MODIFIED SLOW SAND FILTRATION USING CHANCHAGA RIVER BED SAND, SANDY SOIL AND QUARRY SAND DUST AS FILTER MEDIA

O. S. AZEEZ[1*], M. OTORI[1], O. ADEWOLU[1] AND A. NASIR[2]

[1]Department of Chemical Engineering, Federal University of Technology Minna, Niger State, Nigeria.
[2]Department of Mechanical Engineering, Federal University of Technology Minna, Niger State, Nigeria.

AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration between all authors. Authors OSA and AN designed the study, wrote the protocol and interpreted the data. Author MO anchored the field study, gathered the initial data and performed preliminary data analysis. Authors OSA and OA managed the literature searches and produced the initial draft. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

Slow sand filtration for the treatment of water was carried out using three different sand sources – Chanchaga River bed sand, sandy soil and quarry sand dust. The effect of varying bed thickness (8, 13 and 17 cm) and water flow rate through the sand beds for the different sand were tested and found to affect the purity of the filtrates. The characterization of the filtrates from the three sand sources and the various bed thicknesses showed that the results from all the sand bed filters analysed were within the acceptable limit of the standard (except total coliform) for drinking water used as basis in this research. Quarry sand gave the best result in terms of water purification while sandy soil had the least performance in terms effectiveness of filtration.

Keywords: Filtration; bed thickness; sand; purification.

1. INTRODUCTION

Slow sand filtration also referred to as "biological filtration" is a straight forward, cheap and reliable technique used for water purification supplied to most cities in the world [1]. The rate at which the soil can achieve a steady state infiltration under its saturated conditions is determined by the soil texture and structure and this can be referred to as the "soil saturated hydraulic conductivity" [2]. However, due to the soil's capability to get rid of pathogens and contaminants from water, it has been used as a filter media [3]. Slow sand filtration started as far back as 1804in Bleachery Water Treatment Plant, South Carolina, the process which was designed by John Gibb was used in the treatment of water [4]. This process was later improved and adopted in 1829 by the Chelsea Water Company, London for public water supply. In slow sand filtration, the top layer of the sand turns biologically active by the formation of a microbial commonality [5]. Although one of the oldest treatment methods, it is a highly effective technique for getting rid of microbial contaminants and will show no traces of bacteria at the exit [5].

Water quality directly affects the human health [4,6], hence, the soil's ability to remove contaminants from

**Corresponding author: Email: tosin.azeez@futminna.edu.ng;*

water physical capture, chemical sorption and biodegradation is very important for high quality consumable water [4]. The quality of the outlet water is affected by the soil it passes through [7]. These operations that occurs as a result of the interaction between the soil and water depends on the amount and composition of the water [8]. The effectiveness of the soil as a filter for contaminants is driven by the adsorption, degradation rate in the filter and residence time which are subject to transport operation of the soil and concentration of the contaminants [7]. By eradicating some of the undesirable qualities of surface water supplies, slow sand filtration improves water quality and can be considered a water disinfection or treatment system if properly designed and operated as observed in [9] and [10].

This paper is aimed at using modified slow sand filtration for the treatment of water from one water sample using three (3) different sand sources and the characterization of the resulting water samples assessment parameters. This was achieved by:

1. Examining the effect of varying bed thickness on efficiency of purification.
2. Examining the effect of raw water flow rate on the efficiency of purification.
3. Testing/characterizing for some water treatment assessment parameters such as electrical conductivity, pH, major ion concentration, pathogenic test for the filtered water.

2. METHODOLOGY

The following samples were collected as follows; Chanchaga River Sand (CRS) was collected from Chanchaga River, Sand Soil (SS) from Tunga area and Quarry Sand Dust (QSD) from a Block Industry in Gidan Mango area in Minna, Niger State.

The following equipment were used: Multiple purpose meter, Turbidity meter, Conductivity meter probe, Steam bath, Digital weighing balance, Microscope and light source, Boiling bath, Hach Calorimeter, Autoclave, Thermometer, Suction Flask.

