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Contribution to the study of faecal sludge as a resource for the city and province of Kinshasa in the Democratic Republic of the Congo

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ABSTRACT

Introduction

Self-contained sanitation systems such as septic tanks, latrines, and public toilets store faecal sludge, which must be regularly evacuated. If this sludge is not regularly collected, transported, and treated in a wastewater treatment plant, it can cause serious harm to the environment and public health.

Purpose

This study aimed to show that the biosolids resulting from the treatment of septage collected in Kinshasa in the Democratic Republic of the Congo are uncontaminated and contain nutrients and properties that make them a resource to be valorized.

Methods

The present study was carried out in Kinshasa between January and March 2022. Samples of fresh faecal sludge were taken at Ndolo/auto service, a site where tanker trucks dump sludge from all over the city into a stream that flows into the Congo River. Pathogen levels were detected by counting bacteria. Helminth eggs were identified following the US Environmental Protection Agency's "*Rule 503*" recommendations for Class A and B biosolids. Total nitrogen was determined by the Kjeldahl method, while phosphorus and potassium were determined spectrometrically. Statistical analyses were performed using Excel 2021 and SPSS v.21 software.

Results

The results obtained showed values <103 for all germs tested: *E. coli*, faecal coliforms, total coliforms, streptococci, and staphylococci in GS, MC, and Sabouraud media. No active helminth eggs were found. The results of this study showed that treated sludge contains major nutrients such as nitrogen, phosphorus, and potassium (NPK). Nitrogen content ranged from 1.2 mg/Kg to 7.6 mg/Kg, phosphorus from 2 mg/Kg to 3.2 mg/Kg, and potassium from 0.2 mg/Kg to 0.6 mg/Kg. These distributions show that over 95% of the levels of each element are within the confidence zone and indicate a strong correlation between the values of the different biosolids samples.

Conclusion

The analyses carried out have shown that sewage sludge obtained from unplanted drying beds in Kinshasa offers very appreciable average nutrient values, which can be used in agriculture and in the rehabilitation of mining sites.

INTRODUCTION

In most secondary towns in sub-Saharan Africa, there is no sewage system. Excreta is collected in individual household sanitation systems (Montangero et al., 2002). Self-contained sanitation systems such as septic tanks, latrines, and public toilets store faecal sludge, which must be regularly evacuated (Strauss & Montangero, 2002). If this sludge is not regularly collected, transported, and treated in a wastewater treatment plant, it can cause serious harm to the environment and public health (Defo et al., 2015). Environmental pollution can be caused by odour emissions from septic tanks, latrines, or public toilets that are not emptied regularly. Sewage sludge dumped in an uncontrolled manner into the environment because of **a** lack of adequate disposal systems linked to poor management and lack of financial resources, can pollute surface and groundwater, soil, and air, destroying the balance of ecosystems and causing water-borne diseases (Blunier et *al.,* 2004). All these problems could be avoided with an appropriate system of faecal sludge management, involving an adequate system for emptying sewage systems, providing minimum risk during handling and transport, and a sludge treatment system leading to safe disposal or reuse in agriculture (Heinss et al., 1998). When this sludge is not collected, transported, and properly treated in a sewage treatment plant, it can cause major environmental and public health problems (Defo et al., 2015). Malodorous fumes from septic tanks, latrines, or public toilets that are not emptied regularly contribute to air pollution. What's more, the uncontrolled discharge of faecal sludge into the environment, because of poor management and financial constraints, can contaminate surface water, groundwater, and soil, and upset the balance of ecosystems, leading to water-borne diseases (Blunier et al., 2004). So, in this constant drive to find sustainable solutions to environmental and socio-economic challenges, sewage sludge is emerging as a valuable and under-exploited resource, as it constitutes a nutrient-rich organic matter that can be applied as a fertilizer to improve and maintain soil productivity and stimulate plant growth (Defo et al., 2015). At the heart of this problem lies the provincial city of Kinshasa, in the Democratic Republic of the Congo (DRC), where demographic growth is accompanied by increased waste production, whose poor management is leading to increasingly critical situations for the environment and human health (Vuni et al., 2022). Faced with exponential population growth and often precarious infrastructures, the need to rethink how waste, including faecal sludge, is managed and valorized has become imperative. The present study is part of this process, providing an essential contribution to the study of faecal sludge as a potential resource to be valorized for the city of Kinshasa. The study aimed to show that the biosolids resulting from the treatment of septage collected in Kinshasa in the Democratic Republic of the Congo are uncontaminated and contain nutrients and properties that make them a resource to be valorized. Through this study, we aspire to contribute to the advent of a cleaner city, while offering a relevant and applicable reflection to other urban contexts facing similar challenges.

