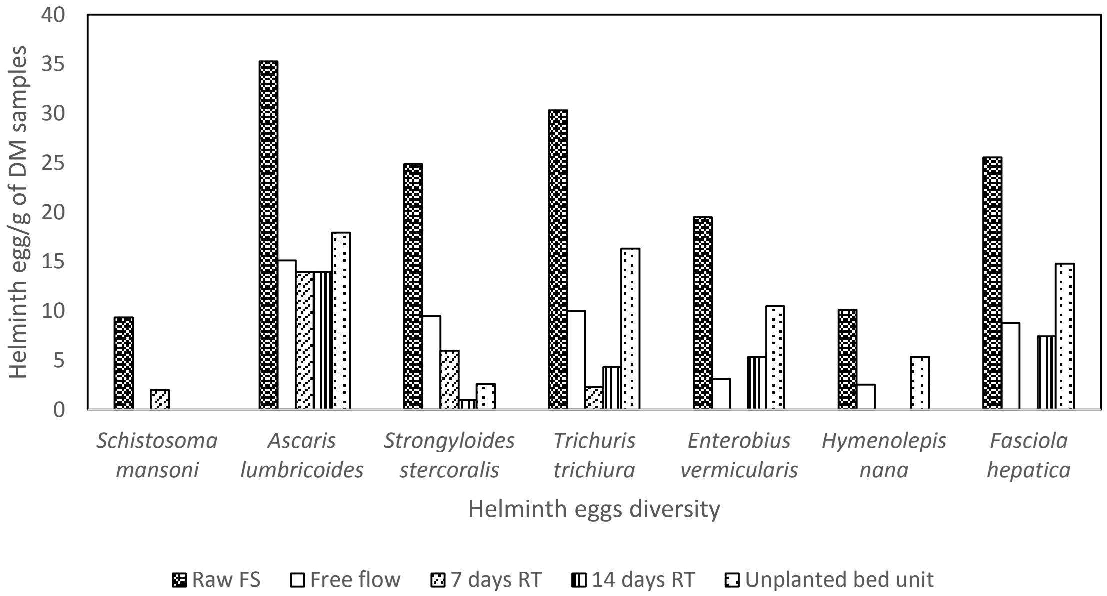
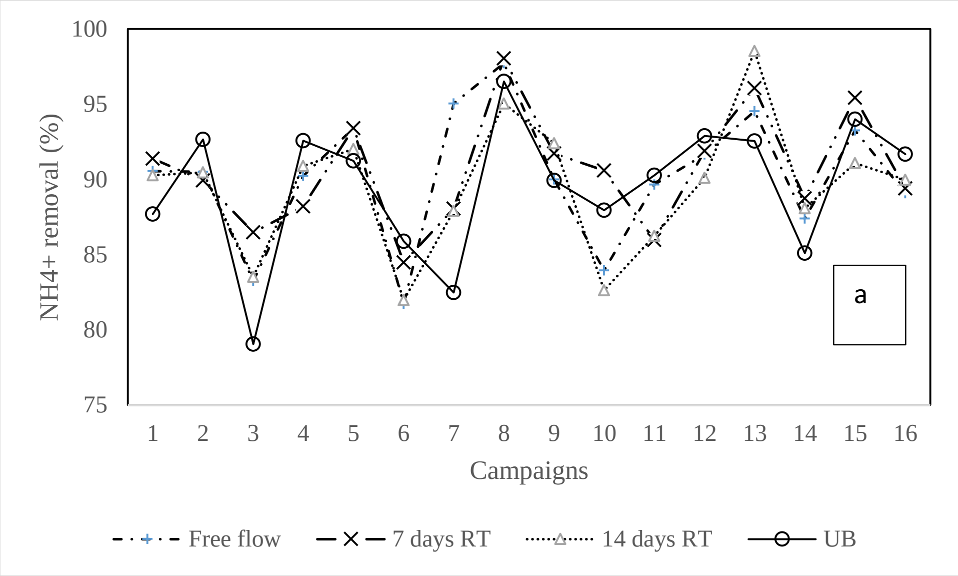


Fig. 62. Variation of the helminth egg species found in the biosolids accumulated on the surface of the beds (n=16) (FS: faecal sludge; RT: retention time; DM: dry matters).

III.5.5. Removal efficiencies

III.5.5.1. Physico-chemical removal

The removal efficiencies of pollutants based on the difference in input and output fluxes showed a great variation within a same pilot bed (Fig. 63). The removal of the physico-chemical parameters in the outlet leachates display with the quality of the incoming faecal sludge applied on the beds units. We have observed that when the quality of the faecal sludge applied on the bed units is concentrated, the quality of the outlet leachates obtained will be concentrated. Indeed, on an average basic removal efficiencies ranged from 75 to 97% for dry matters and from 79 to 96% for the removal of NH_4^+. According to the NH_4^+, the removal efficiencies found in this study was greater than those observed with a vertical constructed wetlands operating in Europe for wastewater treatment (average of 40%) (Meyer et *al*., 2012; Kadlec and Wallace, 2008). This reduction of nitrogen is due to plant uptake, adsorption, ammonia volatilization and denitrification (Kadlec, 2009). The high nitrogen removal observed in this study was likely enhance by the climate, with an average daily temperature of 25°C, which increases metabolic rates of plants and microorganisms, since chemical nitrogen transformations depends on temperature. Looking at the dry matters, sedimentation is the main removal mechanism. In tropical regions, it is possible to achieve dry matters percentages of at least 30% by treating faecal sludge on planted drying beds (Kengne et *al.*, 2009).



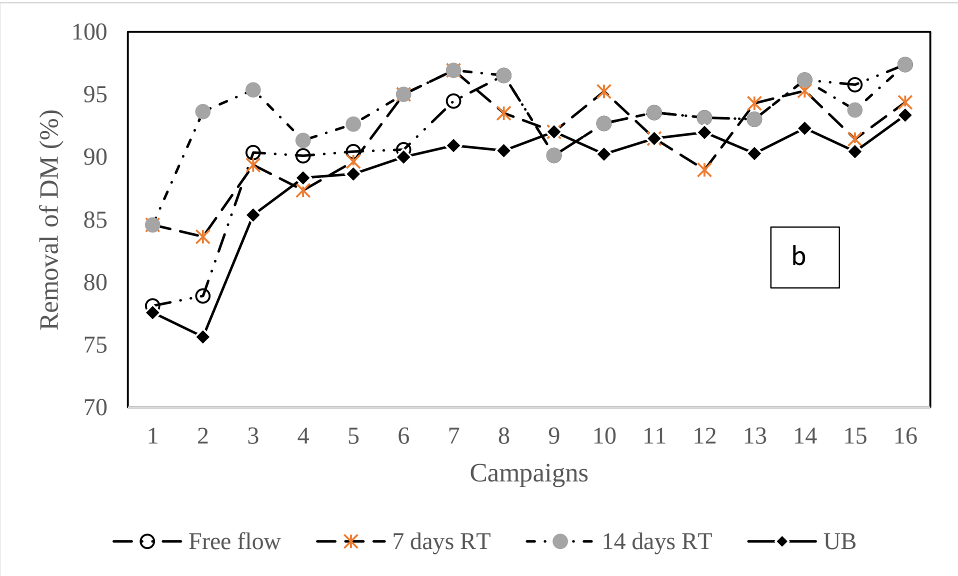


Fig. 63. Variation of the physico-chemical removal efficiencies of ammoniacal nitrogen and the dry matters (n=16) (a: Nitrogen ammonia removal; b: dry matters removal).

III.5.5.2. Removal efficiencies of helminth eggs

Contrary to removal of the physico-chemical parameters, the removal of helminth eggs is mainly due to the sedimentation processes. Indeed after the application of the faecal sludge on the bed units, helminth eggs are trapped on the surface of the filter beds. The removal efficiencies of helminth eggs were ranged from 70 to 100% independent to the retention time tested and unplanted drying bed unit (Fig. 64). The Fig. 64 show that from campaign 8 onwards, the results for all 4 different trials are the same. This result indicates that the retention time does not play a role in the helminth eggs inactivation. Indeed, predation, sedimentation and dehydration are the main mechanisms in planted drying beds that results in pathogen reduction in faecal sludge. The findings of Koné et *al.* (2010), working on the inactivation of helminth eggs within tropical drying beds, have shown that the insufficient retention time may affect the removal processes (filtration and sedimentation) of helminth eggs.

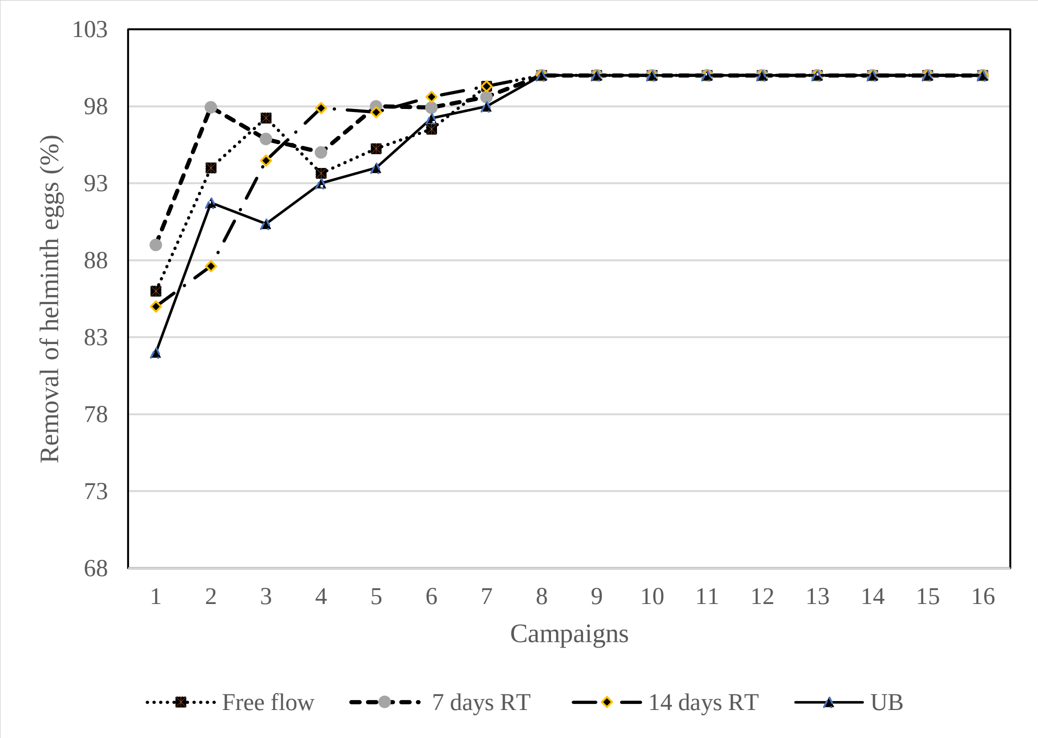


Fig. 64. Variation of the removal efficiencies of helminth eggs (n=16).