2.1 Experimental Procedure

Raw water sample was collected from the river in Chanchaga herein called Chanchaga River. CRS, SS and QSD filter beds were prepared by arranging the finest sand grain at the bottom followed by the finer grain with the effective grain sizes between 0.10 – 0.30 mm, followed by the coarse grain and coarser grain in a manner similar to [9]. An unmeasured quantity of the untreated water sample was poured into the filter beds at varying bed height. As the raw water sample settles on the sand filters, organic matters settled on the surface and different kind of small particles merge. This process aids the removal of various particles by the filter bed.

On the surface of the sand substrate, there is the formation of microbial commonality referred to as *Schmutzdecke* [1,5] or filter skin, through which the water passes and makes contact with filter bed. The downward flow of the water through the gap between the sand grains was followed by the collection of the filtrates at varying flowrates.

Filtrates at varying time from the three different sand beds at varying thickness were taken to the Water Quality Laboratory in Minna, Niger State for physical, chemical and microbial analysis.

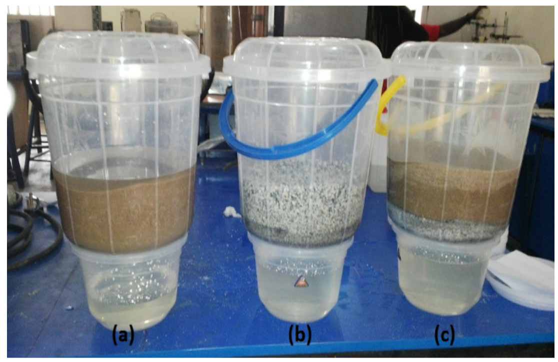

Plate 1. Experimental diagram showing (a) SS (b) QSD, and (c) CRS slow sand filters

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3. RESULTS AND DISCUSSION

From the results shown in Table 3.1, the flowrates of the treated water collected for 8 cm bed thickness increased for CRS, SS and QSD filter beds as the time increased from 1 to 3 hours respectively.

For 13 cm bed thickness, from the results shown in Table 3.2, the flowrates of the treated water collected decreased for CRS and SS filter beds from 1 to 2 hours but increased at 3 hours. However, water sample collected from QSD filter bed increased the time increased from 1 to 3 hours respectively.

From the results shown in Table 3.3, the flowrates of the treated water collected for 17 cm bed thickness decreased with increase in time from 1 to 3 hours for SS filter bed, increased from 1 to 2 hours for CRS and QSD filter beds and thereafter decreases after 2 hours.

3.1 Effect of Electrical Conductivity

Electrical conductivity for raw water and treated water samples generally were below [11,12] standard. Raw water had an electrical conductivity of 71.9 μScm^{-1}which is within the acceptable standard. After treatment, electrical conductivity values for water samples collected from CRS, SS and QSD filter bed decreased with increasing sand bed thickness as seen from the Fig. 1. Quarry sand filtrate was found to have the lowest value of electrical conductivity of 31.0 μScm^{-1}.

3.2 Effect of Total Dissolved solids

Raw water with total dissolved solids value of 35.5 mg/L and collected treated filtrates of different sand with their varying bed thickness were within the [11,12] standards. As seen in Fig. 2, there more total dissolved solids for filtrates at 8 cm and 13 cm bed thickness compared to that of raw water. After filtration, it was observed that for CRS, SS and QSD filter beds, decreased with increase in bed thickness. Quarry sand filter beds has the lowest value of 17mg/L for total dissolved solids.

Table 3.1. Results obtained for bed thickness of 8 cm for a period of 1 – 3 h

S/No.	Soil samples	Time (h)	Filtrate volume (mL)	Flowrate (m^3/s)
1	Chanchaga river bed sand	1	1450	0.40
2	Sandy Soil	1	1600	0.44
3	Quarry sand	1	1720	0.48
1	Chanchaga river bed sand	2	3010	0.42
2	Sandy Soil	2	3500	0.49
3	Quarry sand	2	3900	0.54
1	Chanchaga river bed sand	3	6320	0.59
2	Sandy Soil	3	7850	0.73
3	Quarry sand	3	8200	0.76

Table 3.2. Results obtained for bed thickness of 13 cm for a period of 1 – 3 h

S/No.	Soil samples	Time (h)	Filtrate volume (mL)	Flowrate (m^3/s)
1	Chanchaga river bed sand	1	1225	0.34
2	Sandy Soil	1	1310	0.36
3	Quarry sand	1	1400	0.39
1	Chanchaga river bed sand	2	2345	0.33
2	Sandy Soil	2	1920	0.27
3	Quarry sand	2	3150	0.44
1	Chanchaga river bed sand	3	4325	0.40
2	Sandy Soil	3	4035	0.37
3	Quarry sand	3	5585	0.52