METHODS

Study area

Kinshasa, where the experiment was conducted between January and March 2022, is the capital of the Democratic Republic of the Congo and is considered the country's navel (Reybrouck, 2012). Located between 4° and 5° South latitude, and between 15° and 16° East longitude, it is the largest city in the Democratic Republic of Congo, with an estimated population of over 12,000,000. It covers 9,965 km^2 (De Saint Moulin & Kalambo, 2005; Kamb, 2013). The city of Kinshasa enjoys an AW4 tropical climate according to Köppen's classification. The very dry season extends from late May to mid-September (Nicolaï, 2009). According to Tshibangu et al. (1997), this climate is influenced by its proximity to the Atlantic Ocean, particularly by the south-westerly trade winds and the cold Benguela marine current. The dry season begins in late May and ends in mid-September. The remainder of the year is characterized by a rainy season, interspersed by a short dry season between January and February, which is becoming increasingly unpredictable as the climate changes. Average maximum temperatures in the provincial city of Kinshasa recorded at the Mbinza weather station ranged from 30°C in January to 31.1°C in March 2022, and total rainfall in mm for the same period ranged from 211.1 in January to 151.8 in March. The hydrographic network of the city of Kinshasa comprises the Congo River and its main left-bank tributaries, most of which crisscross the city from south to north. These are mainly the Lukunga, Ndjili, Nsele, Bombo, or Mai-Ndombe rivers and the Mbale (Shomba et al., 2015). Alongside these, there are also the Gombe, Kinkusa, Bitshaku-sthiaku, Kalamu, Lukaya, Mango, Tshwenge, Funa, Bumbu and Mangengenge rivers (Kamb, 2018).

Sample collection

Fresh sewage sludge samples were collected at Ndolo/auto service, a site located at longitude 15°20'9.797" East and latitude 4°19'31.578" South, where tanker trucks dump sludge from all four corners of the city into a stream that flows into the Congo River, to obtain a representative sample. A 25-litre container was filled (3/5 of a 15-litre quantity) with sludge using the driving pressure exerted in a vacuum truck hose and taken to the JEEP garden (Jardin et Elevage des Parcelles), part of the Faculty of Science and Technology at the University of Kinshasa. An area was set aside to store and conduct experiments, under a hangar where the pilot plant for sludge treatment using an adapted unplanted drying bed was erected.

Samples of biosolids (treated sludge) were collected at the treatment plant after 21 days, at several locations: 7 different points were randomly selected in the drying basin where the dried sludge (biosolids) had been collected at a rate of 3 samples per point, giving a total of 21 samples for analysis.

Treatment of faecal sludge

Given the lack of sewage sludge treatment facilities in the city of Kinshasa, the study included an objective to set up a pilot treatment platform adapted to unplanted drying beds. The unplanted drying bed is a highly effective sludge treatment technique (Strande et al., 2018; Katherine et al., 2020; Heinss et al., 1998). As a technique, it involves several physical and biological mechanisms including filtration, dewatering, and mineralization (Tadjouwa, 2016), which achieve the four main treatment objectives including stabilization, nutrient management, pathogen inactivation, and waste removal (Velkushanova et al., 2021). It was chosen for its simplicity, availability of land, cost, and climate. The schematic diagram of an unplanted sludge drying bed is shown in **Figure 1**, while **Figures 2** (A and B) illustrate respectively the main components of the deployed pilot platform and the biosolids being formed on the experimental unplanted drying bed.

Figure 1:
Principle of a non-planted sludge drying bed (Tilley et al., 2014)

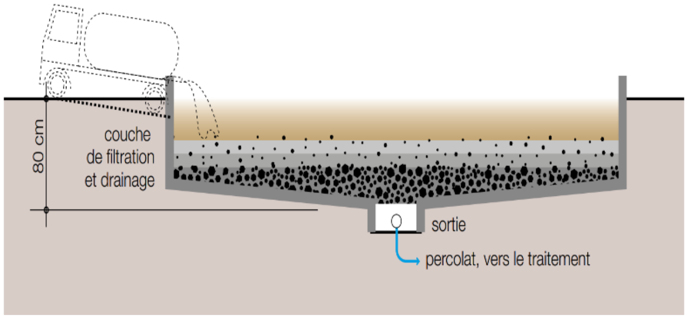

Figure 2:
Treated sludge (biosolids) in drying bed (A), Sludge treatment platform with adapted unplanted drying bed (B)