For Diop et *al*. (2015) working on the effect of plant species on faecal sludge drying and the fate of pollutants in planted drying beds has shown that pathogens are mainly trapped inside the sludge cake accumulated on the surface of planted filters. The elimination of the helminth eggs for the 7 days hydraulic retention time and the 14 days hydraulic retention time could be explained by the long contact time between the helminth eggs adsorbed on the faecal surface and the constituents of the system. Indeed, Feachem et *al*. (1983) working on the excreta reuse, report that helminth eggs in comparison with other pathogens are larger in size and are mainly eliminated by the natural processes in planted drying beds. Basically, to remove helminth eggs from faecal sludge it suffices to realize that they are in fact particles forming a fraction of dry matter contents. This is why the helminth eggs content is related to the dry matters content in wastewater-specifically, to the amount of particles measuring 20-80 µm (Seck et *al*., 2015). As helminth eggs are particles, mechanisms used to remove suspended solids are also useful for removing helminth eggs from faecal sludge.

III.5.6. Effect of plant densities and retention times on the removal performance of the beds

In general, *Echinochloa pyramidalis* exhibited a fast multiplication rate, with density increasing from 12 (acclimatization) to more than 300 shoots/m^2 during the study independent to the hydraulic retention times tested (Fig. 65). There was a significant difference (p<0.05) in plant density and the hydraulic retention times tested. After 09 months of operation, this parameter increased proportionally to the increase in hydraulic retention times. The presence of plants in the bed units affected the removal efficiency of NH_4^+ (p<0.05), as the assessment of the performance between the campaigns of this study revealed a very great variation of the removal efficiency in comparison to the unplanted bed (control test). It is generally assumed that planted drying beds outperform unplanted controls mainly because the plant rhizosphere stimulates microbial community density and activity by providing root surface for microbial growth, and a source of carbon compounds through root exudates (Vymazal and Kröpfelová, 2009). This observation was also mentioned by Rai et *al*. (1995) who obtained a close relation between the increase in concentration of nutrient in wastewater and the absorption by plant growth.

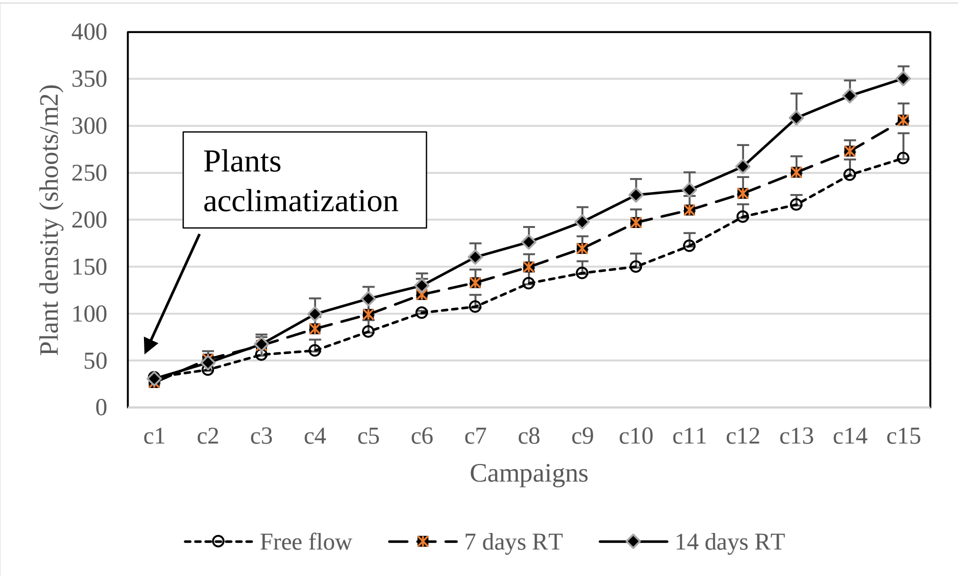


Fig. 65. Variation of the plant density with respect to hydraulic retention times (n=16).

The change in environmental conditions induced by faecal sludge applications certainly influenced the multiplication rate of the macrophytes. The high density of plants could be due to adaptations developed by the plants which allows for growth in faecal sludge treatment beds (Fig. 66). This high density of plants is beneficial for sludge treatment as it helps accelerate its dewatering through high amount of loss by evapotranspiration (Kengne et *al*., 2009).

Fig. 66. Appearance of the planted drying bed at the end of the experiment (photo: Letah Nzouebet).

The presence of plants in the bed units has an effect on the removal efficiency of DM and Helminth eggs ($p<0.05$). This result could be due to the sedimentation of particles including helminth eggs present in faecal sludge on the beds. Indeed, the root system of *E. pyramidalis* allows retention of particles present in the faecal sludge contrary to the unplanted drying bed unit (standard). Furthermore, aquatic macrophytes can affect the redox status of drying beds sediments by releasing oxygen from their roots into the rhizosphere and thereby stimulating aerobic decomposition (Brix and Arias, 2005). Sedimentation has been reported to be effective in removing helminth eggs (Yaya-Beas et *al*., 2015; Wu et *al*., 2016) due to their higher settling velocities (Sengupta et *al*., 2011). In this study, the plant density has an indirect effect on the removal of helminth eggs and dry matters. The plant densities is known to increase the clogging phenomena via the development of it root system.

III.6. Interlink between the parts of this study

This study started by assessing the variability of excreta disposal in 602 households from different urban settings of Yaounde and followed by the assessment of the physico-chemical and helminth eggs variability of faecal sludge from 53 different on-site sanitation systems. The third part of this study assessed the factors affecting faecal sludge in planted drying beds for faecal sludge dewatering. Several outcomes were identified in this study: the traditional pit latrines found in this study exhibited the highest amount of non-faecal matter (trash materials) in the pit in comparison to other types of on-site sanitations systems namely ventilated improve pit latrine, septic tank and piped equipped latrine. The presence of trash materials in traditional pit latrines may affect the desludging activities by clogging the pumps of mechanical trucks during the emptying of the pit. Additionally, the pasty consistence of the faecal sludge recorded in this type of sanitation system during sampling (traditional pit latrine) may also affect mechanical emptying. The presence of trash materials in the traditional pit latrines was found to be proportional to the number of people using the sanitation facility and it was also found to be dependent of instruction level of households. According to the desludging periods, most of the households investigated mentioned emptying their latrine with variable desludging frequencies. Traditional pit latrines and septic tanks are the most emptyied facilities. Looking at the physico-chemical and helminth eggs characteristics of faecal sludge sampled, a heterogeneity in the distribution of these sludge parameters as per latrine groups was recorded. We noted that samples originating from ventilated improved pit latrine, traditional pit latrine and piped equipped latrine were more concentrated than the sample from the septic tank systems according to the parameters COD, BOD_5, electrical conductivity, TKN. In general, according to the hygienic quality of samples, the traditional pit latrines exhibited the highest concentrations of helminth eggs diversity recorded and the population using this type of latrine were found to be more exposed on faecal-oral diseases. In comparison to the faecal sludge obtained at the experimental treatment plant, the values obtained in this part of the study were found to be highest. The lower values of faecal sludge parameters recorded in the experimental treatment plant can be explained by the dilution factors. An amount of water is added in on-site sanitation systems (particularly traditional pit latrines) during mechanical emptying. This practice may affect the quality of faecal sludge received at the experimental treatment plant. The plant densities indirectly affected the removal of dry matters and helminth eggs. According to the retention times, it has no effect on the removal of helminth eggs.

CHAPTER IV. CONCLUSION, PERSPECTIVES AND RECOMMENDATIONS

IV.1. Conclusion

The aim of this study was to examine excreta collection facilities in Yaounde and the assessment of the factors affecting the fate of intestinal parasite in planted drying beds vegetated with *Echinochloa pyramidalis*. It aimed at proposing and applying MDG indicators to characterize the hygienic safety and sustained functioning of the existing on-site sanitation systems in use at household levels. I developed and applied a household survey methodology to collect information on three critical factors: the sanitation facility design, its management and functional state. The quality and variability of raw faecal sludge produced within the city was also assessed based on the determination of the physico-chemicals, heavy metals and helminth eggs concentrations. In addition, I assessed the effect of hydraulic retention times and plant densities on the removal performances of helminth eggs in faecal sludge. Based on the results obtained from this study, the following conclusions are made:

- the variation of the type of sanitation devices in use at household levels independently to the urban settlement investigated was recorded with the predominance of the traditional pit latrines, followed by septic tanks;
- some of the households investigated didn't have any on-site sanitation technologies and thereby practiced open defecation into the natural environment;
- there were some significant relationships between the educational level of householders, the monthly income of households and the type of sanitation facilities in use;
- based on the observation of latrine structures, several materials were used by householders to build their latrines and consisted of concrete, metal sheet, beaten earth and wood;
- looking at the action made when pit of latrines are full, most of respondents mentioned the desludging of their devices, some of them mentioned the use of chemical substances (caustic soda, wood ache), and others mentioned the construction of a new latrine;
- the levels of heavy metals and helminth eggs where generally higher than the restriction values for surface water irrigation and WHO guidelines for reuse in agriculture (<1 egg/g of TS);
- higher prevalence of *Ascaris lumbricoides* was recorded in samples and there was a significant difference in the concentration of helminth eggs species between the groups of latrines;
- the samples from traditional pit latrines and ventilated improved pit latrines exhibited higher concentration of organic parameters (COD, BOD_5) and dry matters content. Assessment of the variation of the sludge physico-chemical parameters as function of latrine types using one

way ANOVA test revealed a strong significant difference in the distribution of parameters COD, TKN and DM;

