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Optimization of the design and operation of faecal sludge dewatering stations

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ABSTRACT

Population growth and urbanization have encouraged the whole world to revamp the sanitation system safely through proper BV management value chain. The objective of this paper was to estimate the potentialities of adaptation in West Africa under a Sudano-Sahelian climate of a process for the treatment of fecal sludge by unplanted drying bed as well as the practical modalities of its implemented to achieve reliable and efficient processing with this type of device. This study was carried out in Togo more precisely in the municipality of Kozah 1. Experimentally, the study is carried out on a pilot system with an area of 0.2 m^2. The determining parameters in the management of faecal sludge have been taken into account at the physical, chemical and microbiological level. The acceptable average organic load after 32 days of drying is 165 Kg DM/year/m^2 with raw sludge and biosolids having respectively the physico-chemical characteristics: 960 mgO_2/L, 384 mgO_2/L for COD; 2814 mgN/L, 1620 mgN/L for NTK; 174.4 mg P/L, 73 mgP/L for P-PO_4^{3-}. The volume relative humidity remaining after 32 days of regular monitoring is 12%. Microbiological germs such as *E. coli*, CF, SF, *Salmonella*, Clostridia and *Listeria* were the subject of this study. The rate of their elimination is respectively: 57%, 100%, 43%, 57%, 100%, 66%. These results show that the system put in place is effective.

Keywords: Drainage**,** filter bed, faecal sludge, filtration, municipality of Kozah 1.

INTRODUCTION

Providing safe sanitation in low-income countries and achieving Sustainable Development Goal (SDG) number six to "ensure availability and sustainable management of water and sanitation for all" (Mallory et al., 2020; WHO, 2019 ; Nguyen, 2015 ; Tagba, 2019) remains a major hurdle to 61% of the global population. Over the past decades, Togo has experienced unprecedented development in the field of sanitation and will experience in the years to come Penn (2021). Faecal sludge, long considered an ancillary operation of waste management, but today its management can no longer be defined lightly.

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In Togo, more specifically in the commune of Kara, the autonomous sanitation system is preponderant and the majority of the populations use this type of sanitation because of its simplicity (Akpaki et al., 2016; Samal et al., 2022). This approach, although suitable for African cities, is poorly implemented and suffers from the insufficiency of certain compartments of the sanitation chain (Théophile et al., 2020). Continued political support may be needed for several decades to sustain and enhance the growth of solar energy in developed and developing countries (Timilsina et al., 2012; Keskes et al., 2012). In fact, the septic tanks are not equipped with infiltration wells and, even worse, the drained sludge is discharged into the natural environment without any treatment (Gnagne et al., 2019). Normally this sludge must follow a preliminary treatment system before being discharged into the natural environment and treatment by solar energy is today one of the most recommended solutions. Faecal sludge, like rejected wastewater, is nowadays an integral part of the system to be purified (Piyabalo et al., 2021). As such, the final treatment of BV goes through well-defined stages, namely dehydration, drying, drainage and evaporation. Solar energy has seen phenomenal growth in recent years due to both technological improvements resulting in cost reductions and government policies supporting the development and use of renewable energy. Natural drying is an economical and environmentally and contextually acceptable alternative (Allariz et al., 2019; Uggetti et al., 2009). Moisture transport within the solid can occur by one or more of the following mass transfer mechanisms (Tilley et al., 2010). The objective of this work was to contribute to providing a deeper analysis of the understanding of faecal sludge dewatering on unplanted drying beds in Kozah 1 commune.

MATERIALS AND METHODS

The methodology is based on two studies: an experimental study and an analytical one.

Experimental study

The filter bed, the aeration and drainage system, the mode of supply and the allowable organic load constitute the experimental study.

Filtering mass

The filter bed is made up of three layers of materials of increasing grain size. From the bottom to the surface, the massif is composed of:

- A draining layer (coarse gravel) 20 cm thick
- A transition layer (gravel) 20 cm of fine gravel and
- A filter layer (sand) of 20 cm with a uniformity coefficient
- $U = \frac{d_{60}}{d_{10}} = 2{,}53$ (Eq 1).

The characteristics of the different materials can be found in Table 1.