To start the treatment process, the freshly collected faecal sludge was discharged into a cylindrical reception tank with a capacity of 10 liters and fitted with a 10 mm grid to ensure the retention of coarse debris. Coarse debris is retained by the grid, which allows other, smaller particles and water to pass through. This basin was connected to the second cylindrical basin, with a capacity of 20 L, by a ½ cm diameter PVC pipe. Water and suspended solids were instantly drawn by gravitational force into the second basin, located at a lower level. After undergoing 48 hours of primary treatment in this second cylindrical buffer tank, covering a reduced, continuous flow, the sludge finally flowed into the unplanted drying bed. The drying bed is 0.5 m long and 0.5 m wide and is fitted from top to bottom with 0.09 to 8 mm sand, 10 to 40 mm gravel, and, lastly, 5 to 10 mm fine gravel. The sludge spent 21 days exposed to the sun in the drying bed.

Analysis

Detection of the level of pathogenic germs after treatment of faecal sludge was carried out by enumerating bacteria (*Escherichia Coli*, faecal coliforms, total coliforms, streptococci, and staphylococci) and helminth eggs according to the recommendations of the US Environmental Agency on Class A and B biosolids, "Rule 503" (Tayler, 2020) and the World Health Organization (WHO, 2006). pH- was measured directly using an electronic electrode in a sludge suspension diluted with distilled water (1/2.5). Organic carbon was determined by the method of Walkley and Black (1934). Total nitrogen was determined by the Kjeldahl method. Assimilable phosphorus was determined by atomic absorption spectrophotometer using the Bray-II method (Bray & Kurtz, 1945). Total phosphorus and total potassium were obtained by multi-element extraction. Conductivity was measured using a WTW INOLAB- Cond 7310 glass electrode conductivity meter immersed in a 1/5 suspension (1 volume of sludge to 5 volumes of distilled water). Dryness was assessed by the amount of solid remaining after heating at 110°C for two hours in the oven (Bray & Kurtz, 1945). Descriptive statistics was used to analyze the data collected. The normal distribution law of a set of elements concerning their mean was used to observe the correlation and disparity of the samples studied. To this end, the mean μ, standard deviation σ, upper control limit μ+2σ, and lower control limit μ-2σ were calculated. According to this law, all items in the interval [μ-2σ - μ+2σ] are in the high-correlation confidence zone and should represent 95% of the study population. Otherwise, i.e., when more elements of the population studied deviate from the confidence zone (less than 95% in the confidence zone), it is difficult or even impossible to establish the correlation. Statistical analyses were carried out using Excel 2021 and SPSS v.21.

RESULTS AND DISCUSSION

Bacteriology

The results obtained show values $<10^3$ for all the germs tested, i.e., *Escherichia Coli*, faecal coliforms, total coliforms, streptococci, and staphylococci in GS, MC, and Sabouraud media, and indicate the absence of turbidity in Thio **(Table 1)**. Microbial growth below 10^3 is insignificant and in line with US Environmental Protection Agency regulations and WHO guidelines (Qin & Stoffella, 2012; Tayler, 2020). The search for helminth eggs resulted in the observation of no active eggs. Pathogen surveillance is essential for public health protection and to protect workers handling sludge (WHO, 2006). Helminth eggs stand out as one of the most resistant pathogens to eliminate during treatment, and *E. coli*, as it is a type of faecal coliform that is used as an indicator of faecal contamination or other organisms that may be present (Velkushanova et al., 2021). Experiments carried out in Accra, Ghana, on biosolids obtained after treatment with drying beds had revealed that dewatered sludge with a dryness < 40% still had considerable helminth egg concentrations. This was not surprising, as drying periods were 12 days maximum (Heins et al., 1998). In experiments where dry matter contents reached values >70%, no helminth egg concentrations were observed. (Heins et al., 1998). Cofie (2006) confirmed these same results (Tadjouwa, 2016). According to the guidelines of the National Water Services Commission in Malaysia, sludge must be dewatered and treated, and the total solids content in liquid form must not exceed 4.0%. In addition, it must reach a dry matter content of at least 20% before being disposed of or used for other purposes (Tan et al., 2003). Studies have shown that sludge dewatered by reed-planted drying beds can reach a dry matter content of 25-40%. (Tan et al., 2003). In this study, the treatment time was 21 days with an average dryness of 67.8 **(Table 5)**, placing it around 70%. This provides an additional element confirming the non-contamination of the product obtained. **Table 1** gives the bacteriological dynamics of biosolids based on culture media.