Table 3.3. Results obtained for bed thickness of 17 cm for a period of 1 – 3 h

S/No.	Soil samples	Time (h)	Filtrate volume (mL)	Flowrate (m^3/s)
1	Chanchaga river bed sand	1	930	0.26
2	Sandy Soil	1	1055	0.29
3	Quarry sand	1	1305	0.36
1	Chanchaga river bed sand	2	2086	0.29
2	Sandy Soil	2	1830	0.25
3	Quarry sand	2	2905	0.40
1	Chanchaga river bed sand	3	2805	0.26
2	Sandy Soil	3	2372	0.22
3	Quarry sand	3	3460	0.32

3.3 Effect of Temperature

High temperature encourages the growth of microorganisms and may also increase taste, odour and corrosion problems [12]. A shown in Fig. 3, temperature of all the filtrates for the different filter beds at varying bed thickness were consistent with values recommended by [11,12].

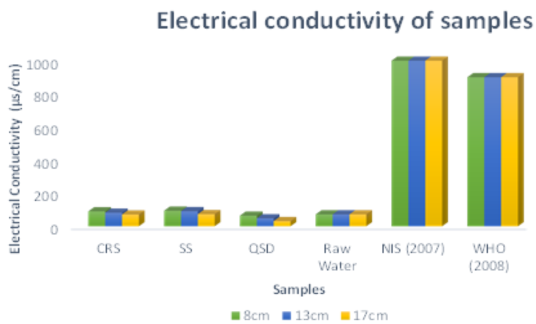

Fig. 1. Effect of soil type and bed thickness on electrical conductivity

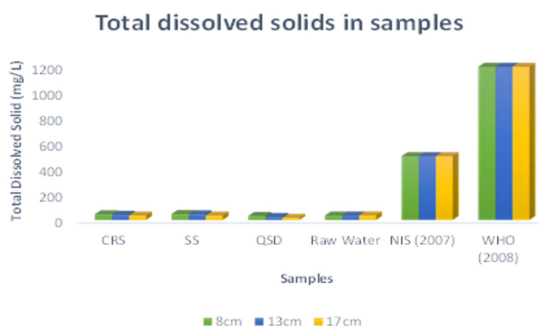

Fig. 2. Effect of soil type and bed thickness on total dissolved solids

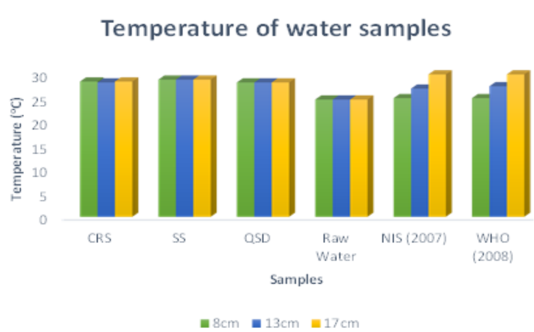

Fig. 3. Effect of soil type and bed thickness on temperature

3.4 Effect of pH

For this research the pH was done in-situ and the value for the raw water was 6.6 which was weakly acidic but all the collected filtrate samples were within the [11,12] standard. As observed in Fig. 4 the pH value obtained for the filtrates using the different filter sand bed ranged from 6.71 – 7.6 which were close to neutral also within the acceptable range as reported by [13].

3.5 Effect of Nitrite

Nitrite an important chemical parameter in water treatment analysis for the raw water sample has a value of 0.7mg/L which is above the [11] and [12] standard for water quality. After filtration, the nitrite value of the CRS, SS and QSD filtrates decreased with increasing sand bed thickness as seen in Fig. 5. It was observed the nitrite values were below the standard values and 0.00 mg/L nitrite was found present in QSD at 17cm bed thickness. This is a good indication as low doses of nitrite are non-carcinogenic to human health.