Ventilation and drainage device

The Figure 1 produced is inspired by the research work of Kouawa (2016) and Uggetti et al. (2010). The aeration system will consist of two 80-100 mm diameter PVC pipes cut in the lower generatrix with 15-30 mm wide slots spaced 40-55 mm apart. This aeration system was installed in the filter bed. These two pipes are spaced 20-40 cm apart and connected by two chimneys of different heights in order to facilitate the flow of air, one is higher by 0.5 m. the aeration device is placed diagonally in the tank. For percolate drainage, a pipe system is installed to collect the percolate.

Sludge feed mode

Constant volume feeding mode was used. In this mode, there are two feeding/resting phases:

- The 1st phase: dehydration & mineralization with an average feed load of 30 Kg of suspended solids/m^2/year;
- The 2nd phase: physico-bio-chemical abatement with an average supply load of 20 Kg of suspended solids/m^2/year;

Contribution of sludge to the beds:

$$V_i = \frac{0{,}2.d_R.Ch_{MES}}{365.C_i} \quad \text{(Eq 2)}$$

Where: Ch_{MES}: planned mass load (30 Kg of MES in the 1st phase and 20 Kg of MES in the 2nd); V_i: volume provided for supply i (L); The coefficient 0.2 represents the surface of an experimental bed (0.2 m2); C_i: concentration of suspended solids determined before feeding (kg of suspended solids/L); d_R: bed rest time (day).

The allowable average organic load

The average load applied was calculated using the equation 3:

$$C_{bv} = MS * FS/s * NS/an * HBA, \text{ with}$$

$$HBA = \frac{V_B}{S_L} * 10^{-3} \quad \text{(Eq 3)}$$

where: C_{bv}: Applied sludge load (KgMS/m^{-2}/year); MS: Dry Matter (kg/L); FA/s: Feeding frequency/week; NS/year: Number of weeks/years; HBA: Height of sludge per feed day (mm/d); V_B: Volume of sludge per feed day (m^3/day); S_L: Bed area (m^2)

Analytical study

The relation given by equation 4 presents the mode of calculation of the daily purification efficiency of the drying beds.

$$\left[R_i(\%) = 100 \frac{C_{i-sludge}.V_{i-sludge} - C_{i-percolate}.V_{i-percolate}}{C_{i-sludge}.V_{i-sludge}}\right] \text{(Eq 4)}$$

where: $R_i(\%)$: Treatment efficiency for parameter i of faecal sludge (%); $C_{i-sludge}$: Concentration of parameter i in raw sludge (mg/L); $C_{i-percolate}$: Concentration of parameter i in the percolate (mg/L); $V_{i-sludge}$: Volume of faecal sludge (L); $V_{i-percolate}$: Volume of percolate (L).

The calculation of the overall efficiency, after N given power supplies will also be made. Equation 5 presents the mode of calculation of this overall purification of the drying beds when the power supplies are stopped:

$$R_{i-Global} = 100 * \frac{\sum_{k=i}^{N}(C_{i-k-sludge}V_{k-sludge} - C_{i-k-percolate}V_{k-percolate})}{\sum_{k=i}^{N} C_{i-sludge}V_{k-sludge}}$$

(Eq 5)

Where: $R_{i-Global}$: Overall purification yield for parameter i after the N feeds (%); $C_{i.k/sludge}$: Concentration of parameter i in the sludge fed k (mg/L); $C_{i.k/percolate}$: Concentration of parameter i in the percolate at feed k (mg/L).; $V_{k/sludge}$: Volume of faecal sludge at supply k (L); $V_{k/percolate}$: Volume of percolate k (L).

La charge organique admissible et le taux d'humidité relative en fonction du temps sont présentés dans le Tableau 2.

The physical, chemical and biological parameters of raw sludge and bio-solid were studied. Organic pollution such as chemical oxygen demand (COD) and biochemical demand (BOD_5) are evaluated by the measuring reflux system method and by the manometric method respectively. Nitrogen pollution such as nitrates ($N\text{-}NO^{3-}$), nitrites ($N\text{-}NO^{2-}$) and ammonium ($N\text{-}NH_4^+$) as well as phosphorus pollution such as ortho-phosphates ($P\text{-}PO_4^{3-}$) and total phosphate (TP) are evaluated by the spectrometric method. The calculation of the overall yield after N given feeds was evaluated. Equation 6 presents the method of calculating this overall purification of the drying beds when the power supplies are stopped:

$$R_{i-Global} = 100 * \frac{\sum_{k=i}^{N}(C_{i/k/boue}V_{k/boue} - C_{i/k/percolat}V_{k/percolat})}{\sum_{k=i}^{N} C_{i/boue}V_{k/boue}}$$

(Equation 6).

