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# The Potential of Subsurface Infiltration for the Treatment of Biofil Toilet Technology Effluent[*]

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Generally discharges from on-site sanitation (OSS) system could be a source of pollution to the environment if not well managed. This work illustrates the potential of subsurface infiltration to treat secondary effluent from a novel on-site vermi-biofiltration system called the Biofil Toilet Technology (BTT). In practice, the BTT effluent is discharged via sub-surface infiltration. The focus of the research was to determine possible contaminant removal within the first 1.5 m depth of soil column. To achieve this objective, laboratory scale soil columns were designed and constructed for the treatment of secondary domestic wastewater from the BTT. Four different soil columns, each with 1.5 m depth of soil (sandy soil—SS, loamy soil—LS, clayey soil—CS, and red laterite soil—RLS) and fifth column with 0.45 m multi-layer sand filter were constructed and characterized. The columns were fed with the BTT effluent and sampled at ports spaced at 0.3 m, 0.8 m, and 1.5 m depths. Using the samples, parameters like COD, $BOD_5$, TSS, T-N, $NO_3$-N, $NO_2$-N, $PO_4$-P, and pathogenic indicator microbes were monitored. RLS and SS columns efficiently removed COD, $BOD_5$, and TSS from the BTT effluent below the Ghana Environmental Protection Agency (GH EPA) guideline values. Up to 99% COD removal were observed in RLS column. A two to five log pathogen removal was recorded for the soil columns. The RLS and SS were found to have a high efficacy for contaminant removal with up to 80% of all contaminants being removed at a depth of 0.3 m along the soil columns. Thus the subsurface infiltration system can serve as a promising technology for the BTT effluent treatment. The study recommends the incorporation of infiltration systems to the BTT especially for areas with high water table or clayey soils.

*Keywords:* Biofil, on-site, blackwater, infiltration, vermicomposting, toilet, soil, *eudrilus euginae*

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## Introduction

Properly designed biological filters or infiltration systems have the capacity to significantly reduce effluent concentrations of pathogenic microorganisms and physico-chemical parameters in wastewater (Stevik, Aab, Auslanda, & Hanssen, 2004). Soil treatment of wastewater has emerged as a crucial concept for many sanitation technologies. In this concept, pre-treated wastewater is allowed to infiltrate through the aerated unsaturated soil zone where it undergoes purification via filtration, adsorption, chemical processes, and biodegradation (Nema, Ojha, Kumar, & Khanna, 2001). On-site sanitation (OSS) technologies are increasingly used in small towns, suburban, and rural areas in many developing countries (Stevik et al., 2004). In Ghana for instance, approximately 85% of inhabitants are served by OSS facilities with only 7% coverage for sewer systems in Accra, Kumasi, and Akosombo cities (Koné & Strauss, 2004). Many of such OSS facilities—pit latrines generally lack physical barriers, such as concrete or block lining, between stored excreta and soil (Van Ryneveld & Fourie, 1997) which may allow contaminants from pits to potentially leach into groundwater. In addition, owing to: (i) the aggravating issue of limited space in urban areas; (ii) inaccessible septic tanks; (iii) occurrence of occasional toilet spillages and indiscriminate discharge of faecal matter; (iv) long haulage distance to disposal facilities; and (v) the escalating cost of transport and disposal, the sanitation menace is likely to increase and affect public health (Thrift, 2007).

The Biofil Toilet Technology (BTT) is a household blackwater treatment unit and comprises of a compact concrete panel box measuring 1.8 m × 0.6 m × 0.6 m (Figure 1). It is installed subsurface at a maximum depth of 0.3 m depending upon the level of the water table or presence of rock bedding. The technology uses aerobic processes for decomposition of faecal matter and other organic components. It has a porous concrete filter (PCF) for rapid solid-liquid separation of blackwater.

Solids remain in the box as residue and are broken down by the action of waste digesters and their interaction with microbes. Effluent after solid-liquid separation within the digester is discharged into the sub-surface soil via a drain field with the bottom of the digester lined (as a full flush) or directly with the bottom of the digester unlined (as a microflush). The main effluent discharge after the BTT is by sub-surface infiltration (Figure 1). On top of the PCF is coir to act as bulking material to create an enabling environment for the main waster digester (*eudrilus euginae*). Since the emergence of the technology, there is little or no literature regarding its treatment mechanism and how it works.

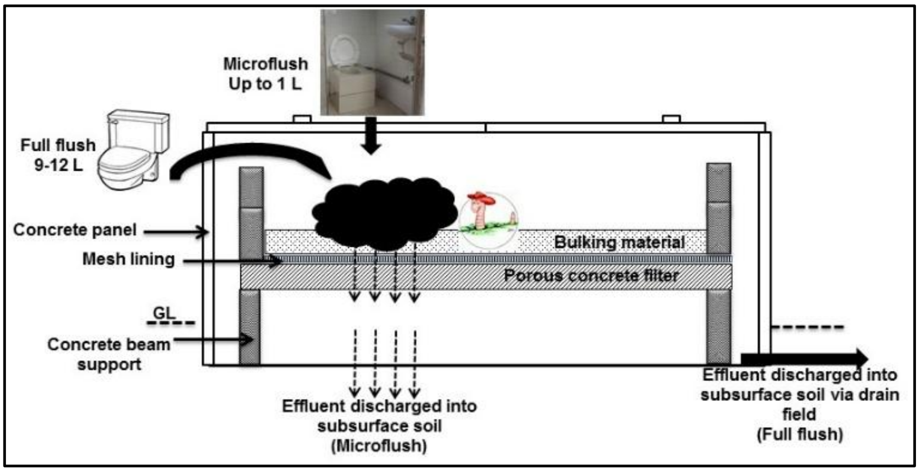

*Figure 1.* Schematic of the Biofil Toilet Technology (Biofilcom design by author).

The objective of this study is to give an overview of treatment capacity of blackwater by the BTT and investigate the removal efficacy of subsurface infiltration using pre-treated effluent from the BTT on different soil columns as commonly practiced in existing installations. The study only focused on the quality of the effluent through the soil columns. A detailed investigation of the treatment capacity of the various components of the BTT is presented in another paper.

## Materials and Method

### General

The research was undertaken on existing biofil toilet installations in the Kumasi Metropolis where about 15 private houses currently use the technology. These toilets are designed to serve 10 people for a regular flush system and 15 people for a micro-flush system. With the flush system, the biofil system receives up to nine litres of flush water whereas the microflush receives up to one litre of flush water. Soil columns were installed and operated under laboratory conditions at the Environmental Quality Laboratory of the Civil Engineering Department of the College of Engineering, KNUST, simulating the natural soil environment of the existing installations. A multi-layer sand filter was also set up (Figure 2). Blackwater and biofil effluent samples were collected from selected households with the BTT for characterization. The Biofil effluent[1] samples were used as feeds for the different soil columns installed throughout the experiment.

### Experimental Design

Polyvinyl chloride (PVC) tubes of 110 mm internal diameter and 180 cm long were used for soil column set-up as presented in the general schematic diagram (Figure 2). Each of the PVC pipes had a 20 cm depth freeboard. The soil columns were sealed at the bottom with a 10 cm depth of 2 cm sized gravel to serve as a supporting base. Sampling ports were provided at 60 cm, 110 cm, and 160 cm below the freeboard. Literature suggests a depth of 200 cm as an optimal clearance to the groundwater table for soil aquifer treatment studies (United Nation Environmental Protection, 2002). However, for the purpose of this study, a depth of 150 cm was used as soil column to represent the clearance between a typical toilet installation and groundwater table for areas with low water table. The different soil samples for the columns were loamy, sandy, clayey, and red laterite soils. Characteristics of the soils have been shown in Table 1.

Table 1

*Characteristics of Soil Used*

| Column soil types | Constituent particle size percentages | | | | Bulk density (kg/m$^3$) | Permeability coefficient (k) | pH |
|---|---|---|---|---|---|---|---|
| | Clay < 0.002 mm | Silt 0.002-0.06 mm | Sand 0.06-2 mm | Aggregate > 2 mm | | | |
| RLS | 38.20 | 21.50 | 40.30 | 0 | 1,367.94 | 0.0005 | 5.55 |
| Sandy soil | 0 | 0 | 99.71 | 0.29 | 1,592.43 | 0.0230 | 5.66 |
| Clay soil | 23.5 | 65.68 | 10.82 | 0 | 1,272.82 | 0.0001 | 4.07 |
| Loamy soil | 10.5 | 78.75 | 10.75 | 0 | 1,336.38 | 0.0003 | 6.02 |

*Notes.* RLS: red laterite soil; SS: sandy soil; CS: clay soil; LS: loamy soil.