- PCA of the physico-chemical parameters for the pit latrines FS samples revealed that the first component of the analyses explained 78 % of the total variance and is strongly correlated (positive) with COD, BOD_5, NH_4^+, DM,water content and TKN;
- the PCA for helminth eggs composition showed that the first component which explained 72.26 % of variation is positively correlate with *Ascaris lumbricoides*, *Hymenolepis nana*, *Trichuris trichiura*, *Schistosoma mansoni*, *Enterobius vermicularis* and the total helminth eggs while the first component of the PCA for heavy metals expressed 47.89 % of the total variance and positively correlated with the parameters Cu, Mn and Cr;
- assessment of the composition of faecal sludge samples using the hierarchical cluster analysis divided the sludge samples into 4, 3 and 3 clusters respectively for the physicochemical composition, pathogen concentration and heavy metals content. The significant difference was observed between the clusters of the physico-chemical composition;
- according to the hygienic quality of the leachates, the recorded median concentrations of pathogens were lower and were found to relate with the hygienic quality of faecal sludge applied on the planted drying beds;
- biosolids removed on the beds revealed high concentration of helminth eggs almost belong to the class Nematoda, with *Ascaris lumbricoides* which are the most common species investigated (80%);
- physico-chemical removal efficiencies of planted drying beds ranged from 75 to 97% for dry matters and from 79 to 96% for the removal of NH_4^+,
- the removal efficiencies of helminth eggs ranged from 70 to 100 % independent of the retention times tested and presence of plants on the bed units significantly affected the removal efficiency of physico-chemical parameters tested.

Due to rapid population growth, most cities especially in developing countries would continue to employ on-site sanitation systems to collect faecal sludge. Therefore, the FS problems needs to be properly managed to minimize environmental pollution and health impacts. The relationship between the FSM indicators and their influencing factors developed in this study could be used to identify conditions to achieve effective FSM practices for each town of Cameroon.

IV.2. Perspectives

In order to increase the knowledge related to the use, perception of sanitation systems, the shortcomings and challenges of an existing faecal sludge management system in Cameroon, this study could be completed by:

- assessment of the sanitary and health impacts associated to the sanitation systems in the context of urban and rural area;
- description of different financial flow models for faecal sludge management in Cameroon;
- assessment of the frameworks for faecal sludge management in Cameroon;
- assessment of the phylogeny of heterotrophic microbial communities involved in the biodegradation processes in on-site sanitation systems;
- effect of the microwave treatment of faecal sludge on the removal of intestinal helminth eggs for agricultural reuse;
- assessment of the deep row applications of faecal sludge for forestry production in Cameroon.

IV.3. Recommendations

At the end of this study, some recommendations were formulated to the main actors involved in the faecal sludge management chain.

1) To households:

- avoid throwing of refuses/trash materials into the pit of the latrine because this practice disturbs the operation of mechanical emptying;
- respect and practice hygiene rules.

2) To the Municipal Authorities Urban Council:

- hygiene and health services of the Municipalities have to convince people to change their behavior particularly in the informal settlement via the focus groups on the community-led urban environmental sanitation planning or via the mass communications (radio, television, …);
- urban council of Yaounde must ensure the strict implementation of the building permits faced with an increase of informal settlements due to a growing population rate;
- create roads for easy access to households for the mechanical emptying services;
- The Yaounde urban council must promote the construction of latrines in the city of Yaounde, especially in urban slums.

3) To the emptying compagnies :

- improve working conditions by wearing personal protective equipment;
- request the construction of faecal sludge treatment plants in the city of Yaounde to limit the uncontrolled discharge of faecal sludge into the natural environment.

4) To the Cameroonian Government:

- Cameroon government has to build faecal sludge treatment plants or transfer stations in Yaounde and other towns of Cameroon to prevent uncontrolled discharge of faecal sludge into the natural environment;
- standardize the costs of the emptying services.

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APPENDIX

Appendix 1. Survey questionnaire for households.

THE WASTEWATER RESEARCH UNIT

RESEARCH PROJECT ON THE "CHARACTERIZATION OF FAECAL SLUDGE IN YAOUNDÉ"

--

SURVEY QUESTIONNAIRE FOR HOUSEHOLDS

Notes: This study is realised under the auspices of a PhD thesis carried out at the Faculty of Science, University of Yaounde I. It aimed at assessing existing faecal sludge collection devices at household levels in the city of Yaounde.

Specific Objectives: To collect information regarding the types of on-site sanitation. Information obtained in this questionnaire is confidential and will serve only for statistical purposes with regards to the exigencies of the project. Global results will be retransmitted in the final report in an agglomerated form (no household will be cited individually).

000/- GENERALITIES

001- Name of the investigator: /__________ /

002- Date: /______________ /

003- Name of quarter: / ________________ / 1-Mendong 2-Biyem-Assi 3- Damas 4-Ngoa-Ekélé 5-Etam-Bafia 6- Kodengui 7-Tsinga 8-Nkolbisson 9- Emana 10-Olembé 11-Melen 12-Nsam 13-Mvan 14-Essos 15-Oyom Abang 16-Carriere 17-Briqueterie 18-Bastos 19-Nfandena 20-Ekounou 21-Nkoldongo 22-Mballa II .

004 – Sheet number: / ___________ /

007 - Type of household /__/

1-High Standing 2- Medium standing 3- low standing 4- Spontaneous

008 – Building Materials /__/ 1- Cement
2- Beaten earth
3- Metal sheet
4- Wood
3- Plank or beaten earth
4-

009 - Location/__/ 1- Crest 2- mid-slope 3- dreg

100/- HOUSEHOLD INFORMATION

101 - Status of house occupant

1- Proprietor 2.-Tenant 3- Family house 4. Other (specify) /_________________________/

102 – Status of the person responding in the household: /_____/

1. Householder) 2-Householder's wife) 3- House help 4. Child of the householder

5-Other (specify): /____/

103 – Year of settlement in the quarter: /___/___/__/__/

104 – Sex of the householder: 1= Male 2= Female

105 – Level of education of the householder/head of the family: /____/

1 = without level 2 = Primary 3 = Secondary 4 = Superior

106 – Number of persons living in the house? /___/ persons

107 – Region of origin /___/
1= Adamaoua 2= Centre 3=East 4=Far North 5=Littoral 6=North 7=North west 8=West 9=South 10=South west
108- Monthly income

109- Monthly expenditure /_______/
1-100 to 200 USD 2-200 to 300 USD 3-300 to 400 USD
4-Over 400 USD 5- Under 100 USD

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200 - INDIVIDUAL SANITATION (Pit Characteristics and Use)

201 – Geographic coordinates
1= Longitude: /___________ / 2= Latitude: /_______ /
3= Altitude: /_______ /
202-In the target service area, on average, are there? /________/
1- One person 2- 2 to 4 people per latrine or pit
3- 4 to 6 people per latrine or pit 4- More than 6 people per latrine or pit
203- How often would you expect that a latrine or pit need to be emptied? /________/
1- More than 2 times per year 2- 2 times per year
3- 3 times per year 4- 2 - 3 years
5- Every 4 – 5 years 6- Over 5 years between emptying
7- Do not know

205- Which system of sanitation of human waste is used in the house? /__/
1 = Traditional latrines 2 = Septic tanks 3 = VIP Latrines 4- Canon equipped Latrines 5 = Open defecation 6- Other/___________________/
206- What is the origin depth of the latrine? /___/
1-1 to 2 m 2-2 to 4 m 3-4 to 6 m 4- 6 to 8 m 5-> 8 m
207- What is the size of pit? /___/
1-1 to 2 m^3 2-2 to 4 m^3 3- 4 to 6 m^3 4- 6 to 8 m^3
208- Is latrine simultaneously used for bathing? /___/ 1- Yes 2- No
209- Is latrine connected to tap water network? /___/ 1- Yes 2- No
210- Is water used to flush? /___/ 1- Yes 2- No
211- If yes, which quantities of water are generally used? /___/
1-5 l 2- 10 l 3- 15 l 4- More than 15 l
212- In case of latrines, what is its final state? /___/
1 = Well-arranged 2 = moderately arranged 3 = Not arranged
213- Do the latrines have any problems? /___/ 1- Yes 2- No
214- If yes, then what are the problems that the latrines are currently posing?

214-1	Access	/___/	1/- difficult to access 2/- Accidental access 3/- Dirty access 4/- other (specify) /……………………………………………………………………………/
214-2	Confort	/___/	1/- Odour 2/- Insecurity 3/- Exposure 4/- Other (specify)
214-3	Hygiene	/___/	1/- Proximity to waste dump 2/- Proximity to well or spring 3/- Rats, cockroaches and flies 4/- Stagnant wastewater 5/- Other (specify) /……………………………../

215- Do the evacuation pipes in the house function properly? /……../
1 = Yes 2 =No
216- What would you do if your pit got filled? /___/ 1 = Construction of another pit

2 = Emptying 3 = Other (please specify) /…………………………………. /
217- If you choose to empty the pit, how is that done? /___/ 1 = Specialised lorries
2 = Manually 3 = Other (please specify) /………………………………………………/
218- What are the criteria that led to your choice in 219 above? /___/
1- Cost 2- Quality of the service 3- Accessibility 4- Other (specify) /____/
219- If you chose manual emptying, who does it? /___/ 1- Members of the family 2- Manual workers 3- Other (specify) /________________________________/
220- Have you ever carried out emptying before? /___/ 1 = Yes 2 = No
221- If yes, how many times? /__/ times
222- When did you carry out the last emptying? /___/ 1) - less than 6 months 2) - 1 year 3) - 2 years 4) - more than 2 years
223 – How much did you spend for the emptying? /____________________FCFA/

224- What are your remarks about the said amount? /___/
1- Very expensive 2- Expensive 3 - Affordable 4- Cheap 5- Other (specify) /____/

300- **OTHER INFORMATION ABOUT PIT**

301-What is the longest pipe or other piece of equipment that could be easily carried into and used in most permanent structures to empty the pit? /___/