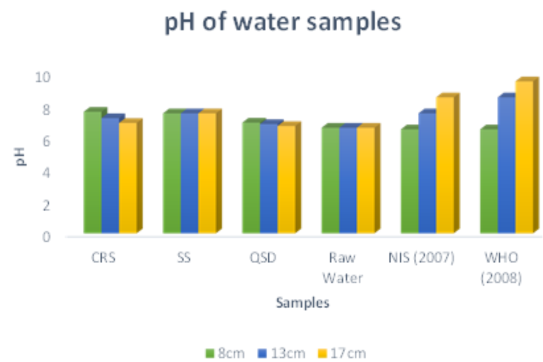

Fig. 4. Effect of soil type and bed thickness on pH

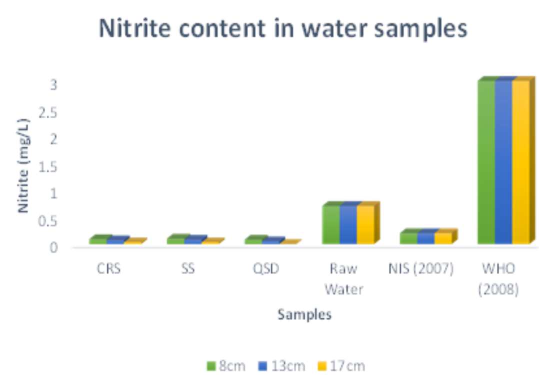

Fig. 5. Effects of soil type and bed thickness on nitrite

3.6 Effect of Iron

Raw water used for this research had a value of 0.10 mg/L as seen in Table 3.4 which is below the acceptable guideline value of [11 and 12]. After filtration as shown in Fig. 6, CRS filtrate iron content value was initially constant at 8 and 13 cm, however decreased to a value of 0.01 mg/L at 17 cm bed thickness. SS filtrate iron content was constant with a value of 0.07 mg/L as bed thickness increased, while QSD filtrate iron content decreased with increase in bed thickness until 0.00 mg/L was obtained at 17 cm. All collected water samples were below the standard value, although the presence of iron does not pose any health hazard after consumption if the intake is within minimum required [12].

3.7 Effect of Nitrate

Raw water had a value of 54 mg/L which is above the acceptable value as recommended in [11] and [12]. After filtration however, filtrates obtained from CRS, SS and QSD sand filters decreased with increase in bed thickness for each sand type as shown in Fig. 7. The QSD filtrate at 17 cm bed thickness had the least nitrate value of 3.1 mg/L.

3.8 Effect of Sulphate

The raw water sulphate value was 28 mg/L which was less than the acceptable range as recommended by [11] and [12]. As shown in Fig. 8 after filtration the sulphate values for CRS, SS and QSD filter beds were found to have reduced slightly compared to that of the raw water.

Table 3.4. Characterization for chemical, physical and microbial results for raw water in comparison with (maximum permissible) standards

Parameter	Unit	Raw water	[11]	[12]
Electrical conductivity	µs/cm	71.90	1000	900*
Total dissolved solid	mg/L	35.50	500	1200
Temperature	ºC	24.70	Ambient	Cool
pH		6.60	6.5-8.5	6.5-9.5
Nitrite	mg/L	0.70	0.2	3
Iron	mg/L	0.10	0.3	2
Nitrate	mg/L	54.00	50	50
Sulphate	mg/L	28.00	100	500
Manganese	mg/L	0.60	0.2	0.4
Total Hardness	mg/L	29.00	150	100-200
Turbidity	NTU	14.00	5	5
Copper	mg/L	0.03	1	2
Total Coliform	CFU/mL	22.00	10	0
E. coli	CFU/100 mL	38.00	0	0