Where: $R_{i-Global}$: Overall purification yield for parameter i after the N feeds (%); $C_{i/k/boue}$: Concentration of parameter i in the sludge fed k (mg/L); $C_{i.k/percolat}$: Concentration of parameter i in the percolate at feed k (mg/L); $V_{k/boue}$: Volume of faecal sludge at supply k (L); $V_{k/percolat}$: Volume of percolate k (L)

Physical parameter

In situ, measurements of pH, conductivity (Cond) and redox potential (Eh) are evaluated using HANNA brand multi-parameters HI 9811 for pH measurement, WTW LF 538 for conductivity measurement and WTW-350i for measuring redox potential. In the laboratory, physical parameters such as measurement of dry matter (DM), suspended matter (MES) and volatile matter (MV), volumetric humidity, organic load. Various parameters commonly used in the characterization of clays such as Density BV

(Kg/m^3), Density of solid particles (Kg/m^3) and Water content (mass) are also evaluated in order to be able to simulate sludge-clay.

Microbiological parameters

Microorganisms present in the raw BV and in the bio-solid are evaluated by counting faecal streptococci (SF), total coliforms (CT), E. Coli, Salmonella, clostridia and Listeria. The abatement of microbial pollution is determined by the Equation 7:

Abattement: $A(\mathrm{Ulog}) = -\log\left(1 - \frac{R}{100}\right)$ (Equation 7).

Table 1: Filter bed characteristics.

	Grain diameter (mm)	Density (kg/L)	Apparent density (kg/L)	Permeability (m/s)
Coarse gravel	20/25	2.70	1.32	-----
Gravel	3.3/16	2.70	1.32	-----
Sand	0/6	2.53	1.56	$6.22*10^{-4}$

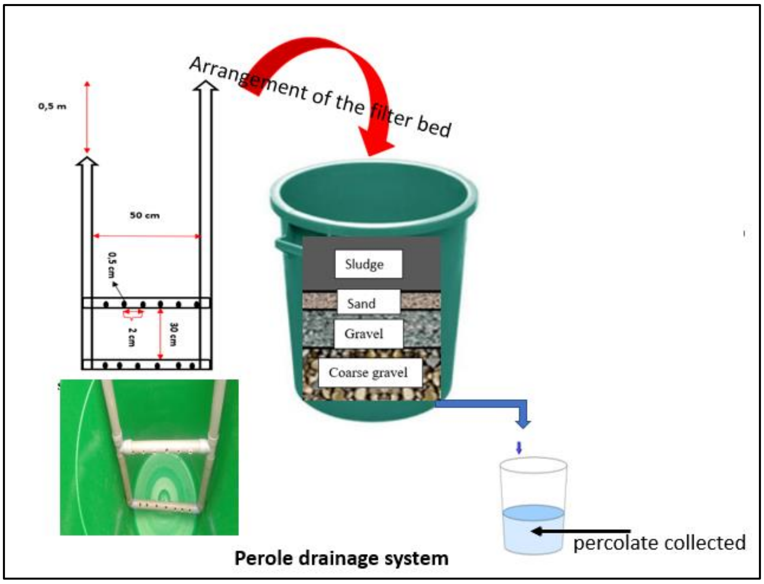


Figure 1: Drainage system.

Table 2: allowable organic load and Volume humidity.

Days	allowable organic load (Kg MS/an/m^2)	Volume humidity (%)
LNP 1 days	130	98
LNP 5 days	135	50
LNP 10 days	139	30
LNP 20 days	147	20
LNP 32 days	165	12

(From the document: Particle size analysis was carried out by sieving according to the NFP18-560 standard.)

RESULTS

Meteorological data and moisture content

Graph 1 represents climate data from 2015 to 2020 and moisture content. Evaporation and insolation evolve proportionally and inversely proportional to rainfall. Evaporation and insolation reach their maximum values at 367.23 mm; 263.2 d/h in December respectively while the rainfall peaks in August with a value of 374.017 mm. The average temperature fluctuates between 30 and 38 degrees Celsius and this value testifies to the good performance of the sludge treatment by a solar system. These climatic data are specific to the municipality of Kara and therefore the methodology remains local and precise. The months of June, July, August and September are inappropriate months to treat a large number of sludge because it is a time of intense rains where insolation and evaporation are low.