1- Less than 2 m 2- 2 – 3 m 3-3 – 4 m 4- over 4 m 5- do not know

302- Pits can be accessed by a traditional vacuum truck? /___/1 = Yes 2 = No

303- Pit can be accessed by a rickshaw or small motorized cart? /___/1 = Yes 2 = No

304- Pit can only be accessed by foot or small hand cart? /___/1 = Yes 2 = No305-The maximum depth of pits is? /___/

1- Less than 2 m 2- 2 – 3 m 3-3 – 4 m 4- over 4 m 5- do not know

306-The surface area of pits latrine.? is? /___/

1- Less than 1 m^2 2- 2 m^2 3-3 m^2 4- greater than 3 m^2 5- do not know

307- Pit has walls below the ground surface is constructed of concrete, brick, rock or other hard material? /___/1 = Yes 2 = No

308-Are wet pits containing faecalmaterial have the bottom constructed of concrete, brick, rock or other hard material? /___/1 = Yes 2 = No

309-Pit is in areas where the water table is usually below the bottom of the pit? /___/

1 = Yes 2 = No

310-Are pit contain trash or other discarded solid material larger than 2.5 cm? /___/

1 = Yes 2 = No

311 -Does pit contains trash or other discarded solid material larger than 5 cm? /___/

2 = Yes 2 = No

312-Does Pit contains trash or other discarded solid material larger than 10 cm? /___/

3 = Yes 2 = No

313-Pits contain fibrous or stringy material (rope, hair, rags, and plastic bags) that could wrap around and jam an auger? /___/ 1= Yes 2 = No

400--NUISANCES FACED BY HOUSEHOLDS

401-There is problem identify in the household relate to:

1-Water quality / ___ / 1 = yes 2 = no

2-mosquito / ___ / 1 = yes 2 = no

3 - Odours / ___ / 1 = yes 2 = no

4 - Inundation / ___ / 1 = yes 2 = no

5 - Diseases / ___ / 1 = yes 2 = no

402- - If yes for disease, at which climatic season can we observe the spread of disease? /___ /

1 - Rainy season 2 – dry season 3 - dry and rainy season

403 - Which diseases do you frequently suffered in the last 6 months? /___ /1 - cholera 2 - amibiasis 3- malaria 4 – diarrhoea 5 - typhoid fever 6 - No 7 - helminthiasis / ___ /8-other (specify) /_ /

404 - Can you give the season of occurrence? / ___ / 1 - Rain 2 – Dry season, 4 –Both season; 5 Other (specify) /______/

405 - Do you have any idea of the origin of these diseases? / _ /1 = yes 2 = no

406- If so, which ones? / _ /1 = poor sanitary condition 2= water quality 3= insalubrities 4= other (specify) / ____/

407- What solution did you use to treat yourself? / ___ / 1 - self-medication 2 - modern medicine 3- traditional medicine 4 - Other (specify) / ________________________________/

500--FIELD TESTING

501-Can you allow visiting for the measurement of some parameters of your latrine and its by-product for University studies? /___/ 1-Yes 2-No

502-Suggestions about water and sanitation in your quarter /___/

1-poor 2- Average 3-Good

4-Other (specify) / ____/

503- Suggestions about solid waste management in your quarter

1-poor 2- Average 3-Good

4-Other (specify) / ____/

____

____

____

504-Comments of investigator: --- -------- -- -- --------------------/

Thanks for your participation

Appendix 2. Survey questionnaire for faecal sludge sampling.

THE WASTEWATER RESEARCH UNIT

RESEARCH PROJECT ON THE "CHARACTERIZATION OF FAECAL SLUDGE IN YAOUNDÉ"

--

FAECAL SLUDGE SAMPLING SURVEY QUESTIONNAIRE FOR FAECAL SLUDGE SAMPLING IN HOUSEHOLDS

Notes: Through this questionnaire, we wish to know the characteristics of excreta and the consequent influence on the quality and variability of faecal sludge. This study is realised under the auspices of a doctorate thesis carried out at the University of Yaounde I.

Specific Objectives: To have information on the types of on-site sanitation and the factors determining the quality and the variability of faecal sludge.

The information obtained in this questionnaire is confidential and will serve only for statistical uses with regards to the needs of the project. Global results will be retransmitted in the final report in an agglomerated form (no household will be cited individually).

000/- GENERALITIES

002- Date: /_______________ /

003- Name of quarter: / _________________ /

1-Mendong 2-Biyem-Assi 3- Damas 4-Ngoa-Ekélé 5-Etam-Bafia 6-Kodengui 7-Tsinga 8-Nkolbisson 9- Emana 10-Olembé 11-Melen 12-Nsam 13-Mvan 14-Essos 15-Oyom Abang 16-Carriere 17-Briqueterie 18-Bastos 19-Nfandena 20-Ekounou 21-Nkoldongo 22-Mballa II .

004- Arrondissement /_________________/

005 – Sheet number: / ____________ /

006 – Number of the sampling point: /__/__/

009 - Topographic position /__/ 1- Crest 2- mid-slope 3- dreg

---

100 - INDIVIDUAL SANITATION (Pit Characteristics and Use)

101 – Geographic coordinates

1= Longitude: /____________ / 2= Latitude: /_______ /

3= Altitude: /_______ /

102- Which system of sanitation of human waste is used in the house? /__/

1 = Traditional latrines with deep bottom 2 = Modern toilets with septic pit and/or drainage 3 = Manual flush toilets 4 = VIP Latrines 5- Canon equipped Latrines 6= Septic tank 7 = other (please specify) /____________________/

103 – Building Materials /__/ 1- concrete 2- Plank 3- Beaten earth 4- Sheet metals 5- Plastic batch (canvas cover) 6-mat 8- other (specify please)

104- What old year has your pit? /_____________________/

1- Less than 3 years 2- 3 to 5 years 3- 5 to 7 years 4-7 to 9 years 5- More than 10 years

105- What is the final state of the latrine? /__________________/

1- Presence of superstructure 2-absence of superstructure 3- other (specify) /____/

106-In the target service area, on average, are there? /_________/

1- One person 2- 2 to 4 people per latrine or pit
3- 4 to 6 people per latrine or pit 4- More than 6 people per latrine or pit

107- How often would you expect that a latrine or pit would need to be emptied? /_________/

1- More than 2 times per year 2- 2 times per year
3- 3 times per year 4- 2 - 3 years
5- Every 4 – 5 years 6- Over 5 years between emptying
7- Do not know

108- What is the origin depth of the latrine? /___/

1-1 to 2 m 2-2 to 4 m 3-4 to 6 m 4- 6 to 8 m 5-> 8 m

109- What is the size of pit? /___/

1-1 to 2 m^3 2-2 to 4 m^3 3- 4 to 6 m^3 4- 6 to 8 m^3

110- Is latrine simultaneously used for bathing? /___/ 1- Yes 2- No

111- Is latrine connected to tap water network? /___/ 1- Yes 2- No

112- Is water use to flush? /___/ 1- Yes 2- No

113- If yes, which quantities of water are generally used? /___/

1-5 l 2- 10 l 3- 15 l 4- More than 15 l

114- In case of latrines, what is it final state? /___/

1 = Well-arranged 2 = moderately arranged 3 = Not arranged

115- Do the evacuation pipes in the house function properly? /……../

1 = Yes 2 =No

116- What would you do if your pit got filled? /___/ 1 = Construction of another pit

2 = Emptying 3 = Other (please specify) /…………………………………. /

117- If you choose to empty the pit, how is that done? /___/ 1 = Specialised lorries
2 = Manually 3 = Other (please specify) /……………………………………………………. /

118- What are the criteria that led to your choice in 219 above? /___/

1- Cost 2- Quality of the service 3- Accessibility 4- Other (specify) /____/

119- If you chose manual emptying, who does it? /___/ 1- Members of the family 2- Manual workers 3- Other (specify) /________________________________/

120- Have you ever carried out emptying before? /___/ 1 = Yes 2 = No

121- If yes, how many times? /__/ times

122- When did you carry out the last emptying? /___/ 1) - less than 6 months 2) - 1 year 3) - 2 years 4) - more than 2 years

123 – How much did you spend for the emptying? /____________________FCFA/

124- What are your remarks about the said amount? /___/
1- Very expensive 2- Expensive 3 - Affordable 4- Cheap 5- Other (specify) /____/

200- **OTHER INFORMATION ABOUT PIT**

201-What is the longest of the piece of equipment that could be easily carried into and used in most permanent structures to empty the pit? /___/
1- Less than 2 m 2- 2 – 3 m 3-3 – 4 m 4- over 4 m 5- other (specify please)

202-The surface area of pits is? /___/
1- Less than 1 m^2 2- 2 m^2 3-3 m^2 4- greater than 3 m^2 5- do not know

203- Pit has walls below the ground surface is constructed of concrete, brick, rock or other hard material? /___/1 = Yes 2 = No

204-Are wet pits containing faecal material have the bottom constructed of concrete, brick, rock or other hard material? /___/1 = Yes 2 = No

205-Pit is in areas where the water table is usually below the bottom of the pit? /___/
2 = Yes 2 = No

206-Is pit containing trash or other discarded solid material larger than 2.5 cm? /___/
4 = Yes 2 = No

207- What is the colour of the faecal sludge collected (sampled)? /___________________/

208- What is the aspect of the faecal sludge collected (sampled) /__________________/

209- Pits can be accessed by a traditional vacuum truck? /___/1 = Yes 2 = No

210- Pit can be accessed by a rickshaw or small motorized cart? /___/1 = Yes 2 = No