Table 1:
Bacteriological dynamics of biosolids based on culture media

Germes	GB*	MC*	Sab*	Thio*
C.F*	$< 10^3$	$< 10^3$	$< 10^3$	$< 10^3$
C.T*	$< 10^3$	$< 10^3$	$< 10^3$	$< 10^3$
Strep*	$< 10^3$	$< 10^3$	$< 10^3$	$< 10^3$
Staph*	$< 10^3$	$< 10^3$	$< 10^3$	$< 10^3$

GB : Fresh blood gelose; MC: mac conkey; Sab: sabouraud; Thio: Thioglycolate; C.T: total coliforms; C.F: Faecal coliforms; Strep: *Streptococcus*; Staph: *Staphylococcus*.

The World Health Organization considers that the above-mentioned indicator values should not be the sole basis for assessing the sterility of the treated product. The WHO rightly recommends that possible limitations also be considered, given that quantitative microbial risk assessment remains the most robust method alongside the bacteriological analysis used here and epidemiological studies, and that knowledge of the impact of the use of faecal sludge on public health still needs to be further developed (WHO, 2006). The WHO therefore rightly recommends adopting a multi-barrier management approach to the use of treated sludge. Treated sewage sludge should not be used for vegetables, fruit, or root crops intended for raw consumption, except for fruit trees. The mobilization of barriers also includes measures relating to food preparation (washing, disinfection, peeling, cooking) and the prevention of human exposure, as well as hygiene education. Finally, a withdrawal period must be applied between fertilization and consumption, to allow resistant pathogens to die out. This period should be at least one month (WHO, 2006). Based on the results obtained through this study, the WHO recommendations are to be adopted as complementary actions when all three approaches proposed by the WHO cannot be implemented, often due to a lack of resources.

Nutrients and other parameters

Observations show that biosolids nitrogen values are in the range 1.2 mg/Kg - 7.6 mg/Kg with an average value of 4.4 mg/Kg, total phosphorus values are in the range 2 mg/Kg - 3.2 mg/Kg with an average value of 2.6 mg/Kg, potassium values are in the range 0.2 mg/Kg - 0.6 mg/Kg with an average value of 0.4 mg/Kg. These distributions show that over 95% of the contents of each element are within the confidence zone and indicate a strong correlation between the values of the different biosolids samples. The nutrient content of treated sewage sludge, as summarized in **Table 2**, confirms that treated sludge contains nutrients, represented here by the major elements nitrogen, phosphorus, and potassium (NPK). **Table 2** gives the Major nutrient content in biosolids.

Table 2:
Major nutrient content in biosolids

Nutrient content in biosolids (mg/Kg)			
Nutriments	K	N	P
Moyenne	0,4	4,4	2,6
Ecart type	1,1	1,3	0,3

Several studies have confirmed the presence of Nitrogen, Phosphorus, and Potassium in biosolids (Heinss et al., 1998; Kingel et al., 2021; Cofie et al., 2006; Wijesekara et al., 2016; Katherine et al., 2020; Segun et al., 2023). A study of nutrient levels in biosolids from over 240 samples collected and analyzed from 12 Pennsylvania wastewater treatment plants between 1993 and 1997 revealed average N, P, and K contents of 4.74 %, 2.27 %, and 0.31 %, respectively. These biosolids underwent aerobic digestion, anaerobic digestion, or alkaline treatment (Qin et al., 2012). Wijesekara et al., (2016) report content of 0.29% and 3.2% total nitrogen, 1.0 % total phosphorus, and 0.13% potassium. Myriam et al. (2019) confirm results close to those obtained through ongoing research regarding the presence of nitrogen, phosphorus, and potassium. Although containing fewer nutrients compared with commercial chemical fertilizers, biosolids are a valuable source of nutrients, containing between 2 and 8% nitrogen, 1.5-3% phosphorus, and 0.1-0.6% potassium (Qin et al., 2012). In comparison with results obtained through other studies, the current study revealed acceptable levels of major nutrients as illustrated in **Figure 3**.