These were selected as they depicted the different prevailing soil samples on the field. A separate multi-layer sand filter (MLSF) comprising a bottom layer of 10 cm packed gravel, followed by a 45 cm layer of

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[1] Biofil effluent is the liquid after solid-liquid separation of blackwater through the PCF within the biofil digester before being discharged in the sub-surface soil.

washed sand (effective particle size of 0.25-0.65 mm and uniformity coefficient of 3-4) and a 5 cm gravel layer with particle size of 6-12 mm (adopted from Baig, Mahmood, Nawab, Shafqat, & Pervez, 2011) was used. Only one sampling port was provided to collect filtrate samples from the MLSF column at the bottom. The MLSF was adopted and tested as a modified sand filter for cleaning the effluent.

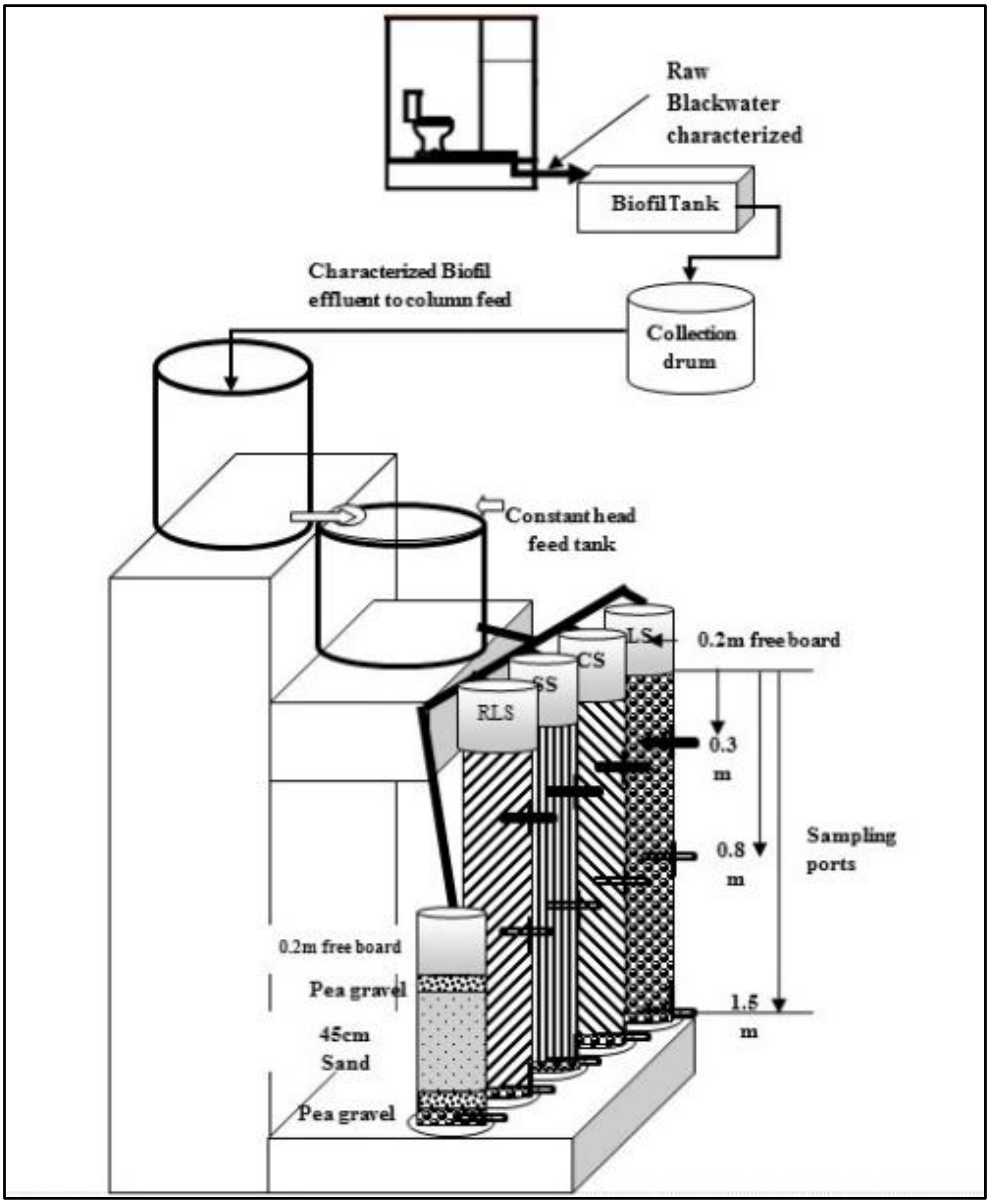


*Figure 2*. Conceptual scheme of the experimental soil column set-up.

## Column Feeding Regime and Periodic Sampling Schedule

Biofil effluent was collected every morning between 6:00 am and 7:00 am for two consecutive months from private homes and transported immediately to the experimental setup. Blackwater was initially characterized for its physico-chemical and microbiological constituents as baseline data. The BTT effluent was also characterized to determine the contaminant removal from the blackwater by the Biofil digester to establish the organic loading being applied onto the different soil columns. The effluent was poured into a collection tank connected to a constant head feed tank from which effluent was evenly distributed via a 10 mm flexible distribution pipe onto the different soil columns. Sampling was done at three different depths along the columns for physico-chemical and microbiological analyses. Three samples from the various sampling ports were taken on the second, fifth, and eighth week after the start of the filter runs for laboratory analyses. This sampling schedule was selected based on the average rate of filtration through the soil columns. Collection of samples was done under non-saturated conditions to depict typical flushes from the BTT into the sub-surface soil. Depending on the hydraulic conductivity of the different soils, infiltration through the soils decreased with time of runs.

### Analytical Methods

BOD, COD, TKN, nitrate, and ammonia were measured according to the Standard Methods for the Examination of Water and Wastewater (Clesceri, Greenberg, & Eaton, 1998). Total dissolved solids (TDS) and total suspended solids (TSS) were measured using filtration, gravimetric, and oven drying methods. The total coliform numbers were estimated by the membrane Filtration Technique (Clesceri et al., 1998).

## Results

### Physico-Chemical and Microbial Characteristics of Blackwater and BTT Effluent

Generally, the characterization of the blackwater revealed it to be strong with high upper limits for some key pollution indicating parameters of water: BOD (5,304 mg/L), COD (12,090 mg/L), TSS (30,000 mg/L), and TDS (4,347 mg/L). The wastewater product of the BTT showed a drastic change in its major physico-chemical and microbial parameters (Table 2). The BTT effluent was typically basic with a pH range of 7.3-8.8.

Table 2

*Blackwater and BTT Effluent Characterization*

| | Influent characteristics | | Effluent characteristics | | Ave. Removal efficiency (%) | GH EPA |
|---|---|---|---|---|---|---|
| | Range | Mean ± SE | Range | Mean ± SE | | |
| pH | 5.4-9.0 | 7.7 ± 0.1 | 7.3-8.8 | 8.1 ± 0.0 | - | 6.0 to 9.0 |
| BOD (mg/L) | 337.0-5304.0 | 1,692.0 ± 140.0 | 42-825.0 | 271.0 ± 26.0 | 84.0 | 50.0 |
| COD (mg/L) | 1,087.0-12,090.0 | 5,599.0 ± 344.0 | 188.0-3,100.0 | 775.0 ± 70.0 | 86.1 | 250.0 |
| TSS (mg/L) | 480.0-30,000.0 | 2,847.0 ± 689.0 | 12.0-3,440.0 | 500.0 ± 55.0 | 82.4 | 50.0 |
| TDS (mg/L) | 1,035.0-8,950.0 | 3,449.0 ± 255.0 | 286.0-4,347.0 | 1,648.0 ± 73.0 | 52.2 | 1,000.0 |
| $NH_3$-N (mg/L) | 32.5-385.0 | 139.8 ± 11.8 | 37.7-253.0 | 132.8 ± 8.0 | 5.0 | - |
| $NO_3$-N (mg/L) | 2.1-47.0 | 10.1 ± 1.3 | < 0.001-71.9 | 8.1 ± 1.8 | 19.8 | 50.0 |
| $PO_4$-P (mg/L) | 3.1-42.8 | 11.6 ± 1.1 | 0.2-36.1 | 8.9 ± 0.8 | 23.3 | - |
| E. coli (CFU/100 ml) | $2.0 \times 10^7$-$3.2 \times 10^9$ | $4.6 \times 10^7 \pm 4.6 \times 10^7$ | $1.0 \times 10^5$-$1.0 \times 10^7$ | $1.7 \times 10^7 \pm 1.8 \times 10^7$ | 63.0 | 10 |
| Total coliform (CFU/100 ml) | $7.0 \times 10^7$-$9.0 \times 10^9$ | $1.6 \times 10^9 \pm 1.4 \times 10^8$ | $1.0 \times 10^2$-$3.2 \times 10^8$ | $7.0 \times 10^7 \pm 6.4 \times 10^7$ | 95.6 | 400 |
| Helminths (egg L-1) | 0.0-1.0 | 0.2 ± 0.1 | 0.0 | 0.0 | 100 | - |

Source: Biofilcom & IWMI (2015).