211- Pit can only be accessed by foot or small hand cart? /___/1 = Yes 2 = No

300—ABOUT FIELD TESTING

1-Other information's / ____/

____

____

____

____

____

____

2-Comments of investigator:--

--------------------------------/

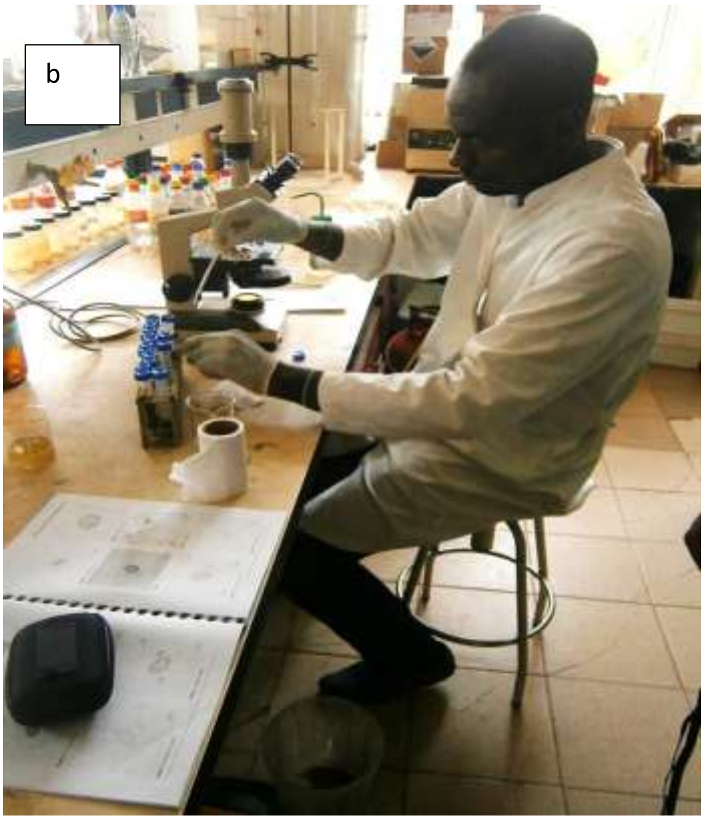
Thanks for your participation

Appendix 3. Field team sampling a pit latrine

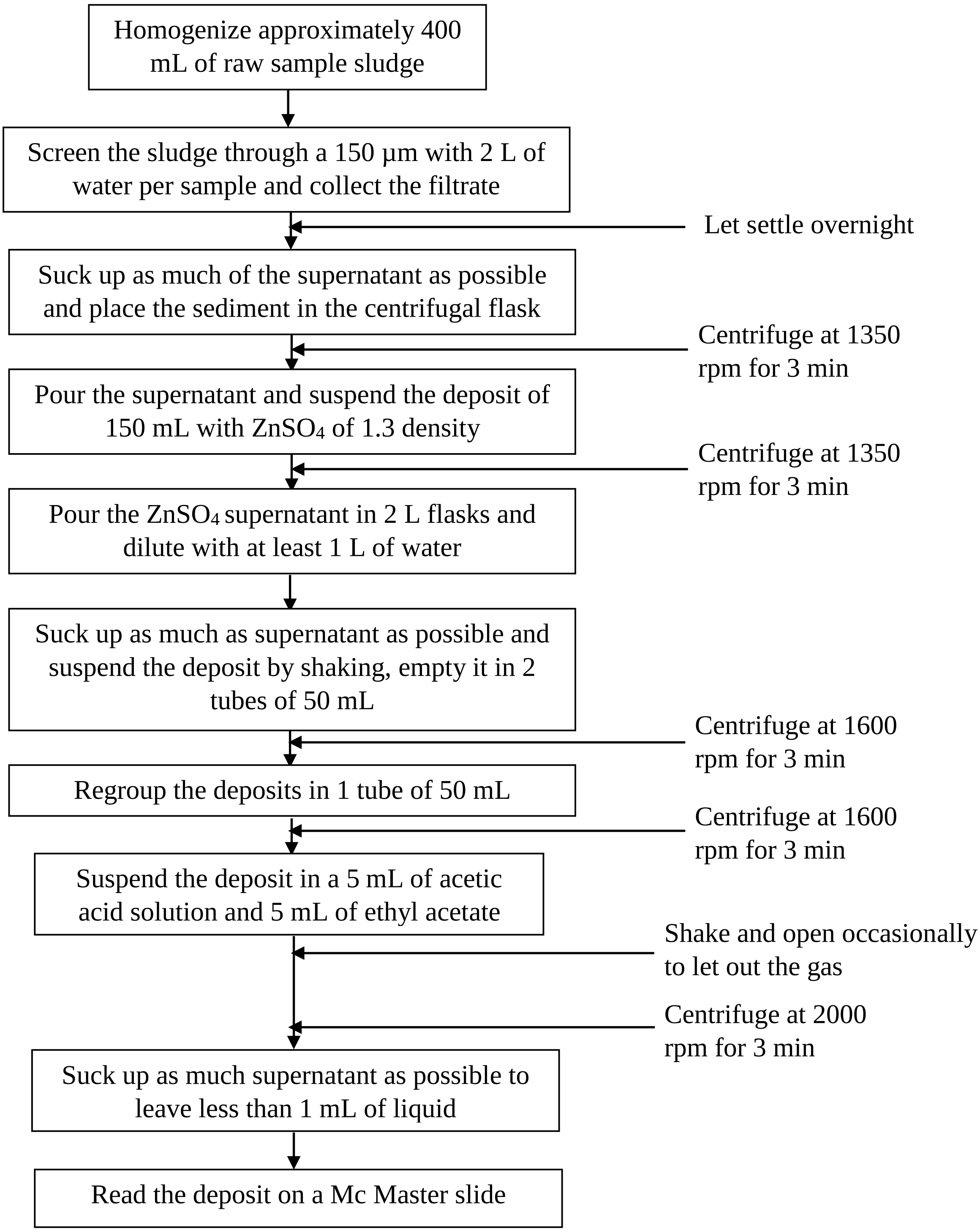
Appendix 4. Some of the laboratory apparatus used for this study.

(a : Conductimeter Hach HQ14D ; b: COD reactor ; c: Spectrophotometer, Hach DR 3900 ; d : Weight ; e : Oven ; f:: Hach distillatory unit; g : BOD_5 apparatus; h: centrifuge; i: Photonic microscope)

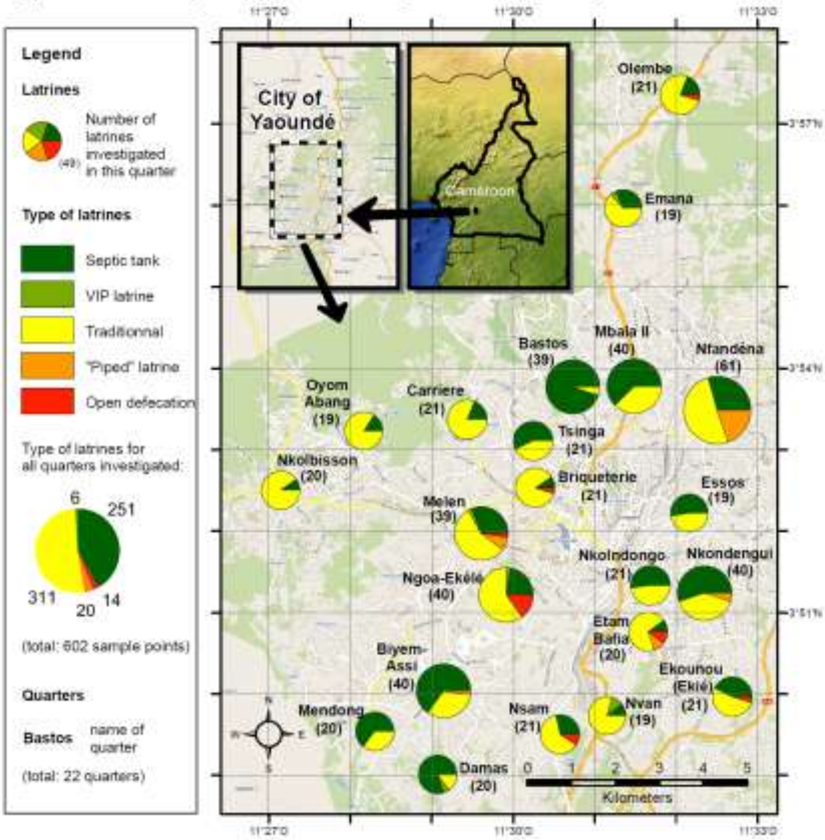
Appendix 5. View of the laboratory during the manipulation of the on-site sanitation faecal sludge (a: Physico-chemical analysis, b: Parasitological analysis).



Appendix 6. Procedure for the determination of helminth eggs in faecal sludge samples (Schwartzbrod et *al.*, 2003)



Appendix 7. Map showing the distribution of household latrines diversity in different urban settings investigated.



Appendix 8. Evolution of the mean removal efficiency of NH_4^+ per campaign of the study in function of the retention times tested.

Campaigns	Mean removal_Free flow	Mean removal 7 days RT	Mean removal_ 14 days RT	Removal_UB
1	90.55 ± 9.04^{a}	91.37 ± 6.53^{a}	90.27 ± 7.52^{a}	85.03^{b}
2	80.50 ± 8.98^{b}	89.92 ± 7.33^{a}	90.46 ± 5.92^{a}	90.50^{a}
3	83.23 ± 3.64^{b}	86.47 ± 3.65^{bc}	83.52 ± 6.78^{b}	72.85^{a}
4	91.22 ± 5.64^{b}	88.20 ± 6.89^{a}	90.89 ± 7.61^{b}	90.22^{b}
5	92.42 ± 6.76^{b}	93.20 ± 3.63^{b}	92.02 ± 5.60^{b}	89.45^{a}
6	81.72 ± 8.35^{a}	84.47 ± 11.09^{b}	81.96 ± 7.92^{a}	81.72^{a}
7	85.04 ± 11.90^{a}	88.06 ± 8.71^{b}	87.90 ± 9.41^{b}	89.46^{b}
8	97.72 ± 1.23^{a}	98.04 ± 1.90^{a}	98.04 ± 0.90^{a}	97.03^{a}
9	88.67 ± 7.78^{a}	91.72 ± 5.01^{b}	90.39 ± 6.31^{a}	88.66^{a}
10	93.95 ± 3.40^{b}	92.58 ± 5.91^{a}	92.62 ± 5.70^{a}	89.35^{a}
11	91.64 ± 6.18^{b}	85.96 ± 10.12^{a}	86.25 ± 10.90^{a}	89.64^{b}
12	90.66 ± 7.61^{a}	91.89 ± 5.22^{a}	90.09 ± 6.49^{a}	90.99^{a}
13	95.53 ± 3.45^{a}	96.05 ± 2.09^{a}	95.53 ± 3.25^{a}	94.46^{a}
14	77.39 ± 8.92^{a}	81.73 ± 10.92^{bc}	88.07 ± 9.14^{bd}	89.16^{bd}
15	93.24 ± 5.24^{b}	95.41 ± 2.24^{bc}	90.90 ± 7.69^{a}	93.24^{b}
16	88.31 ± 7.50^{a}	90.40 ± 7.93^{a}	89.97 ± 6.42^{a}	88.07^{a}

(RT: retention time; UB: unplanted drying beds, Values followed by the same letter are not significantly different from each other following one-ways ANOVA test, $p<0.05$)

Appendix 9. Evolution of the mean removal efficiency of dry matters per campaign of the study in function of the retention times tested.