**As provided in [14]*

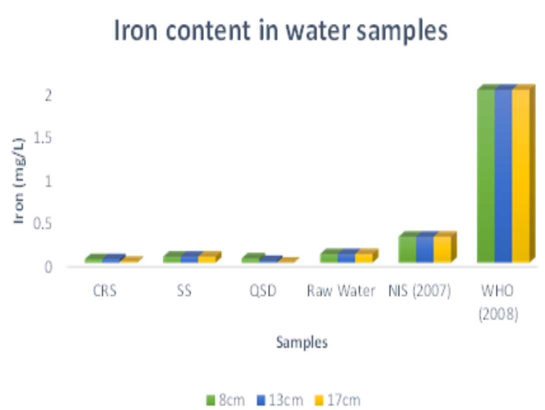

Fig. 6. Effects of soil type and bed thickness on iron

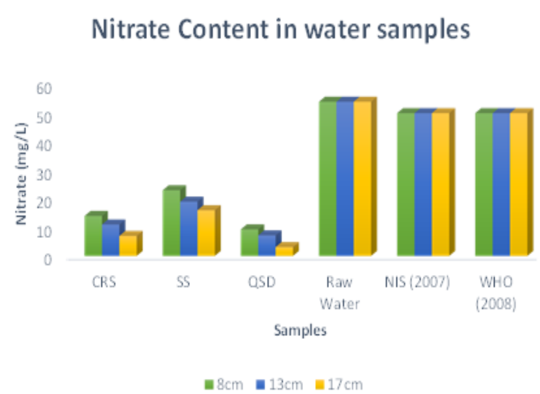

Fig. 7. Effects of soil type and bed thickness on nitrate

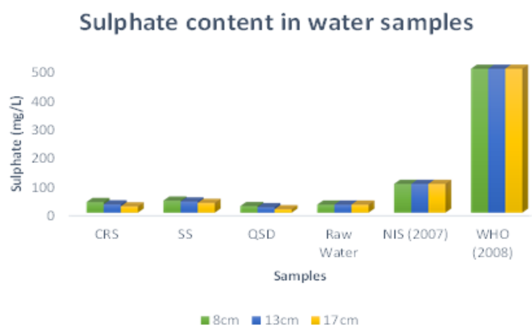

Fig. 8. Effects of soil type and bed thickness on sulphate

3.9 Effect of Manganese

Manganese content is very important to be checked in the filtrates so as to ascertain if the value is within the acceptable guideline values. The raw water was found to contain 0.60 mg/L manganese which is higher than the values suggested by [11] and [12] as the standard. However as shown in Fig. 9, CRS, SS and QSD filtrates manganese contents declined with increase in the bed thickness. Also, QSD filtrate had 0.00 mg/L manganese content at 17 cm bed thickness of the filter bed.

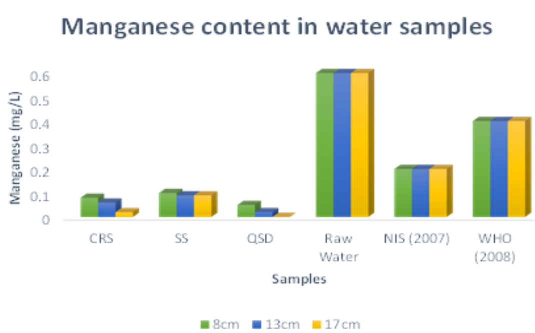

Fig. 9. Effects of soil type and bed thickness on manganese

3.10 Effect of Total Hardness

Hardness of water is as a result of the presence of calcium and to a lesser extent magnesium ions which can possibly lead to scale deposition on heating if greater than 200 mg/L and may be corrosive to water pipes if less than 100 mg/L [12]. In Table 3.4 it was observed that raw water had a total hardness value of 29mg/L which is much lower than the acceptable guideline value as prescribed by [11] and [12]. Note that the recommended values by [11] and [12] shown in Table 3.4 are the maximum permissible values. From Fig. 10, it was observed that CRS, SS and QSD filtrates hardness decreased with increase in bed thickness. The hardness content of these filtrates were higher than that of raw water except in the case of QSD filtrate at 17 cm bed thickness whose hardness content was less than that of raw water. It can be implied from the results obtained that the filtrates will have low buffering capacity and lead to corrosion.