Preliminary experiments on existing BTT installations suggested a high percentage removal for TSS, $BOD_5$, and COD concentrations (80%-85% reduction in blackwater) with a fair percentage removal for TDS concentration (approximately 50% reduction in blackwater). This notwithstanding, the upper limits of the BTT effluent recorded concentrations (i.e., $BOD_5$ 825 mg/L; COD 3,100 mg/L; and TSS 3,440 mg/L) above the acceptable Ghana Environmental Protection Agency (GH EPA) limits for discharge into water bodies. The results also indicated a relatively low removal capacity for nutrients ($NH_3$-N, $NO_3$-N, and $PO_4$-P: < 40% reduction). The results revealed a decrease in $NH_3$-N concentration and an increase in the $NO_3$-N concentration in the BTT effluent. $NO_3$-N concentrations in the BTT effluent were typically within the GH EPA acceptable limits for discharge into water bodies. There was generally high percentage removal of total coliforms and E. coli in the BTT effluent; though the upper limit concentrations indicated values not permissible for discharge into natural water bodies. The BTT also indicated an excellent removal for helminth.

### Physico-Chemical Characteristics in the Soil Columns

Filtrates collected from the sampling ports were analyzed for pH, conductivity, TDS, COD, TSS, $BOD_5$, $NH_4$-N, $NO_2$-N, $NO_3$-N, faecal, and total coliform.

The pH of the influent and effluent from the soil columns were typically basic within a range of 6.5 to 8.86. The effluent sampled at a depth of 1.5 m from the SS column was acidic with a value of 5.04.

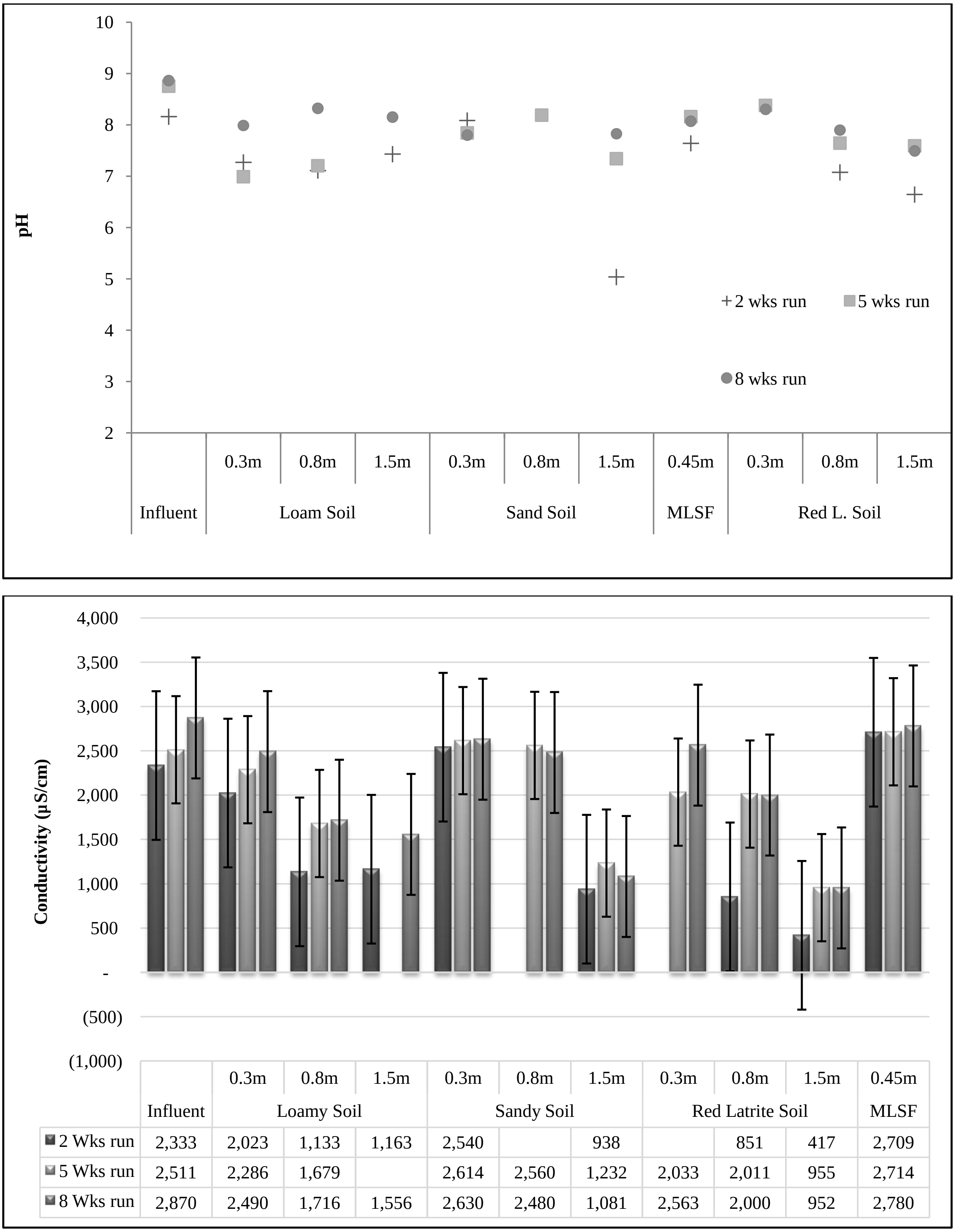
Conductivity concentration generally varied at different depths of the soil columns with the lowest concentration of 417 µS/cm measured at a depth of 1.5 m in RLS. The maximum was observed in the MLSF (Figure 3). Throughout the experiment, a minimum average temperature of 28.2 $^oC$ and maximum 31.8 $^oC$ (mean deviations of 0.3 to 1.8) was recorded.

There was a general trend of decreasing TDS concentration with increasing depth in the different soil columns (Figure 4) with the influent concentration (1,200-1,500 mg/L) reducing to 500 mg/L in the RLS at a depth of 1.5 m for instance. An exception was observed in the SS and MLSF where TDS concentrations generally did not change from the influent concentration. LS, SS, and RLS recorded an average of 50%, 60%, and 80% TDS removal respectively at the maximum depth of 1.5 m. The RLS demonstrated good percentage removal at depth of 1.5 m.

A similar trend of decreasing COD concentrations with increasing depth was recorded (Figure 4). The influent concentration was generally reduced from a range between 900-1,200 mg/L to below 300 mg/L in the RLS and SS. The RLS and SS performed better (with residual COD concentration below 250mg/L) than LS and the MLSF. Effective COD removal occurred within 30 cm of these soil columns. However, the COD concentration for LS between 0.3 m and 0.8 m increased in the five weeks run.