Campaigns	Mean removal_ free flow	Mean removal_7 days RT	Mean removal_14 days RT	Removal_UB
1	78.12±8.63[a]	84.57±10.25[b]	84.57±11.52[b]	77.57[a]
2	78.90±7.63[a]	83.63±11.25[bc]	93.63±4.32[bd]	75.63[a]
3	90.36±8.45[b]	89.36±7.23[b]	95.36±3.25[bc]	85.36[a]
4	90.10±3.85[b]	87.34±6.65[a]	91.34±6.23[b]	88.34[a]
5	90.44±5.85[b]	89.64±5.89[a]	92.64±4.85[bc]	88.64[a]
6	90.58±7.51[a]	94.82±3.25[b]	95±2.89[b]	90[a]
7	94.47±2.45[bc]	96.92±1.63[bd]	93.92±3.85[bc]	91.92[a]
8	94.53±2.15[bc]	93.50±4.45[bc]	96.53±2.56[bcd]	90.52[a]
9	90.12±5.15[a]	93.03±4.35[b]	90.12±8.95[a]	92.03[b]
10	92.69±4.75[a]	95.24±2.35[b]	92.69±4.35[a]	90.24[a]
11	93.54±5.25[b]	91.49±5.12a	93.54±4.65[b]	90.49[a]
12	93.13±4.32[b]	88.97±8.85[a]	94.13±4.01[b]	91.97[b]
13	93.02±3.52[b]	94.29±2.85[b]	94.02±3.02[b]	90.29[a]
14	95.15±2.85[b]	95.27±2.12[b]	96.28±2.25[b]	92.29[a]
15	95.76±2.53[bc]	91.42±5.32[a]	93.76±4.12[b]	90.42[a]
16	96.38±1.56[b]	94.36±3.25[a]	97.38±1.32[b]	93.36[a]

(RT: retention time; UB: unplanted drying beds, Values followed by the same letter are not significantly different from each other following one-ways ANOVA test, $p<0.05$)

Appendix 10**.** Evolution of the mean removal efficiency of helminth eggs per campaign of the study in function of the retention times tested.

Campaigns	Free flow	Mean removal_7 days RT	Mean removal_14 days RT	Removal_UB
1	86±8.65[b]	89.9±7.02[bc]	85±9.12[b]	82[a]
2	94.47±4.23[bc]	97.93±1.46[bd]	87.6±10.56[a]	91.73[b]
3	97.24±1.33[bc]	95.86±3.12[b]	94.48±3.24[b]	90.35[a]
4	93.65±4.63[a]	95.54±3.52[b]	97.88±1.02[b]	93.05[a]
5	95.24±3.25[a]	98.05±0.23[b]	97.62±1.25[b]	94.23[a]
6	96.51±2.06[a]	97.91±1.28[a]	98.6±1.01[b]	97.21[a]
7	99.29±0.26[a]	98.09±0.98[a]	99.29±0.52[b]	98.39[a]
8	100	100	100	100
9	100	100	100	100
10	100	100	100	100
11	100	100	100	100
12	100	100	100	100
13	100	100	100	100
14	100	100	100	100
15	100	100	100	100
16	100	100	100	100

(RT: retention time; UB: unplanted drying beds, Values followed by the same letter are not significantly different from each other following one-ways ANOVA test, $p<0.05$)

PUBLICATION

Prevalence and diversity of intestinal helminth eggs in pit latrine sludge of a tropical urban area

Wilfried Arsène Letah Nzouebet, Ives Magloire Kengne Noumsi and Andrea Rechenburg

ABSTRACT

The aim of the study was to investigate the prevalence and diversity of helminth eggs in pit latrine sludge in Yaounde, Cameroon. A total of 30 faecal sludge samples were collected in various latrines and analysed for physico-chemical parameters and helminth eggs' characterization was undertaken using standard protocols. Effects of physico-chemical parameters (pH, temperature, salinity, electrical conductivity, chemical oxygen demand, biochemical oxygen demand for 5 days, nitrogen ammonia, dry matter (DM), moisture content) on the parasite eggs were addressed. The total helminth egg concentration in the samples ranged from 8.5 eggs/g DM to a maximum of 264.5 eggs/g DM with a median of 81.1 eggs/g DM. Nematodes represented 67% of the total species followed by Trematodes and Cestodes. The helminth species with high prevalence in the sludge were *Ascaris lumbricoides* (41.4 eggs/g DM), *Ankylostoma duodenale* (31.5 eggs/g DM), *Fasciola hepatica* (34.9 eggs/g DM) and *Trichuris trichiura* (32.5 eggs/g DM). The physico-chemical parameters had no effect on the parasite concentration. Due to the high helminth egg concentrations in positive samples analysed, the need for proper health and environmental protection measures has to be stressed to prevent helminthic disease transmission due to untreated sludge discharge into the environment after pit latrine emptying or via direct agricultural use.

Key words | health consideration, parasite, pit latrine, tropical urban area, waste management

Wilfried Arsène Letah Nzouebet (corresponding author)
Ives Magloire Kengne Noumsi
Wastewater Research Unit, Faculty of Science,
University of Yaounde I,
P.O. Box 812,
Yaounde,
Cameroon
E-mail: *wnzouebet@ymail.com*

Andrea Rechenburg
GeoHealth Centre, Institute for Hygiene and Public Health,
University of Bonn,
Sigmund-Freud-Str. 25,
Bonn 53105,
Germany

INTRODUCTION

Adequate sanitation is an important foundation for health, economic development and well-being (Bartram & Cairncross 2010). In low- and middle-income countries, most urban dwellers (>70%) use mainly on-site sanitation systems such as pit latrines, public toilets and septic tanks for excreta and wastewater disposal (Tilley *et al.* 2014). In areas where access to sustainable sanitation, i.e., safe storage, collection, treatment and safe disposal/reuse of faeces and urine is insufficient or poor, parasites spread in the natural environment (Bartram & Cairncross 2010). Lack of sanitation leads to several diseases, and diseases associated with poor sanitation are particularly correlated with poverty and are responsible for about 10% of the global burden of diseases. In fact, about half the urban population of Africa have diseases associated with poor sanitation, hygiene and water (Wolf *et al.* 2014). It has been stated that 1 g of fresh excreta from an infected person can contain around 10^6 viral pathogens, 10^6–10^8 bacterial pathogens, 10^4 protozoans cysts or oocysts and 10–10^4 helminth eggs. The geohelminth *Ascaris lumbricoides* is a global health concern because it infected nearly 800 million people in 2010, especially in tropical and subtropical regions (Pullan *et al.* 2014). The negative health outcomes of these infections are numerous and include morbidity due to nutritional impairment, negative impact on child growth, cognitive development and

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worker productivity (Bethony *et al.* 2006). Helminth infections are acquired from an environment contaminated by worms' infective stages that developed from their fertilized eggs (Pullan *et al.* 2014). People infected with helminths pass eggs in their faeces, which will then mature in the environment before becoming infective again. Thus, the storage practice of human excreta is an important factor to reduce the risk of infections with helminths (Yen-Phi *et al.* 2010; Stenström *et al.* 2011).

The survival of parasites outside the host depends on environmental conditions. There are many abiotic and biotic factors, such as temperature, which affect resistant stages of parasite eggs (Manser *et al.* 2015). Pecson *et al.* (2007) revealed that there are some factors that may contribute to the survival of *Ascaris* eggs in sewage sludge including temperature and pH. Another chemical factor known to affect the survival of helminth eggs is ammonia. It was shown that an increase of the pH may be favourable to the conversion of NH_4^+ to NH_3, a chemical element which is known to inactivate many pathogenic organisms (Thangarajan *et al.* 2014). Inactivation of *Ascaris* eggs was found to be proportional to the concentration of NH_3 (Fidjeland *et al.* 2015). Also, lack of oxygen suppresses the overall metabolism of many nematodes (Etewa *et al.* 2014). The biological factors that have been shown to affect parasite eggs include the presence of fungi and various invertebrates. Results from de Carvalho *et al.* (2014) indicated that ovicidal fungi were capable of attacking and destroying *Ascaris lumbricoides* eggs. Additionally, desiccation (solar drying), which is a parameter depending on the water content, may influence the survival of helminth eggs. Indeed, the observations made by Seck *et al.* (2015), working on the effects of solar drying on helminth eggs' removal in unplanted drying beds treating faecal sludge (FS) under tropical conditions revealed high effects of solar drying on the die-off of helminth eggs.

The presence of helminth eggs in FS limits its options for reuse (Nelson *et al.* 2004; Maya *et al.* 2012). Despite the potential health risks, human excreta is a valuable resource as a fertilizer for agricultural production (Appiah-Effah *et al.* 2015). Excreta contains nutrients such as phosphorus, nitrogen and potassium, which are essential to plant growth. Thus, application of excreta in agriculture can help communities to increase agricultural productivity through the recycling of nutrients while saving on cost for chemical fertilizers, resulting in economic benefits (Buit & Jansen 2016). The use of human excreta is a common practice that has long been part of the agricultural tradition in Vietnam (Yen-Phi *et al.* 2010). Various biological processes have been studied to determine the effectiveness of parasites' inactivation in domestic wastewater/FS during treatment processes (Jimenez *et al.* 2000). However, there is limited knowledge about the survival, the prevalence and diversity of parasites in the storage devices. Knowledge of the prevalence and diversity of parasites in pit latrine sludge could contribute to the choice of appropriate technologies for the inactivation of parasites during storage before treatment. In this study, the diversity and prevalence of helminth eggs in pit latrine sludge were assessed as well as the relation between the physico-chemical parameters and the helminth egg content.