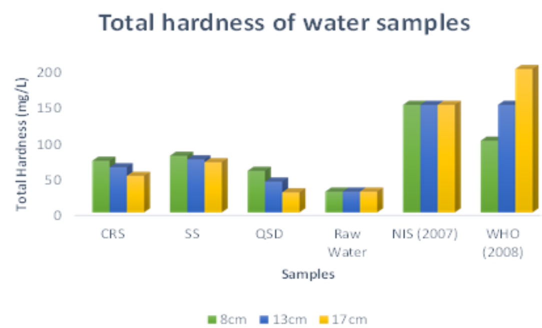

Fig. 10. Effects of soil type and bed thickness on total hardness

3.11 Effect of Turbidity

Turbidity an important parameter in the analysis of water, caused by suspended solids as a result of inadequate filtration as seen in Table 3.4, raw water had a turbidity of 14 NTU which is much higher than the acceptable guideline value as [11] and [12] prompted. From Fig. 11, it was observed that CRS and SS filtrates turbidity declined with increase in bed thickness, however, QSD filtrates at varying bed thickness had 0.0 NTU turbidity which were all within the acceptable standard. Hence, QSD filtrate had no suspension of sediments in the resulting water.

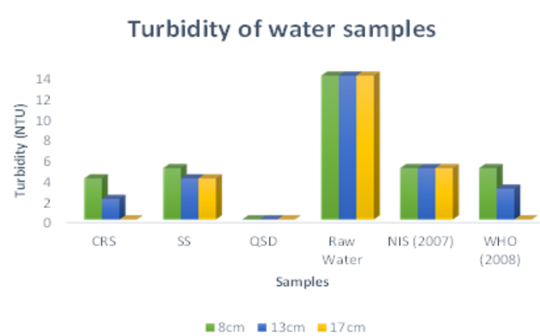

Fig. 11. Effect of soil type and bed thickness on turbidity

3.12 Effect of Copper

Copper found in water is usually as a consequence of corrosive action of water leaching copper from copper pipes. The acceptable copper value according to [11 and 12] are 1mg/L and 2 mg/L respectively as its health implication is gastrointestinal disorder. Copper value for raw water was 0.03mg/L as seen in Table

3.4 and after filtration, the copper contents for CRS, SS and QSD filtrates although greater than that of the raw water were lower than that presented by [11] and [12]. The copper contents of the filtrates decreased with increase in bed thickness as shown in Fig. 12.

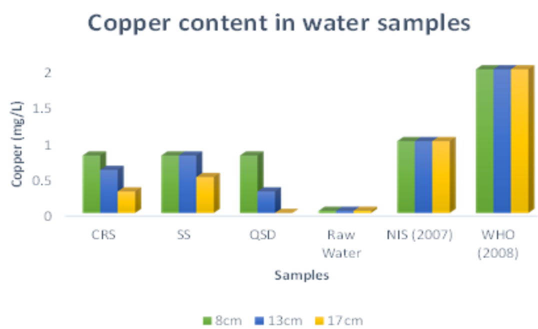

Fig. 12. Effects of soil type and bed thickness on copper

3.13 Effect of Total Coliform

Total Coliform is simply organisms that can survive and grow in water and their presence implies inadequate treatment of the water. Total coliform indicates faecal contamination, hence, they should be absent after treatment [12] as stored water supplies can reveal regrowth. Raw water had total coliform value was 22 CFU/mL which is much greater than the guideline values given by [11] and [12]. After filtration, the total coliform present in CRS, SS and QSD filtrates were found to be lower than that of the raw water as they decreased with increase bed thickness as shown in Fig. 13.0.However, the total coliform present in QSD filtrate was found to be in agreement with values suggested by [12].

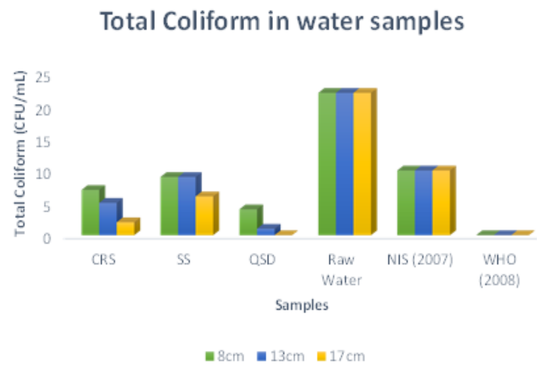

Fig. 13. Effects of soil type and bed thickness on total coli form

3.14 Effect of *E-coli*

E. coli has the tendency to cause danger to human health [12]. The acceptable value for E-coli is 0.0 CFU/100 mL anything higher than 0.0CFU/100mL is outside acceptable limit. Ecoli initially present in the raw water sample was found to be 38 CFU/100mL as shown in Fig. 14, however, after filtration using the CRS, SS and QSD filter beds, this value was found to be in agreement with the values given by [11] and [12].