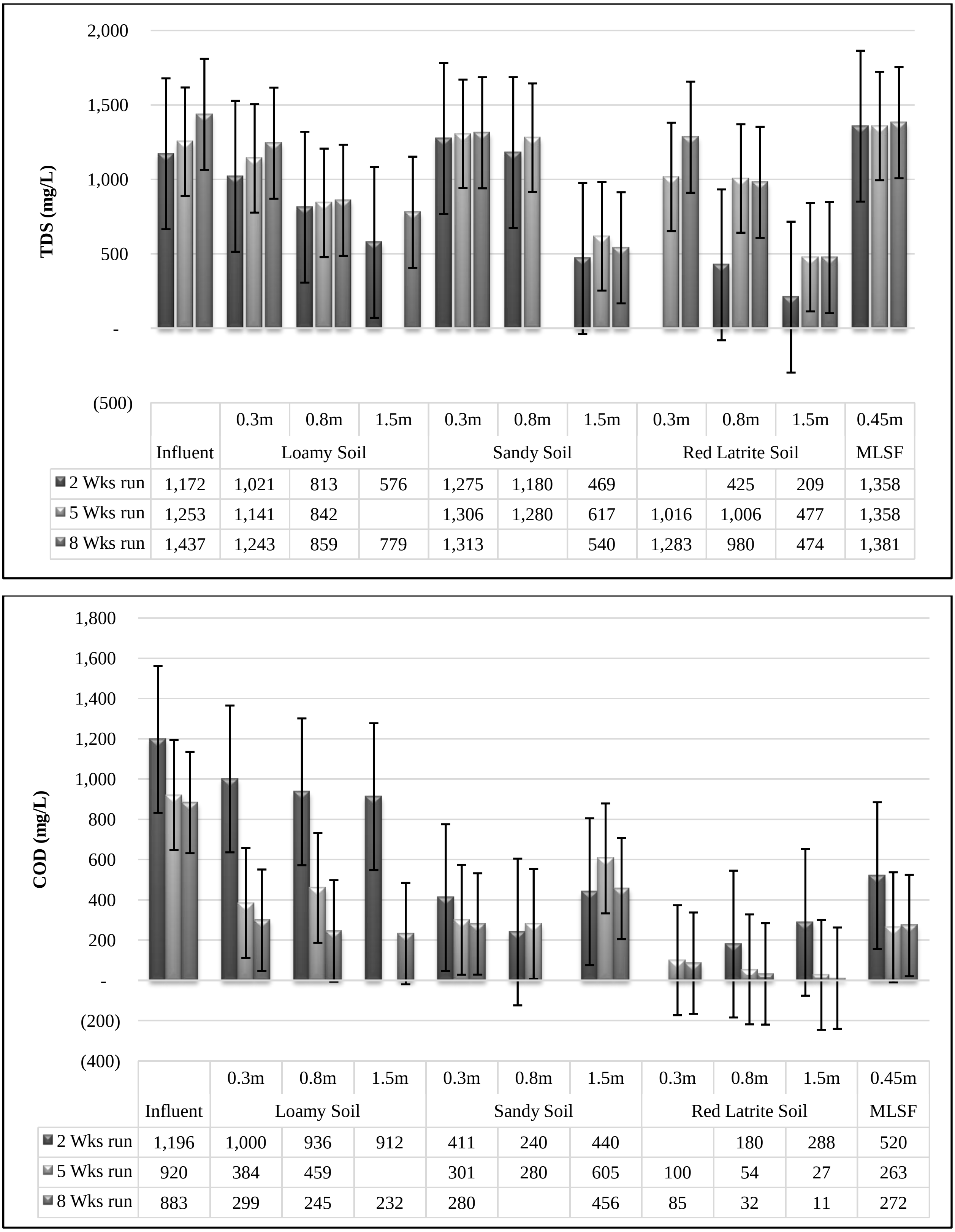
The RLS and SS columns also achieved better TSS and $BOD_5$ concentration removals than the LS and MLSF (Figure 5). TSS concentrations were efficiently reduced in the RLS and SS columns from an average of 500 mg/L in the effluent to below 50 mg/L at a depth of 0.8 m. The MLSF also achieved good TSS concentration reduction of approximately 400 mg/L. A similar trend was observed with the $BOD_5$ concentrations in the RLS and SS columns. The influent concentrations were reduced by 450 mg/L with the residual concentration within the EPA acceptable limits of 50 mg/L for discharge. In the case of the LS, the TSS concentration was not consistent with increasing depth. An increase in concentration occurred at a depth of 0.8 m.

Generally TSS and $BOD_5$ concentrations were effectively reduced within a depth of 0.3 m of the RLS and SS columns.



| | Influent | Loamy Soil 0.3m | Loamy Soil 0.8m | Loamy Soil 1.5m | Sandy Soil 0.3m | Sandy Soil 0.8m | Sandy Soil 1.5m | Red Latrite Soil 0.3m | Red Latrite Soil 0.8m | Red Latrite Soil 1.5m | MLSF 0.45m |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ▪ 2 Wks run | 2,333 | 2,023 | 1,133 | 1,163 | 2,540 | | 938 | | 851 | 417 | 2,709 |
| ▪ 5 Wks run | 2,511 | 2,286 | 1,679 | | 2,614 | 2,560 | 1,232 | 2,033 | 2,011 | 955 | 2,714 |
| ▪ 8 Wks run | 2,870 | 2,490 | 1,716 | 1,556 | 2,630 | 2,480 | 1,081 | 2,563 | 2,000 | 952 | 2,780 |

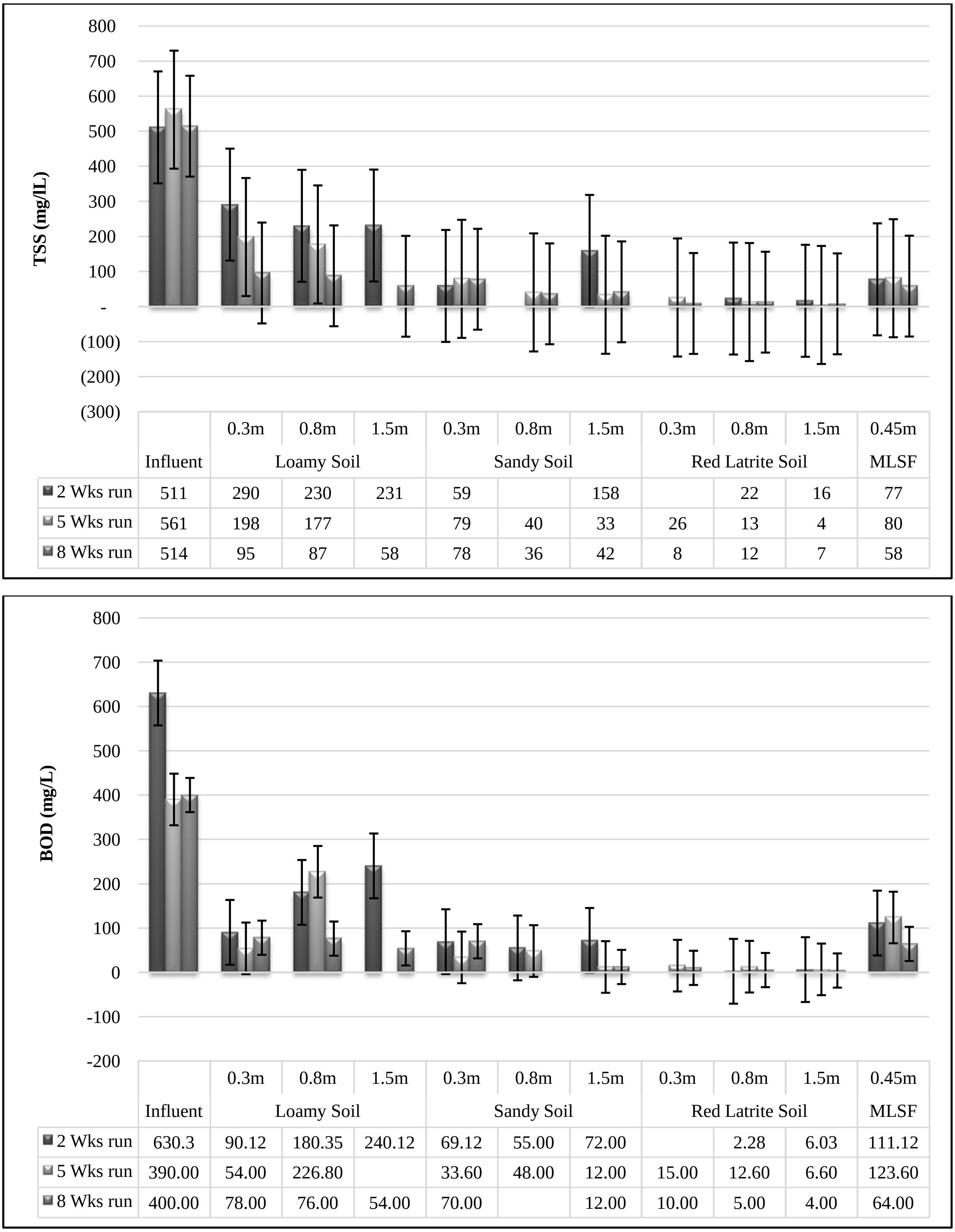
*Figure 3*. pH and conductivity levels of influent and effluent in soil columns.



| | Influent | Loamy Soil | | | Sandy Soil | | | Red Latrite Soil | | | MLSF |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.3m | 0.8m | 1.5m | 0.3m | 0.8m | 1.5m | 0.3m | 0.8m | 1.5m | 0.45m |
| ■ 2 Wks run | 1,172 | 1,021 | 813 | 576 | 1,275 | 1,180 | 469 | | 425 | 209 | 1,358 |
| ■ 5 Wks run | 1,253 | 1,141 | 842 | | 1,306 | 1,280 | 617 | 1,016 | 1,006 | 477 | 1,358 |
| ■ 8 Wks run | 1,437 | 1,243 | 859 | 779 | 1,313 | | 540 | 1,283 | 980 | 474 | 1,381 |

| | Influent | Loamy Soil | | | Sandy Soil | | | Red Latrite Soil | | | MLSF |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.3m | 0.8m | 1.5m | 0.3m | 0.8m | 1.5m | 0.3m | 0.8m | 1.5m | 0.45m |
| ■ 2 Wks run | 1,196 | 1,000 | 936 | 912 | 411 | 240 | 440 | | 180 | 288 | 520 |
| ■ 5 Wks run | 920 | 384 | 459 | | 301 | 280 | 605 | 100 | 54 | 27 | 263 |
| ■ 8 Wks run | 883 | 299 | 245 | 232 | 280 | | 456 | 85 | 32 | 11 | 272 |