MATERIALS AND METHODS

Study area context

The study was carried out in Yaounde (Cameroon), an urban area of about 256 km^2, limited by latitudes 03°45′ and 04° N and longitudes 11°20′ and 11°40′ E (Figure 1). The town is located at about 700–800 m above sea level and had an estimated population of 2.5 million inhabitants in 2011 (BUCREP 2012). Yaounde has an equatorial climate with four seasons: two dry seasons (December–February, July–August) and two rainy seasons (March–June, September–November). The average annual rainfall is 1,600 mm with an average temperature of 23 °C. Facing overpopulation, like many other towns in developing countries, a large part of the capital consists of informal settlements with very basic water supply, sanitation and waste disposal infrastructures (Parrot *et al.* 2009). On-site sanitation systems for excreta collection are widespread, with the predominance of pit latrines (>59%). The city does not have any FS treatment plants and it was estimated that about 700–1,300 m^3 of FS is discharged weekly into the environment of peri-urban areas (Figure 1) (Berteigne 2012).

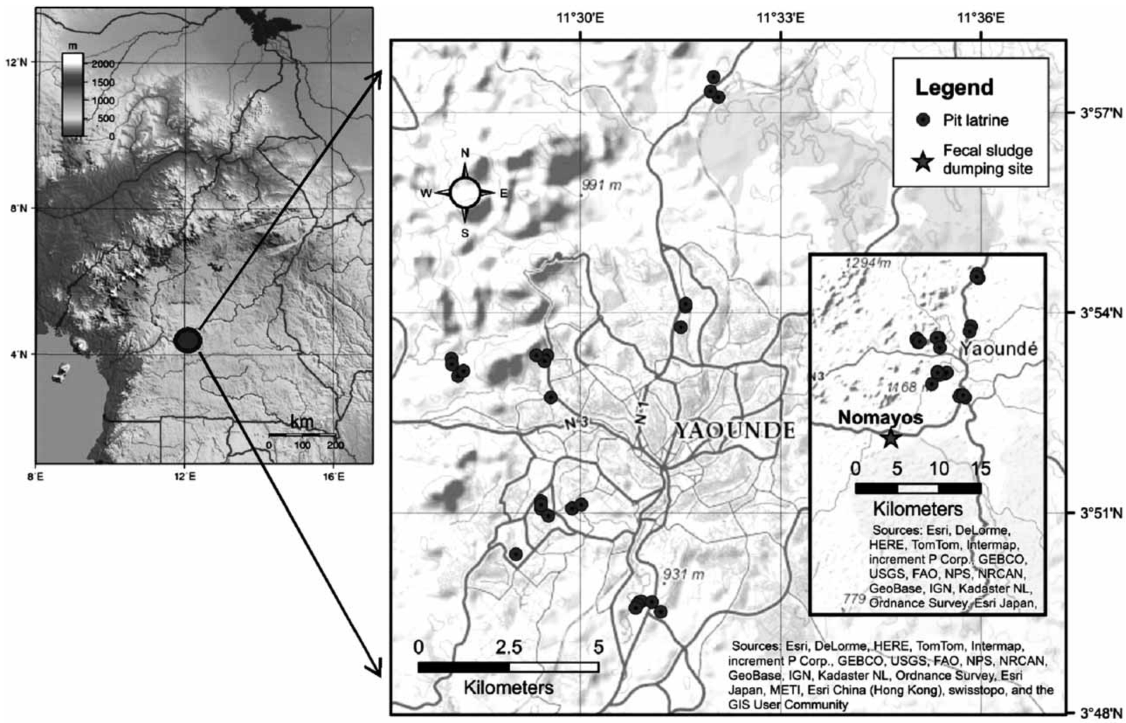

Figure 1 | Spatial distribution of the pit latrines sampled in the study area as well as the illegal FS dumping site (Nomayos).

Assessment method

Prior to the collection of raw sludge samples in pits, a survey of 602 households was conducted in informal settlements and planned settlements of the town to assess the household on-site sanitation facilities' typology as well as their excreta management. Only 53 of the 602 investigated households issued a favourable response for the sampling of their pits, among which 30 were traditional latrines, 13 were septic tanks, 6 were ventilated improved pit latrines and 4 piped equipped latrines (latrines having a pipe for the release of excreta during flooding events). The depth of the pits for latrines investigated and the number of users varied widely from less than 2 m to more than 8 m and from less than 4 persons to more than 10 persons, respectively, for the depth and the number of users.

Only data for sludge from traditional pit latrines are presented in this paper. The sampling material was composed of a metal bar of 1.5 m in length and 3 cm diameter (Figure 2(a)). The metal bar was linked to a metallic box (10 cm in diameter and 20 cm in height), welded at its lower end for collecting the sludge, and the upper end was connected to a 15 m graduated rope. The use of the rope allowed the sampling team to sample deep latrines found in the study area. The mass of the metal bar allowed the easy entrance of sampling material into the pit sludge substrate.

The sampling method took into account a number of considerations including a non-destructive operation: removal of sludge through the hole of the slabs in the latrine and easy cleaning after the sampling operations. Sampling was performed in the first 2 m of the sludge layer after vigorous stirring with the device. Additionally, the depth of the pits (the height between the surface of the sludge layer and the slab of the latrine) was measured as well the information about the size of the pits, the number of persons using the latrines and the presence of other material in the pits. Observations made in the field during sampling showed that the pits investigated were still being loaded with fresh faeces and all of them were simultaneously used for bathing. Additionally, solid wastes were found in the investigated pits and consisted of menstrual hygiene products, plastic materials, papers, clothes, baby diapers, broken glasses, and other waste materials (Figure 2(b)).

Figure 2 | Solid wastes found in the pits of the latrines investigated during FS sampling: (a) clothes and (b) a mixture of wastes in a shallow pit.

Analysis of samples

Physico-chemical parameters such as pH, electrical conductivity (EC), salinity, chemical oxygen demand (COD), biochemical oxygen demand for 5 days (BOD_5), nitrogen ammonia (NH_4^+), moisture content and dry matter (DM) are known to affect helminth eggs' survival in the environment. The parameters were chosen to access their potential effects on the prevalence and diversity of helminth eggs in this study. pH was chosen because of its indirect role in the inactivation of helminth eggs and water chemistry processes. EC and salinity are known to affect the surrounding environment by their osmotic effects. The nitrogen ammonia (NH_4^+) and the moisture content (affected by the desiccation rate) are known to inactivate helminth eggs in the environment. DM is known to affect the concentration of helminth eggs in sludge, as they constitute a part of the total solids and behave as particles in solution.

Analyses were made following standard protocols for water and wastewater analysis (APHA/AWWA/WEF 2005). Parasitic characterization of samples was performed by the determination of their concentrations and diversities of helminth eggs. This determination of helminth eggs was performed following the protocol described by Schwartzbrod (2003). The method was based on the separation and concentration of sludge solid fractions in an interphase of ethyl acetate solution and flotation with a solution of zinc sulphate with a relative density of 1.18. Samples were observed and identification of the different species of helminth eggs was made using the key for identification of intestinal parasites of the World Health Organization (WHO 2006). The number of eggs was counted in a McMaster chamber and the prevalence was calculated according to the following formula: $N = YM/CV$, with N = number of eggs per litre of sample; Y = mean number of helminth eggs counted in the different chambers observed (because three chamber McMaster cells were used in this study); M = volume of final product (mL); C = volume of the McMaster cell (0.3 mL); V = volume of sample (L).

Statistical analysis

Data analyses were performed using the software SPSS 22. Pathogens' detection frequencies as well as the distribution of their diversity in samples were examined. Descriptive statistics of the samples were undertaken to express the parameters' dispersion. Due to the non-normal distribution in the prevalence and diversity of parasites in this study, Spearman rank correlation test was computed to assess the relationship between helminth egg species and the total helminth eggs in samples as well as the description of the relationship between the parasitic and physico-chemical parameters of the sludge. Levene's test for homogeneity of variance was used to access the parameters' dispersion. The level of significance was set to $p < 0.05$ for the analysis of variance.

RESULTS AND DISCUSSION

Physico-chemical characteristics of sludge

The storage duration of sludge in the latrine pits was found to be highly variable among the latrines investigated. It varied between a period of less than 2 years to more than 20 years. The mean value of the pit operation period before emptying, recorded in this study, was 8.4 years with standard deviation of 6.01.

The physico-chemical characteristics of the sludge samples of the 30 pit latrines are shown in Table 1. Levene's test for homogeneity of variance revealed a significant variation between the 30 samples analysed, considering the physico-chemical parameters tested. Regarding the pH, the minimum value measured was 5.9, attaining a maximum of 8.9 with a median of 7.2, showing that the pit latrine sludge pH studied is slightly basic. Samples also exhibited a high solids content with a median value of 44.8% of DM. Medians for EC and salinity were, respectively, 4.8 mS/cm and 2.4‰.

The high concentrations illustrate that the samples were strongly concentrated by inorganic dissolved solids and cations. Very high variation could be seen in the distribution of organic contents in the samples. Values recorded for COD varied between 0.4 g O_2/L and 124.2 g O_2/L, with a median value of 34.0 g O_2/L. High variation of BOD_5 concentration was also noted with a median value of 3.2 g O_2/L. As for other physico-chemical parameters, the distribution of NH_4^+ showed a high heterogeneity, and varied between 0.01 and 2.5 g/L, with a median value of 0.3 g/L. The median value of moisture content found in this study was about 55.2%, and this fell within the range reported in the literature (50–60% of the total weight; Bakare *et al.* 2012).

However, water content values of more than 80% were recorded by Radford & Fenner (2013) working on the fluidization of synthetic pit latrine sludge. The variation in the concentration of FS parameters has been mentioned by several authors (e.g., Strauss *et al.* 1997; Bassan *et al.* 2013). The findings of Bakare *et al.* (2012) revealed that the variation of sludge from on-site sanitation systems can be attributed to household habits and local environmental conditions. This includes differences in storage duration, toilet usage, inflow and water infiltration into the latrine pits.