The volumetric humidity was studied as a function of time. The average feed load of 30 kg of suspended solids/m^2/year made it possible to regularly monitor dehydration and mineralization, whereas with a load of 20 kg of suspended solids/m^2/year served to break down the settings.

After 32 days of monitoring, the load in terms of dry matter is 165 Kg DM/year/m^2. The remaining relative humidity rate is 12% in the sludge after 32 days of dehydration according to graph 1.

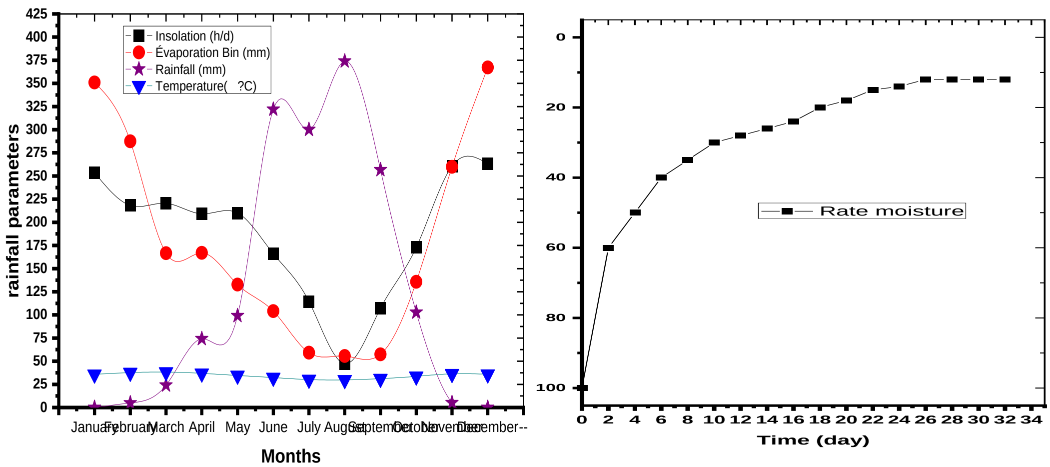
Physico-chemical parameters

The values of physical parameters such as hydrogen potential (pH), electrical conductivity (EC), suspended solids (SS), dry matter (DM) and MVS (%DM) are respectively 7.75; 1902 S/cm; 466 mg/L; 1773.5mg/L; 2663.5 mg/L MVS (%MS) 46.5%. The density of faecal sludge, the density of solid particles, the (mass) water content and the volumetric humidity have values of 970.5 kg/m^3 respectively; 225kg/m^3; 149 and 88.5%. Global pollution parameters such as chemical oxygen demand (COD), five-day biochemical oxygen (BOD_5), nitrogen and phosphorus are the key parameters in sewage sludge management. The physico-chemical parameters have been represented on the **graph 2a** and the global chemical parameters of the raw sludge and bio-solid on the **graph 2b**.