*Figure 4*. TDS (EPA value of 1,000 mg/L) and COD (EPA value of 250 mg/L) performance in soil column tests.



|  | Influent | Loamy Soil |  |  | Sandy Soil |  |  | Red Latrite Soil |  |  | MLSF |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | 0.3m | 0.8m | 1.5m | 0.3m | 0.8m | 1.5m | 0.3m | 0.8m | 1.5m | 0.45m |
| ▨ 2 Wks run | 511 | 290 | 230 | 231 | 59 |  | 158 |  | 22 | 16 | 77 |
| ▨ 5 Wks run | 561 | 198 | 177 |  | 79 | 40 | 33 | 26 | 13 | 4 | 80 |
| ▨ 8 Wks run | 514 | 95 | 87 | 58 | 78 | 36 | 42 | 8 | 12 | 7 | 58 |

|  | Influent | Loamy Soil |  |  | Sandy Soil |  |  | Red Latrite Soil |  |  | MLSF |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | 0.3m | 0.8m | 1.5m | 0.3m | 0.8m | 1.5m | 0.3m | 0.8m | 1.5m | 0.45m |
| ▨ 2 Wks run | 630.3 | 90.12 | 180.35 | 240.12 | 69.12 | 55.00 | 72.00 |  | 2.28 | 6.03 | 111.12 |
| ▨ 5 Wks run | 390.00 | 54.00 | 226.80 |  | 33.60 | 48.00 | 12.00 | 15.00 | 12.60 | 6.60 | 123.60 |
| ▨ 8 Wks run | 400.00 | 78.00 | 76.00 | 54.00 | 70.00 |  | 12.00 | 10.00 | 5.00 | 4.00 | 64.00 |

*Figure 5*. TSS and $BOD_5$ levels of the biofil effluent and soil column effluent compared to GH EPA guideline values of 50 mg/L.

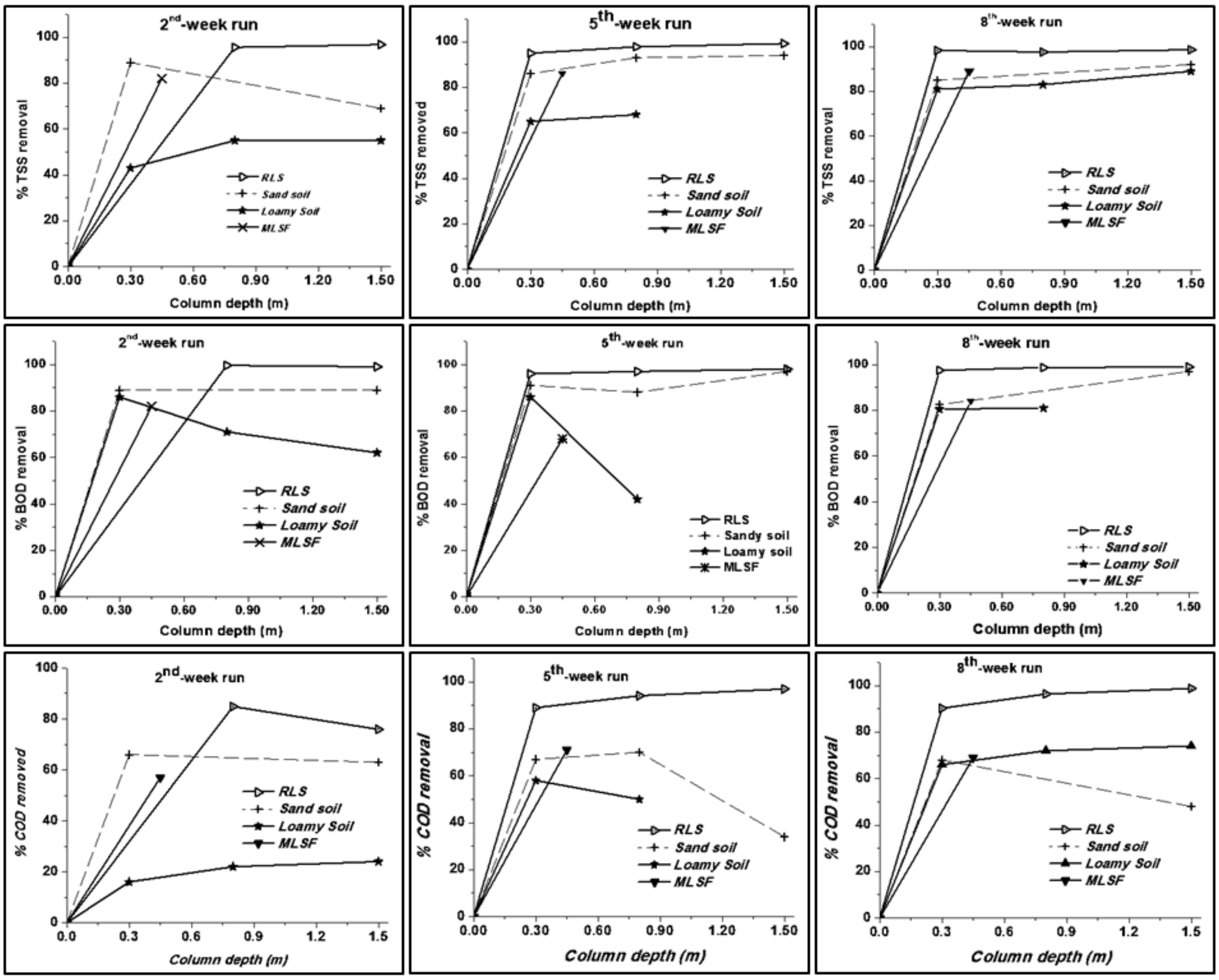


*Figure 6*. Percentage removal of TSS, BOD, and COD at different infiltration depths of soil columns.

The nutrient levels in the BTT influent had high concentrations of T-N and $NH_4$-N up to 250 mg/L (Figure 7), compared with the GH EPA general effluent guideline values for discharge to natural water bodies (50 mg/L $NO_3$-N) (GH EPA, 2003). Most of the nutrient levels recorded (particularly $NO_3$-N) were very low (0.06 mg/L for $NO_3$-N). There were significant reduction in these concentrations at depths of 0.8 m. $NO_3$-N and a $NO_2$-N concentration in both the influent and effluent were generally less than 50 mg/L, but observed to increase at a depth of 1.5 m within the soil columns, notably in the SS. Similarly, T-N concentrations increased at a depth of 1.5 m in the SS. RLS column were effective in reducing the concentrations of T-N and $NO_3$-N in the BTT effluent compared to the other sol columns. Phosphorus concentrations ($PO_4$-P) in the influent were above the Ghana-EPA guidelines but were significantly reduced in the soil columns notably in the RLS.

## Pathogen Characteristics in Soil Columns

The levels of total and faecal coliforms applied as feed onto the different soil columns were $1.63 \times 10^8$ and $8.47 \times 10^7$ cfu/100ml respectively. Analyses of the effluent collected at various depths of the soil columns revealed good reductions in coliform counts with increasing depth. The highest removal rates were recorded within the RLS, SS, and LS columns in that order (Figure 8). Faecal and total coliform removals of 2-5 log were recorded in the RLS and SS columns (Figure 9).