The higher values of organic matter (BOD_5 and COD) obtained in samples could be explained by the variation of biodegradation process taking place in the latrine pits. Chen *et al.* (2014) mentioned the influence of anaerobic degradation processes taking place in on-site sanitation systems on FS characteristics. The rate and intensity of these anaerobic processes vary according to the system design, the retention periods and the presence of inhibiting substances. The findings of this study correspond to those obtained by Kengne *et al.* (2008), who characterized 44 sludge samples provided by vacuum trucks in an FS treatment plant in Yaounde (Cameroon). The authors pointed

Table 1 | Descriptive statistics of the physico-chemical parameters of sludge samples (n = 30)

Sludge parameters		pH	EC (mS/cm)	Salinity (‰)	COD (g O_2/L)	BOD_5 (g O_2/L)	NH_4^+ (g/L)	TKN (g/L)	DM (%)	Moisture content (%)
Minimum		5.9	0.2	0.1	0.4	0.1	0.01	0.04	32.7	44.4
Maximum		8.9	17.2	10.1	124.2	18.5	2.5	4.9	55.5	67.3
Median		7.2	4.8	2.4	34.0	3.2	0.3	1.7	44.8	55.2
Std deviation		0.8	3.8	2.5	34.1	4.2	0.6	1.6	6.3	6.3
Percentile	25	6.74	3.3	0.7	14.2	2.1	0.2	0.9	38.5	52.5
	75	7.9	8.9	4.7	58.2	7.7	1.2	3.5	47.7	61.9
Kengne *et al.* (2008)		6.5–9.3			30.5		0.4	0.9	2.9	
Heinss *et al.* (1998)					20–50		2–5		≥3.5	
Bassan *et al.* (2013)					12.4	2.1				

out that there is a significant difference between samples according to the distribution of the parameters' DM, pH, COD and NH_4^+. Differences observed between the concentration of DM recorded in this study and the results of Kengne *et al.* (2008) could be explained by the fact that FS collected directly from on-site sanitation systems (this study) did not have the same quality as FS being discharged at treatment plants, because water is frequently added into the pit to dilute FS during mechanical emptying.

Effect of physico-chemical characteristics of FS on the prevalence of helminth eggs

Our results demonstrated no significant effects of the physico-chemical parameters on the prevalence of helminth eggs (Spearman rank correlation; 0.05 level).

Hygienic quality of sludge

Helminth eggs in sludge may pose significant health risks to exposed populations through direct or indirect contact. Helminth eggs were detected in 100% of pit latrine sludge tested, corroborating the study of Yen-Phi *et al.* (2010) in Vietnam. Berteigne (2012) estimated that about 900 to 1,350 m^3 of untreated FS is discharged weekly into the peri-urban area of Yaounde (Cameroon). Thus, treatment is necessary to minimize the risk of helminth infection by excreta. This study revealed heterogeneity in the distribution of helminth species and the total helminth eggs (Table 2). The detection frequencies among individual helminth species varied significantly. *Ascaris lumbricoides* was detected in over 70% of all samples, which is in line with the results of previous studies (Koné *et al.* 2007; Yen-Phi *et al.* 2010), indicating a high prevalence of Ascariasis in the population. Indeed, observations by Nkengazong *et al.* (2010), assessing the prevalence of geohelminths in 420 Cameroonian pupils, revealed a high prevalence of *Ascaris* eggs. The predominance of *Ascaris* eggs in the sludge samples could also be explained by high egg production (200,000 eggs/day) and durable eggs (Feachem *et al.* 1983). The parasite *Ankylostoma duodenale* had the lowest detection frequencies (13.79%) (see Table 2). Nematodes represented 67% of the total species, followed by Trematodes and Cestodes. The helminth species prevalence (median values) found in samples were *A. lumbricoides* (41.4 eggs/g DM), *A. duodenale* (31.5 eggs/g DM), *Fasciola hepatica* (34.9 eggs/g DM), *Trichuris trichiura* (32.5 eggs/g DM), *Strongyloides stercoralis* (24.8 eggs/g DM), *Taenia* sp.

Table 2 | Concentration of helminth eggs found in FS

		Median		Minimum		Maximum		Std deviation		Percentile			
										25		75	
Helminth eggs	***n***	**Eggs/L[a]**	**Eggs/g[b]**	**Eggs/L[a]**	**Eggs/g[b]**	**Eggs/L[a]**	**Eggs/g[b]**	**Eggs/L[a]**	**Eggs/g[b]**	**Eggs/L[a]**	**Eggs/g[b]**	**Eggs/L[a]**	**Eggs/g[b]**
Ascaris lumbricoides	21	16,667	41.4	667	1.9	36,667	90.3	11,039	26.8	6,667	13.9	21,833	60.9
Ankylostoma duodenale	4	16,611	31.5	4,222	9.4	32,000	81.0	12,262	31.6	9,306	17.4	29,556	71.4
Enterobius vermicularis	11	8,667	22.7	3,333	7.1	20,000	61.1	7,004	19.7	4,167	8.9	19,778	38.7
Fasciola hepatica	7	16,222	34.9	1,111	2.8	30,000	66.8	9,098	20.3	10,778	20.1	18,889	37.5
Hymenolepis nana	7	5,556	13.4	3,333	6.6	16,667	48.8	4,572	14.3	4,389	10.0	7,556	18.6
Schistosoma mansoni	8	11,389	22.8	4,444	8.5	32,222	79.7	9,867	25.5	5,805	12.2	21,833	51.7
Strongyloides stercoralis	13	10,889	24.8	4,333	8.5	40,889	107.2	11,838	27.5	7,333	18.9	18,778	37.0
Taenia sp.	11	10,000	24.7	667	1.7	26,667	64.2	8,815	19.0	8,333	18.2	22,444	45.4
Trichuris trichiura	6	13,444	32.5	4,445	9.3	22,889	67.0	8,432	22.7	5,945	17.5	20,722	56.0
Total helminth eggs	30	33,222	81.1	37,778	8.5	100,889	264.5	30,522	74.5	15,222	38.9	70,889	155.2

[a]Helminth eggs per litre of sludge.
[b]Helminth eggs per gram of DM.

(24.7 eggs/g DM), *Enterobius vermicularis* (22.7 eggs/g DM) and *Hymenolepis nana* (13.4 eggs/g DM). The diversity of helminth species found in the samples is in accordance with Jimenez *et al.* (2000), who characterized wastewater sludge in Mexico and Yen-Phi *et al.* (2010), who characterized FS in Vietnam. The high variability in terms of number and diversity of helminth eggs could be attributed to the health status of pit latrine users, the epidemiological conditions of the populations in the study area as well as the storage condition in the pit of the latrines. By assessing pathogens in septage in Vietnam, Yen-Phi *et al.* (2010) recorded a correlation between helminth ova concentration and retention time of FS. In Vietnam, in order to reduce human health risks associated with excreta use in agriculture, the Vietnamese Ministry of Health has stipulated the time for human excreta storage in latrines to be at least six months before application as fertilizer (Jensen *et al.* 2008). Strauss *et al.* (1997) reported the effect of storage duration on FS stabilization. The effects of retention time could not be applied to explain the prevalence and diversity of helminth eggs recorded in our study as pits were sampled while in use.

The most prevalent helminth eggs found among the nine species identified is *A. lumbricoides*, which is in accordance with data reported in the literature stating that Ascariasis is globally one of the most frequent causes of helminthic infections (Pecson *et al.* 2007). Furthermore, *Ascaris* eggs are also characterized by their high resistance to environmental conditions, such as pH, temperature, desiccation, etc. (Ingallinella *et al.* 2002; Cofie *et al.* 2006; Koné *et al.* 2007). As the observed parasite egg concentrations in samples were higher than the limit recommended in the WHO (2006) guidelines for safe use of excreta in agriculture (<1 egg/g of DM), the need for proper health and environmental protection measures has to be stressed, in order to avoid the transmission of helminthic diseases through untreated sludge discharge into the environment or direct agricultural application. Mara & Sleigh (2010) pointed out that the persistence of helminth eggs in the environment is the most important risk factor for disease transmission. To prevent disease transmission, it is necessary to apply particular interventions for safe disposal and storage of excreta. The number of species found varied from 1 to 6 per sample with more than 70% of the sample containing more than one species. The difference in the number of helminth species found could be explained by the different transmission routes of helminth eggs and the latrine user's specific risks factors. Traub *et al.* (2004) demonstrated that the transmission of helminth eggs is influenced by several factors like micro-climate, sanitation, hygiene and environmental contamination with human excreta.

Our findings could contribute to the knowledge of helminthiasis epidemiology in the studied area. Furthermore, the presence of many helminth species in FS could result in co-infections (poly-parasitism) of farmers using faecal matter for crop fertilization. In the tropics, it is common for a single individual to be infected with several parasite species at the same time (Jensen *et al.* 2008). Assessment of the relationship between parasite species and the total helminth eggs using Spearman rank correlation was done. Significant relationships at 0.05 level were observed between *S. stercoralis* and *A. lumbricoides* ($R^2 = 0.620$), *A. lumbricoides* and the total helminth eggs ($R^2 = 0.694$), *S. stercoralis* and the total helminth eggs ($R^2 = 0.863$), *T. trichiuria* and the total helminth eggs ($R^2 = 0.829$). The said correlation could be explained by the fact that the helminth species involved in the correlation presented a similar distribution/pattern according the detection frequency in samples.

CONCLUSION

The prevalence and diversity of helminth eggs detected in pit latrine sludge collected from various locations in Yaounde indicate an infectious risk if the sludge is not properly managed. The sludge showed high variations of physico-chemical parameters and helminth egg concentrations. Nevertheless, physico-chemical parameters were not found to be associated with the prevalence of helminth eggs. All samples were characterized by a very high load of helminth eggs, thereby constituting a very high health risk for the population. Based on these findings, there is a need for further assessment on the public health implications of helminth infections as well as the sludge treatment process for parasite die-off or inactivation. In order to minimize the risks of infections along the FS management chain, investigations of helminthic organisms in sludge should receive more attention for health planning and environmental protection measures.

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