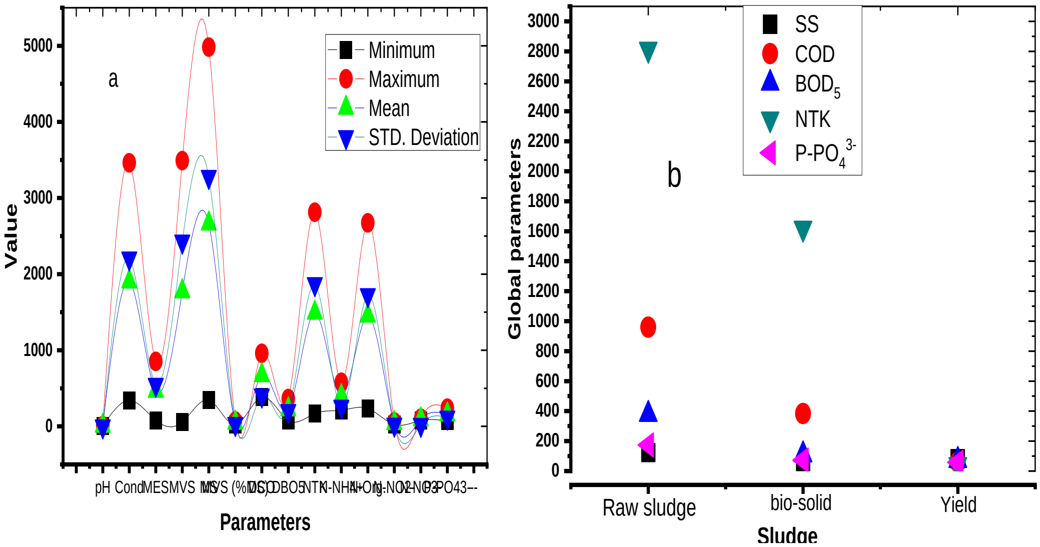
Biological parameters

Variables such as E. coli, SF, CF, Salmonella, Clostridium and Listeria are the parameters considered in this article. These parameters were evaluated upstream in the raw sludge and downstream in the bio-solid, the results of which in terms of yield and ULog reduction are given in Table 3.

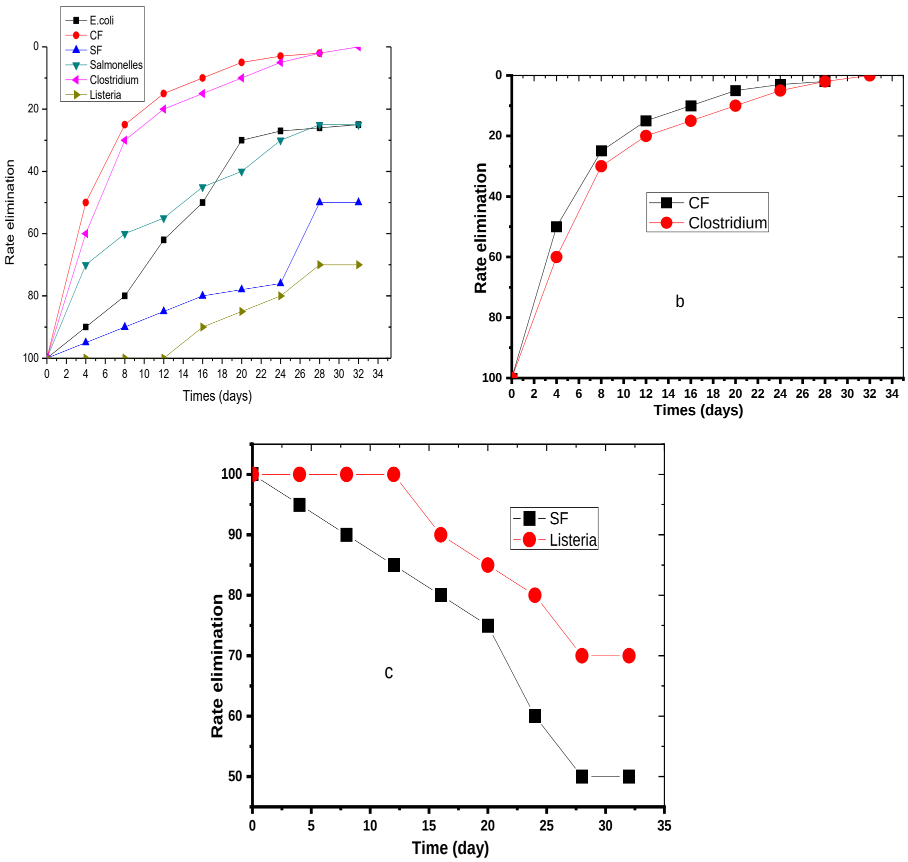
These different pathogenic germs were eliminated as a function of time presented in Graph 3.



Graph 1: Climate data from 2015 to 2020 in Kara area (a) and moisture content (b) solid on the graph 2b.



Graph 2: Content of chemical parameters (a) and evaluation of raw sludge and bio-solid (b).



Graph 2: Reduction rate of biological parameters (a), biological parameters completely eliminated after 36 days (b) and biological parameters weakly eliminated after 36 days (c).

Table 3: Abatement of microbiological germs.

	E. coli	CF	SF	Salmonelles	*Clostridium*	*Listeria*
Yield %	25%	100%	50%	25%	100%	70%
Abatement (ULog)	0.13	-	0.3	0.13	-	0.6

DISCUSSION

Meteorological data

Evaporation and insolation evolve proportionally and inversely proportional to rainfall. Evaporation and insolation reach their maximum values at 367.23 mm; 263.2 day/h in December respectively while the rainfall peaks in August with a value of 374.017 mm. These data show that the dry season is more appropriate for drying fecal sludge in the open air for more optimization in the municipality of Kara.