Figure 3:
Comparison of nutrients in this study (E1) with other studies

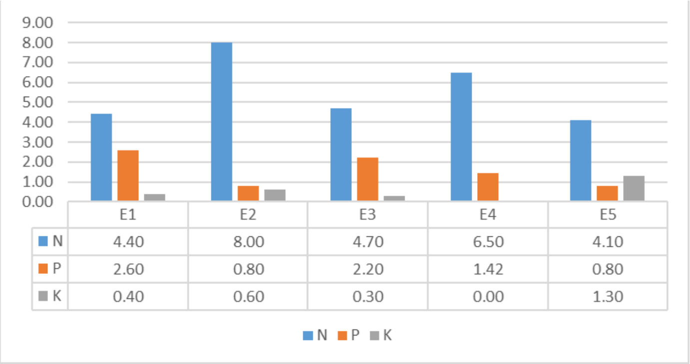

Figure 3 shows that the nitrogen, phosphorus, and potassium contents obtained through this research are very close to those obtained by E5; at the same time, it shows a large discrepancy concerning E3 nitrogen, representing almost double. E5 represents the average of cases studied in Ghana, where biosolids were obtained after treatment by drying beds under climatic conditions very similar to those of the current study. E3 refers to the highest content of the cases studied (Heinss et al., 1998; Tadjouwa, 2016). The other illustrative cases, E6 and E7, refer to situations where biosolids were obtained by anaerobic digestion for E7 and a combination of anaerobic and aerobic digestion for E6 (Myriam, 2019). This could explain the discrepancies observed. The other parameters analyzed in the biosolids obtained (**Table 3**) reinforce the good quality of the biosolids for agriculture and other uses.

Table 3:
Valeurs du pH, Cot, de la CE, des MS et des H.E des biosolides

Parameters	pH	Cot%	CE (ds/m)	MS%
Moyenne	6,9	35,5	6.6	67,8
Ecart type	0.3	0.3	0.2	0,1

The significant values obtained for hydrogen potential, total organic carbon, electrical conductivity, and dryness presented in **Table 5** reinforce the power of biosolids, particularly in mine site revegetation. When used to rehabilitate mine sites, these and other properties can have a considerable beneficial effect. The addition of biosolids improves most soil physical properties in land degraded by mining. The high organic matter content of biosolids is the main cause of improved physical properties in mine-cutting soils. Improvements in physical properties include decreases in bulk density and temperature, increases in porosity and aggregation, increases in hydraulic conductivity and water-holding capacity, infiltration, maintenance of soil texture, and reductions in erosion and sedimentation. Biosolids application increases chemical properties such as pH, electrical conductivity (EC), cation exchange capacity (CEC), nutrient levels, and soil organic matter. Applying biosolids to mine cuttings increases key plant nutrients such as N, P, Ca, and S, thereby enhancing fertility. Biosolids application increases microbial biomass, carbon, and microbial enzymatic activities in subsequent soils receiving mine spoil (Wijesekara et al., 2016). The main nutrients contained in biosolids are in organic form, not as soluble as those in chemical fertilizers, and are released more slowly. Consequently, biosolids can feed plants at a slower rate and over a longer period with greater utilization efficiency and a lower probability of polluting groundwater when the application rate is appropriate (Qin et al., 2012). The good performance observed in the current studies can be explained by the small quantity of sludge to be treated (15 L of fresh sludge on a bed 0.5 m long and 0.5 m wide), the climate (with maximums of 30°C), the nature of the sludge treated (mainly human excreta from septic tanks) and, finally, the treatment time (21 days). The properties of biosolids do indeed depend on the combination of several parameters (Giwa et al., 2023). This scientific contribution focused primarily on the removal of contamination from treated septage and the analysis of major nutrients. It did not assess the possible presence of heavy metals and emerging contaminants, whose presence at unauthorized levels may prove problematic for ecosystems and public health.

CONCLUSION

The study showed that biosolids obtained from the treatment of sewage sludge by unplanted drying beds in Kinshasa, Democratic Republic of Congo, offer very appreciable average nutrient values and properties and that the DRC should stop wasting them and exposing the environment and public health by dumping them untreated into ecosystems. They can be used in agriculture and the rehabilitation of mining sites. It should be pointed out, however, that depending on the results of this study, restrictions must be imposed on the use of the product. Hence the benefit of the multi-barrier approach proposed by the World Health Organization. Further research may focus on analyzing the presence or absence of other chemical substances, pharmaceuticals, etc., which may be harmful to human health and the environment.

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Ethical Approval: Not applicable

Conflicts of Interest: None declared.

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