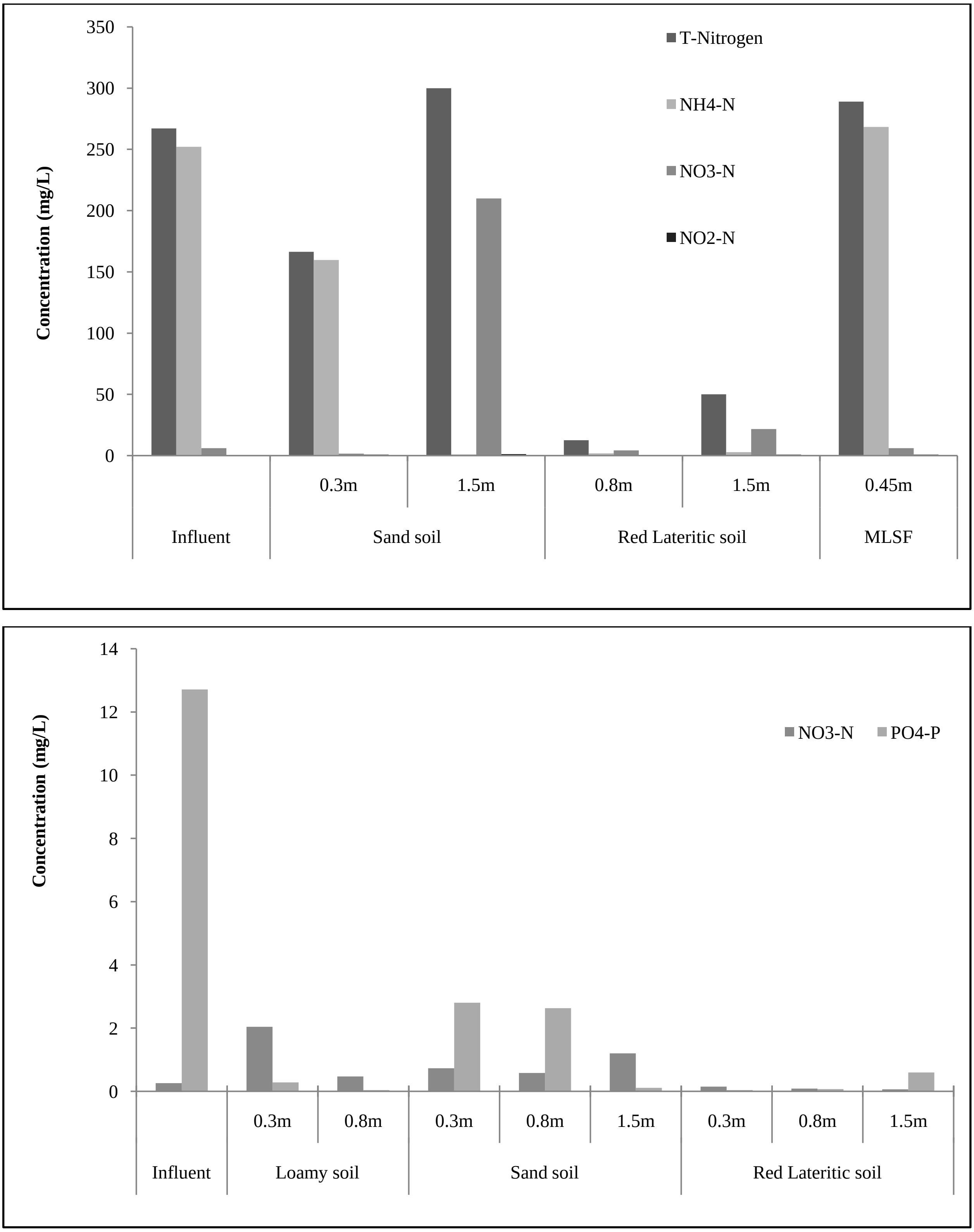


*Figure 7*. Nutrient concentrations in soil column effluent.

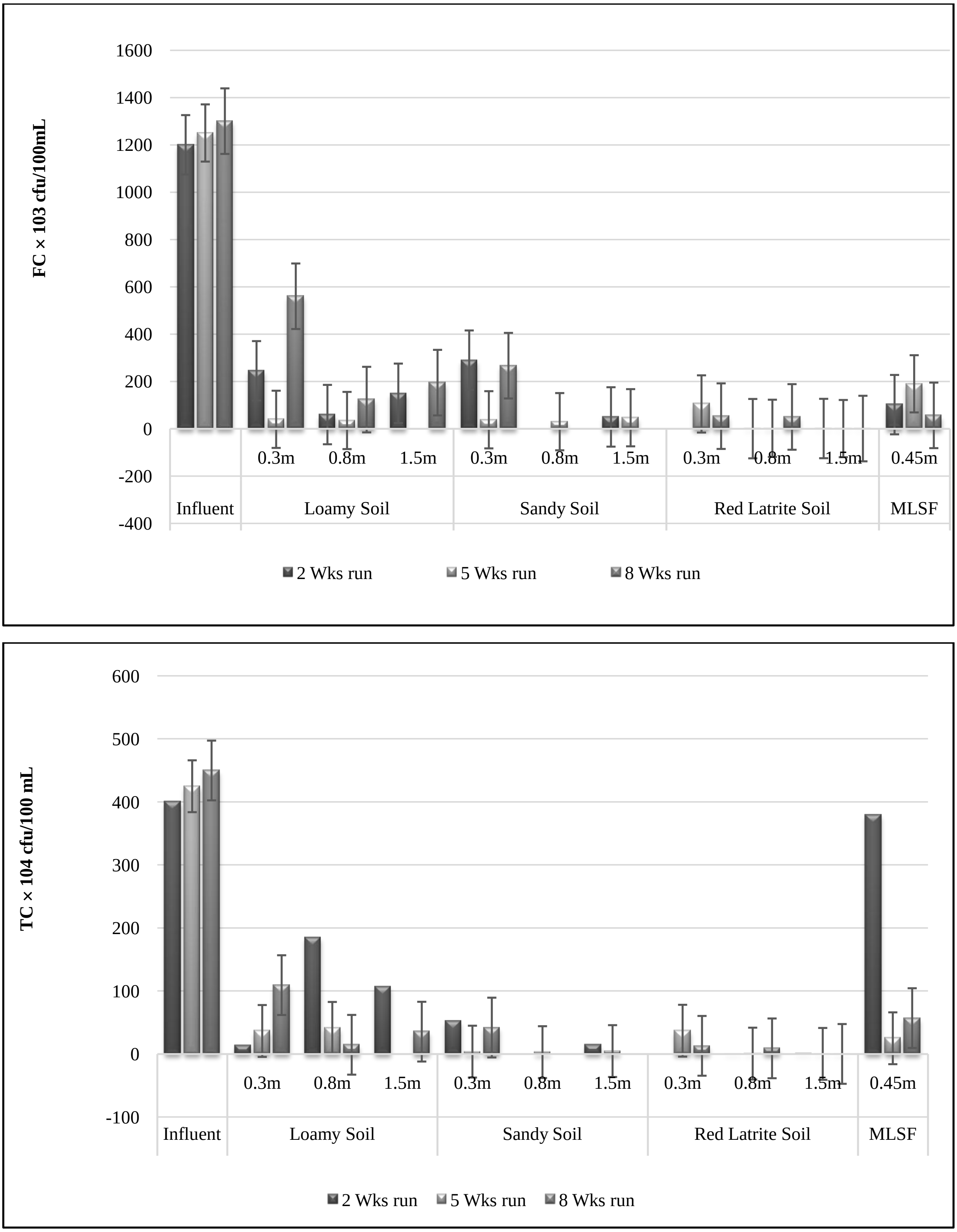


*Figure 8*. Pathogen levels in influent and effluent of soil columns.