Mode of feeding and allowable organic load

The average feed load of 30 kg of suspended solids/m^2/year made it possible to regularly monitor dehydration and mineralization, whereas with a load of 20 kg of suspended solids/m^2/year served to break down the settings.

Physico-bio-chemical

After 32 days of monitoring, the load in terms of dry matter is 165 Kg DM/year/m^2. This value is below that found by Gnagne et al., (2019) in Côte d'Ivoire and Kouawa (2016)in Burkina Fasso respectively 0.43 Kg of suspended solids/d/year and 150 kg of suspended solids/m^2/year. Feeding/rest was done according to the constant volume mode with an alternation of three (03) days of rest. On large-scale stations, this study will make it possible to really know the time and speed of sludge sedimentation for the next scraping. The filter bed was very effective with an elimination of 82% of water in the sludge.

Physico-chemical parameters

Knowledge of the physical and chemical composition of sludge is of great importance for effective and efficient sludge management in a given municipality. Physical data such as faecal sludge density, solid particle density, water (mass) content, volumetric humidity, hydrogen potential (pH), electrical conductivity (EC), suspended solids (SS), dry matter (DM) and MVS (%DM) have values of 970.5 kg/m^3 respectively; 225 kg/m^3; 149 kg/m^3 and 88.5%; 7.75; 1902 S/cm; 466 mg/L; 1773.5 mg/L; 2663.5 mg/L; 46.5%. These values show that the sludge is charged and deserves treatment before being discharged into the environment. The MS and MVS influence on the contribution of volatile matter (agricultural recovery), on the lower calorific value (energy recovery) and on the stability of the sludge. i.e., the fermentability of the material (storage). Global parameters such as chemical oxygen demand (COD), biochemical oxygen demand in five (05) days (BOD_5), NTK and $P\text{-}PO_4^{3-}$ were evaluated on the raw sludge and on the biosolid (dehydrated) and have values respectively of 960 mgO/L, 379 mgO/L, 2814 mgN/L and 174 mgP/L for raw sludge and 384 mgO/g, 109 mgO/g 1620 mgN/g 73 mgP/g for dewatered sludge (biosolid). The removal efficiency is 60%, 71%, 43% and 58% respectively COD, BOD5, NTK and $P\text{-}PO_4^{3-}$. These values are comparable to the values found in the studies made by (Piyabalo et al. - 2021 - Quantification and characterization of faecal slud.pdf, s. d.) where the study was made according to the different types of pits (DL, DST and PST) in the city of Kara. In the city of Lomé in Togo, several studies have been carried out, in this case those by Akpaki et al. (2016) and Tagba (2019), which shows that from one city to another, from a pit to another the sludge does not have the same physical and chemical composition. The COD/BOD5 ratio gives a value equal to 2.45 which gives substantially the same value found in the study by Piyabalo et al. (2021) and Uggetti et al. (2010) at the level of DL and DST but higher for DSP (1.72). This comparative study testifies to the biodegradability of the sludge because this ratio is less than 3 according to the standards for the management of fecal sludge.

Microbiological parameters

Yields in terms of output and input on the raw sludge and on the biosolid of microbiological parameters such as E. Coli; CF; SF; Salmonella; Clostridium and Listeria are 25% respectively; 100%; 50%; 25%; 100% and 70%. These same parameters were evaluated in ULog and have values of 0.13 ULog; - ULog; 0.30 LogU; 0.13 ULog; - ULog and 0.6 ULog taken in that order. These results remain lower than those of Tagba in 2019 in Sokodé.

Conclusion

The results of the pilot tests show a very good purifying capacity in real size. The allowable average organic load of 165 Kg MS/year/m^2 gave the following performances: CF and Clostridium which are eliminated at 100% whereas the COD; BOD5; the NTK and $P\text{-}PO_4^{3-}$ were eliminated by more than 55%. Thus, the transferability of the pilot scale to a larger scale is not yet established and this will be done in our next studies. The climatic condition is favorable to the dehydration of sludge in the commune of Kara.

COMPETING INTERESTS

The authors declare that they have no competing interests.

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AUTHORS' CONTRIBUTIONS

All authors contributed to the success of this article. PK contributed to the field study, sampling and writing in French, EKK, NMK and BTB contributed to the various analysis and KNS contributed to translation of this article. We are proud of everyone's contribution.

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