Table 3.5. Filtrates characterization: Chemical, physical and microbial results for Chanchaga river bed sand

Parameter	Unit	8 cm	13 cm	17 cm
Electrical conductivity	µs/cm	90	82	71
Total dissolved solid	mg/L	45	41	35
Temperature	ºC	28.5	28.3	28.5
pH		7.6	7.2	6.9
Nitrite	mg/L	0.09	0.07	0.03
Iron	mg/L	0.04	0.04	0.01
Nitrate	mg/L	14	11	7
Sulphate	mg/L	37	29	22
Manganese	mg/L	0.08	0.06	0.02
Total hardness	mg/L	72	63	51
Turbidity	NTU	4	2	0
Copper	mg/L	0.8	0.6	0.3
Total coliform	CFU/mL	7	5	2
E. coli	CFU/100 mL	0	0	0

Table 3.6. Filtrates characterization: Chemical, physical and microbial results for Sandy Soil

Parameter	UNIT	8 cm	13 cm	17 cm
Electrical conductivity	µs/cm	94	91	73
Total dissolved solid	mg/L	47	45	35
Temperature	ºC	28.9	28.9	28.9
pH		7.5	7.5	7.5
Nitrite	mg/L	0.1	0.08	0.03
Iron	mg/L	0.07	0.07	0.07
Nitrate	mg/L	23	19	16
Sulphate	mg/L	42	39	34
Manganese	mg/L	0.1	0.09	0.09
Total hardness	mg/L	79	74	70
Turbidity	NTU	5	4	4
Copper	mg/L	0.8	0.8	0.5
Total coliform	CFU/mL	9	9	6
E. coli	CFU/100 mL	0	0	0

Table 3.7. Filtrates characterization: Chemical, physical and microbial results for Quarry Sand Dust

Parameter	UNIT	8cm	13cm	17cm
Electrical conductivity	µs/cm	64	48	31
Total dissolved solid	mg/L	32	24	17
Temperature	ºC	28.3	28.3	28.3
pH		6.92	6.83	6.71
Nitrite	mg/L	0.08	0.05	0.00
Iron	mg/L	0.05	0.02	0.00
Nitrate	mg/L	9.3	7.2	3.1
Sulphate	mg/L	23	19	12
Manganese	mg/L	0.05	0.02	0.00
Total hardness	mg/L	58	43	28
Turbidity	NTU	0	0	0
Copper	mg/L	0.8	0.3	0
Total coliform	CFU/mL	4	1	0
E. coli	CFU/100 mL	0	0	0

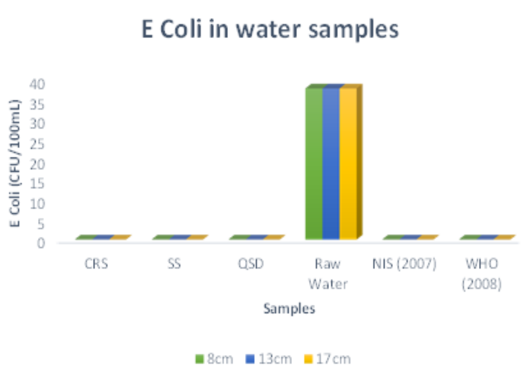

Fig. 14. Effects of soil type and bed thickness on total *E. col*

4. CONCLUSIONS

The operation of modified slow sand filtration using CRS, SS and QSD as filter beds was successful. The results obtained showed that QSD had the best performance while SS had the least performance in terms effective filtration.

From the results obtained for effects of varying bed thickness for the different sand, it was observed that bed thickness length affected the purity of the filtrate gotten irrespective of the type of sand used. As the bed thickness increases purity of the filtrate also increases.

The flow rates of the filtrates through the filter beds was observed to have effects on the purity. It was observed that the lower the flow rates of the raw water sample through the filter bed, the better the purity of the filtrates, and this was irrespective of the sand used.

Finally, the characterization of the filtrates from the three sand sources with their varying bed thickness showed that the analysis result of the filtrates from all the filter beds were all within the acceptable limit of the [11] and [12] except total coliform. However, QSD filter bed gave a better result for the analysed filtrates in terms of purification.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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