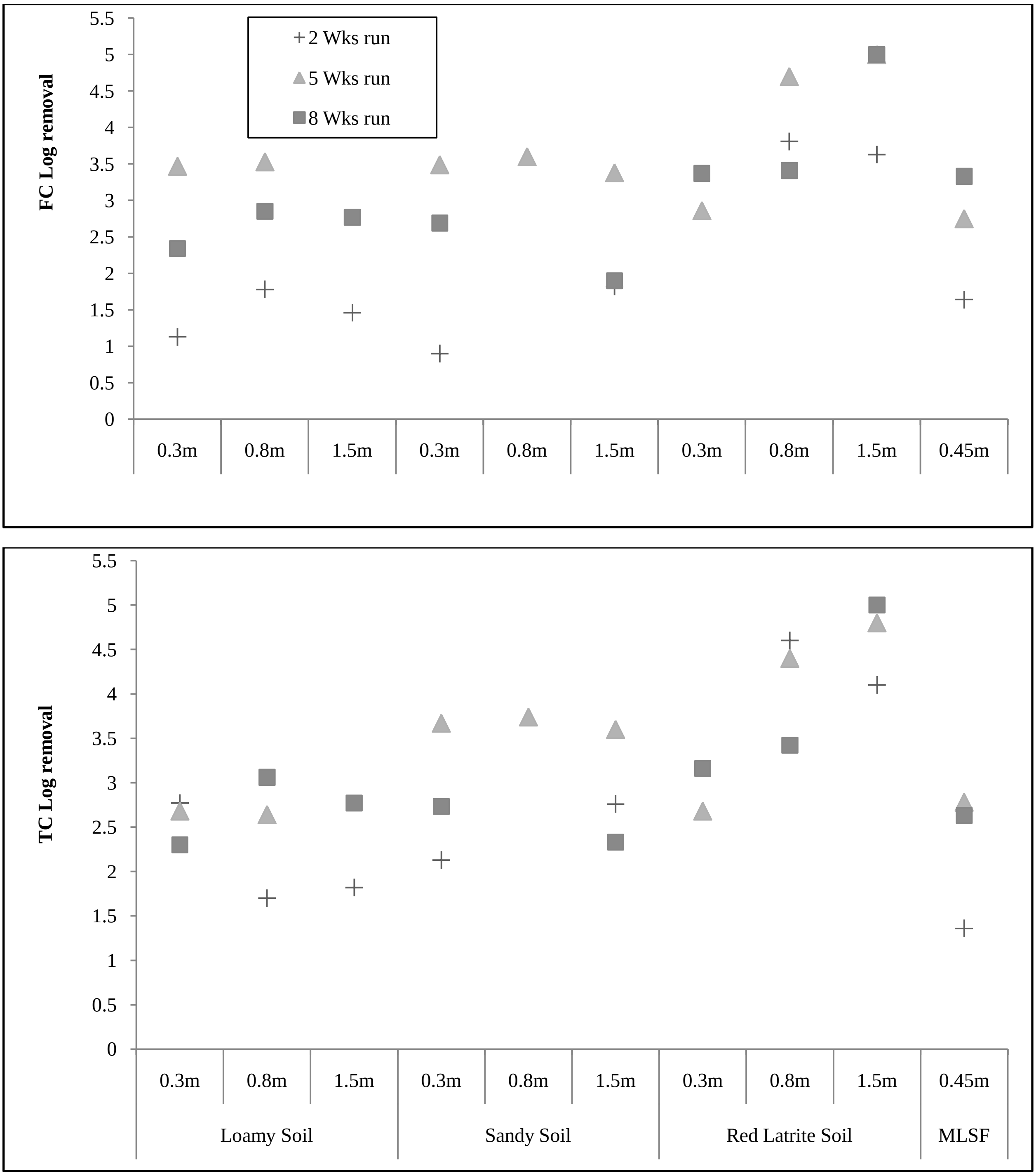


*Figure 9*. Faecal and total coliform log removal rates of experimental soil columns.

## Discussion

### Overview of the Performance of the BTT for Contaminant Removal in Blackwater

Studies have indicated that COD and BOD concentrations less than 100 mg/L and 50 mg/L respectively can be considered as stable wastewater (Molla & Kaba, 2011). Blackwater characterization in this study seems to agree with the assertion. The decomposition of organic fractions of wastewater, mainly by microbes in water, produces some species of mineralized organic materials ($CO_3^{2-}$, $NH_4^+$, and $NO^{3-}$) which play an important role in shifting of pH scale (Suthar & Tomar, 2011). The high urea content in urine which forms a major part of blackwater may have contributed to basic nature of the BTT effluent and seem to correspond to existing studies. It is reported that urea will be hydrolysed rapidly by the enzyme urease to form ammonium ions, according to the following reaction equation (Orhon & Artan, 1994):

$$(NH_2)_2CO + 2H_2O \Leftrightarrow 2NH_4^+ + CO_3^{2-} \quad (1)$$

The production of carbonate ions increases the alkalinity of the liquid and thereby causes an increase in the pH. The high concentration of $BOD_5$, COD, and TSS can be attributed to the presence of non-faecal materials, such as anal cleansing (i.e., toilet paper) in the blackwater. The pollution potential of toilet paper as reported by Almeida, Butler, and Friedler (1999) indicated as much as 706 and 546 mg per sheet for COD and TSS concentrations respectively. Their removal from the blackwater by the BTT is mainly due to solid-liquid separation by physical straining. However, the proliferation of COD, BOD, and TSS concentrations in the BTT effluent seems to suggest the presence of slowly biodegradable organic matter contents or dissolved organic matter contents in the effluent and would need to be trapped for continuous breakdown. The COD/BOD ratio of 4.1 suggests that part of the organic matter content is difficult to degrade biologically (Asia & Akporhonor, 2007). Different researches agreed that COD/BOD ratios in the range of 1.5-2.0 have easy removal of organics. The BTT effluent had a COD/BOD ratio of 2.6 after the rapid solid-liquid separation suggesting the removal of such resistant organic contaminant as part of the TSS within the BTT digester. Moreover, particulates of organic matter contents may be carried out through the filtration system of the BTT with continuous flushing. Additionally, the high removal of Total coliform and E. coli from the influent blackwater seems to conform to the high removal of TSS. TSS generally provides adsorption sites for chemical and biological agents and is removed from the liquid portion of the blackwater. Other studies seem to suggest the presence of food substrate as a determining factor for the fluctuating levels of coliforms (Monroy, Aira, & Domínguez, 2009). This is indicative with this study where there is very high removal of coliforms and E. coli in blackwater but the emerging effluent still has some high concentrations of coliforms and E. coli.

That for nutrients (i.e., $NH_3$-N, $NO_3$-N, and PO4-P) was relatively low due to limited contact time for chemical transformation and precipitation. The increase in $NH_4$-N in the BTT effluent leading to the production of $NH_3$-N and $NO_3$-N can be attributed to the disposal of urine with faeces (Koné & Strauss, 2004). The urine fraction contributes 93% of the total nitrogen concentration. In this fraction, 84% consists of urea-nitrogen, which is readily converted to ammonia. Urea is hydrolysed rapidly by the enzyme urease to form ammonium ions (Orhon & Artan, 1994). The ammonium ions ($NH_4$+) produced during the hydrolysis of urea is also kept in equilibrium with ammonia ($NH_3$) according to the following reaction equation (Benefield, Judkins, & Weand, 1982):

$$NH_3 + H_2O \Leftrightarrow NH_4^+ + OH^- \quad (2)$$

When the pH increases, the equilibrium of the reaction will shift to the left and ammonium ions will form ammonia gas. Ammonia gas is very insoluble in water and will escape to the atmosphere (Metcalf & Eddy Inc., 2003). In this study, the results indicate a reduction in the concentration of $NH_3$-N from the BTT which seems to agree with the phenomenon described. Additionally, $NH_4$-N in the presence of oxygen undergoes nitrification to form $NO_3$-N (Metcalf & Eddy Inc., 2003):

$$NH_4^+ + 2O_2 \Leftrightarrow NO_3^- + 2H^+ + H_2O \text{ (Nitrifying bacteria)} \quad (3)$$

The concentration of $NO_3$-N in this paper can be explained under two phenomena to explain the lower and upper limits of the $NO_3$-N concentration ranges. Contrary to expectation of system working under aerobic process to produce $NO_3$-N concentration, the results indicated very low concentration of $NO_3$-N (< 0.001 mg/L) and in most cases below the permissible limits of 50 mg/L for discharge into water bodies in the BTT effluent. This occurrence may possibly be due to denitrification process as a result of development of unexpected anoxic conditions within the BTT. The BTT is normally aerated by a connecting vent. Depending on the surrounding environment, the levels of aeration in the BTT (i.e., biofil digester) can be influenced. Additionally, low filtration in the BTT as a result of organic matter contents build-up could lead to slight ponding:

$$6NO_3^- + 5CH_3OH \Leftrightarrow 5CO_2 + 7H_2O + 6OH^- + 3N_2 \text{ (Denitrifying bacteria)} \quad (4)$$

### Physico-Chemical Parameters in Soil Columns

**Total dissolved solids.** A variety of complex chemical reactions within the soil columns, such as adsorption, may have played a key role in the removal of dissolved contaminants during infiltration in the soils (Schmoll, Howard, Chilton, & Chorus, 2006). The results indicated a statistically significant reduction of conductivity and dissolved solid concentration along the depth of soil columns ($\alpha$ = 0.0009 < 0.05). As infiltration depth increased, the adsorptive surface area increased and hence there was more contaminant removal. This was evident in the MLSF (as a separate modified sand filter with filtering depth of 0.45 m) and at a depth of 0.3 m in the RLS, SS, and LS columns with no significant difference in terms of TDS concentration reduction. Short circuiting may partly be the cause of TDS levels showing higher values at increasing depth. The performance in reducing TDS concentration compared to TDS effluent concentrations at a depth of 0.3 m within the RLS, SS, and LS was also similar ($\alpha$ = 0.56 > 0.05). However, at depths beyond 0.3 m, RLS, SS, and LS performed better at reducing TDS concentrations in the effluent notably in the RLS and SS at a depth of 1.5 m. This decrease in conductivity level with increasing depth might be related to the conversion of $NO_3$ into diatomic molecular nitrogen ($N_2$), which also decreases conductivity levels in domestic wastewater (Shama, Rabia, Iffat, Naeem, & Safia, 2013).

**Organic matter and suspended solids.** Under the tested conditions, the sandy soil and the RLS columns produced effluents with water quality parameters having values below the guideline values recommended for effluent discharge into the environment (GH EPA, 2003). The ability of the RLS to effectively remove TSS, BOD, and COD at all depths as compared to the sandy and the other soil columns can be attributed to reduced filtration rates thus increasing the residence time for effective filtration and microbial reaction. Infiltration rate has a direct impact on retention time and hence contaminant removal processes with the time defendant behaviour more pronounced up to 1.5 m depth in the vadose zone (Drewes & Fox, 1999). The rare increase in COD concentration in the LS during the five weeks run between 0.3 m and 0.8 m can be attributed to possible short circuiting. Additionally, suspended solids are removed by filtration through the upper soil layer and the largest part is of organic nature in form of volatile suspended solids (Idelovitch, Icekson-Tal, Avraham, & Michail, 2003).

Loamy soil showed greater variability along the experimental durations particularly at 0.8 m and 1.5 m depths. This variation at these specific depths could be due to the incremental infiltration and leaching of contaminants at lower depths specifically for the first two weeks experimental run. Sandy soil and red laterite soil show minimal variability, with the red laterite soil performing approximately uniformly. Generally, the soil columns attained their optimum performance by way of TSS, BOD, and COD removal at depth up to 0.8 m.

In all the soil columns, relatively limited contaminant removal performance was observed for the first two weeks possibly due to microorganisms adapting to the new environment. Literature has it that a period of 50 to 90 days is required at 10-30 $^{o}$C for soil microorganisms to acclimatize, adapt, and degrade organic matter (Essandoh, Tizaoui, Mohamed, Amy, & Brdjanovic, 2011).

A multivariate statistical analysis of the results revealed that there is a significant performance difference across the various soil columns in terms of TSS and BOD removal; loamy soil vs. sandy soil ($\alpha = 0.021$), loamy soil vs. red laterite soil ($\alpha = 0.001$), RLS vs. MLSF ($\alpha = 0.044$). From the analysis, it follows that RLS performed extremely better than the loamy soil and the MLSF column with respect to BOD and TSS removal ($\alpha = 0.001$ and 0.044 for BOD and $\alpha = 0.000$ and 0.032 for TSS respectively). Loamy soil and MLSF performed the same ($\alpha = 0.843 > 0.05$) meaning that both performed poorly. As stated by Ireland Environmental Protection Agency (2009), filtration, micro-straining, and aerobic biological decomposition processes in the biomat and infiltration zone remove more than 90% of BOD and suspended solids and 99% of the bacteria. Statistics also confirmed that the first two weeks of experimental run demonstrated lower rates of contaminant removals as compared with the fifth and eighth week run; meanwhile, there was no significant difference in the results observed between the fifth and eighth week of experimental run. These confirmatory tests agreed with justifications presented above by various researchers for the development of biomat (Essandoh et al., 2011). Generally red laterite soil exhibited an exceptionally remarkable contaminant removal performance for TSS, BOD, and COD.

**Pathogen characteristics in soil columns.** Coliform removal in filters has generally been associated with the removal of suspended particles and adsorption processes within the filter bed. Adsorption of cells to the porous media is influenced by the content of organic matter, degree of biofilm development, and electrostatic attraction, due to ion strength of the solution or electrostatic charges of cell- and particle-surfaces (Stevik et al., 2004). Multivariate statistical analysis on the faecal coliform removal capacity of the different soil types revealed that there was no statistically significant difference (using a 95% confidence level; $\alpha = 0.093 > 0.05$) in the extent of performances of the soils. The total coliform reduction, however, showed some significant differences ($\alpha = 0.001 < 0.05$ for RLS vs. MLSF: $\alpha = 0.003 < 0.05$ for sandy soil vs. MLSF and $\alpha = 0.046 < 0.05$ for RLS vs. loamy soil). Studies have suggested faecal coliforms to be relatively naturally resistant and living longer compared to other coliform groups (Bitton, 2005). MLSF performed poorly compared to RLS column ($\alpha = 0.001 < 0.05$). The RLS and SS performed similarly in terms of pathogen removal. Comparison of the performance of the SS with LS however did not show significant difference ($\alpha = 0.364 > 0.05$).

Generally, the columns showed remarkable pathogen removal potential, however, the effluent of all the columns did not satisfy the effluent guideline requirement of ≤ 10 MPN/100ml and ≤ 400 MPN/100ml for faecal and total coliform respectively for discharges into the environment (GH EPA, 2003). The study seems to suggest that the microbes multiplied quickly with the right conditions for growth. One way ANOVA test for the various soil depths did not appear to have statistically significant impact on pathogen reduction despite high removal. The reason can be attributed to the continuous application of wastewater onto the soil columns. The absence of alternate drying and wetting regimes that would have made the environment hostile for pathogens survival might have led to their proliferation and continuous presence (Crites, Middlebrooks, & Reed, 2006). To employ subsoil infiltration to polish the effluent from the BTT, the depth of the soil column is a critical factor to consider in the light of the water table prevalent in a location. For locations with high water table, the need for a filter system that can effectively remove pathogens within a shallow depth (of about 0.3-0.5 m) cannot be over emphasized.

**Nutrients.** The composition of the biodegradable nitrogen and organic compounds in effluent normally change, as it moves through soils due to natural biological processes that occur (Babel, Sae-Tang, & Pecharaply, 2009). Some researches indicated elevated concentrations of nitrogen species specifically nitrate in groundwater surrounding pit latrines (Tredoux, Talma, & Engelbrecht, 2000). However, significant nitrification and simultaneous denitrification can occur during soil infiltration, facilitating removal of nitrogen from the system (Güngör & Ünlü, 2005) depending on the redox potential (Fox, Houston, Westerhoof, & Drewes, 2001a). To promote denitrification, a considerable amount of carbon source, nitrate-N and anoxic condition (sufficient BOD level) should prevail.

The generally low concentrations of $NO_3$-N in the soil column seem to suggest the existence of anoxic conditions within the first 1.5 m vadose zone of the different soils. Anoxic conditions promote carbon degradation and denitrification with nitrate as the electron acceptor. As wastewater percolates through the vadose zone, dissolved oxygen can become rapidly exhausted and the redox potential decreases. With decreasing redox potential, nitrate is converted to nitrogen gas (Fox et al., 2001a). In the loamy soil column for instance, the highest concentration of $NO_3$-N (2.04 mg/L) was recorded at 0.3 m depth, dropping down to 0.47 mg/L at 0.8 m depth of the same column. In all of the other soil columns in this experiment, the $NO_3$-N concentrations were below EPA guideline values. Though denitrification occurs under anoxic conditions, it has been reported to also occur in limited anaerobic pockets in the aerobic zone making it localized and partial (Idelovitch et al., 2003). The proliferation of $NO_3$-N at a depth of 1.5 m can be attributed to a possible re-aeration of the gravel supporting base of the soil columns experimental setup through the outflow nozzle. Under aerobic conditions, nitrification will take place in an unsaturated zone and part of the nitrogen adsorbed on soil particles undergoes nitrification (Fox, Narayanaswamy, Genz, & Drewes, 2001b). A rare scenario was noticed in the SS where the T-N seemed to increase. This may have been caused by limited dissolved oxygen to accelerate the conversion of T-N to $NO_3$-N at a depth of 1.5 m. This phenomenon is also confirmed with the sudden drop in pH of 5.0 in the two weeks run in the SS. Bacteria involved in the second stage nitrification may have been inhibited by the drop in pH causing elevation of the T-N concentration, due to possible accumulation by continuous inflow of the influent T-N (Anthonisen, Loehr, Prakasam, & Srinath, 1976).

The relatively low phosphorus removal trend observed for the sandy soil and the MLSF could be attributed to the exhaustion of the adsorption capacity of the layer for phosphorus. All the samples from the various depths of the red laterite soil and deeper depths of the sandy soil removed significant amounts of the phosphorus; this trend of removal could be due to the adsorption onto iron and aluminum containing minerals and/or precipitation with these minerals (Reemtsma, Gnirß, & Jekel, 2000). Laterite soils generally have a high content of iron oxides and oxyhydroxides that have zeta potentials that enhance adsorption at pH beyond six. In addition, the iron ions are capable of bonding with the phosphate groups (Gidigasu, 1976) and eventually render them soluble. This probably explains the occurrence of phosphates in the effluents. Removal efficiency of total nitrogen and ammonia has been reported to reduce with time of operation due to the formation of anaerobic conditions in the soil zones preventing ammonia to nitrate conversion process since growth of nitrifyers requires oxygen. In comparison, the removal efficiency of phosphorous is generally more stable (Idelovitch et al., 2003).

## Conclusions

Under the test conditions, the sandy, RLS, and loamy soil columns showed up to 90% contaminant removal within the 1.5 m vadose depth. Up to 80 % contaminant removal was achieved for all the different soil columns within the top 0.3 m depth of the soil columns.

The RLS was the most effective in the removal of both organics and nutrients in the biofil effluent (TDS, COD, BOD, TSS, T-N, $NO_3$-N, $NO_2$-N, $PO_4$-P, TC, and FC), followed by the sandy soil. Subsurface infiltration demonstrates a good option for pre-treated BTT effluent suggesting the incorporation of biological filters or infiltration systems for areas with high water table or clayey soils.

The study suggests better contaminant removal, such as pathogens with alternating wetting and drying regime during subsurface infiltration. This is in line with existing studies where microbial adsorption to the soil solid material during the wetting time and decay during the drying time typically occurs.

Detailed analyses of pathogen removal should be conducted under low to high hydraulic loading rates to determine the optimum hydraulic loading rate for pathogen removal in the technology development.

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