Treatment of Light Contaminated Surface Water Using Slow Sand Filtration in China

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Abstract: This was a comparative study to investigate the effectiveness of slow sand filtration with the best type of sand in filtering water from the domestic lake at China University of Geosciences (CUG) in Wuhan. It was a laboratory scale experiment which had four columns with all having a length of 100 cm in height, 3cm in diameter, and the sand was filled to a depth of 80cm with sand sizes of 0.075-2mm, 0.075-0.5 mm, 0.5-2mm and a control of 0.075-2mm with no pre-growth of bio-film. The rate of trickling water was set at 2 rounds per meter (rpm) and the filter run period was 15 days with 7 days wet and 3 days dry cycle to prevent clogging. COD, TN, TP, DO and OC were analyzed. Overall, fine sand column had the best results but specifically, COD efficiency rate was best in column of fine sand with 83%, TP in mixed sand with 81%, TN in fine sand column with 67% and DO in the control column with 8.15mg/L and OC was best in fine sand column with 22.59g. The best type of sand would be considered as 0.075-0.5 mm because it dominated in most results. With all the conditions in place, slow sand filtration was very effective as it removes most of the organic matter and suspended materials hence the water can easily be re-used not only due to its efficiency but also its simplicity in operation, cost effectiveness as well as being environmentally sound. [Journal of American Science 2010;6(4):47-57]. (ISSN: 1545-1003).

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1. Introduction

Treatment of water has for more than decades been a problem in both developed, developing and third world countries. Industrialization, globalization, population growth and some other factors continue to pose threats on both surface waters and underground water hence this has aroused the need to devise new methods and enforce the ones already existing to manage the water resources. In developed countries, treatment of contaminated water is not really a critical issue however it is still not economically viable since most activities of life and non-life revolve around water. If treatment of wastewater is done appropriately and recycled, wastewater can become a vital option in water resources at the same time, meeting the definition of sustainable development as in “Our Common Future”, 1987. However, the greatest challenge therefore comes in where monitory funds are a constraint and this is usually the case in most developing countries in Africa, Asian, and South America. Not only lower cost alternative methods have to be adopted in treating contaminated water, but also technologies which would have optimal use without causing damage on the environment and one of it, is Sand Filtration method. Though the method is archaic, its efficiency has been proven to be about 85% - 90% and it has been accepted and widely recognized as well as being adopted by World Health Organization (WHO), Oxfam, United States Environmental Protection Agency (US-EPA), and other UN organization. There are various types of sand filters namely; Rapid Sand Filtration (RSF), Up-flow Sand filtration and Slow Sand Filtration. This research focussed on treatment of surface water which is light contaminated using Slow Sand Filtration (SSF). The method was first established by John Gibb from Scotland around 1804 and in 1829, it was first adopted in London, WHO (1989).

As the name itself suggests, Slow Sand Filtration is a water treatment process that uses sand in treating water and in the process, it naturally uses biological activity. Slow sand filters have been in use for centuries, and are time-tested systems for cleaning drinking water. It is used to eliminate chemical oxygen demand (COD), organic content like phosphorous, suspended materials through decomposition, adsorption, absorption, electrostatic force and van der waals force, Shenkut Mesfin, (1996). Therefore, the objectives of this study were to investigate the quality of water after trickling through sand filtration using different types of sand and find the best sand size hence in the process, promoting the use of sand filtration. In this research, a comparative study was conducted using different types of sand and the parameters which were analyzed after treatment of the effluent were; Chemical Oxygen Demand (COD), Total Phosphorous (TP- PO_4^{3-}), total nitrogen (TN) which comprises Nitrate $(NO_3 - N)$ and Nitrite $(NO_2 - N)$, Organic Nitrogen and Ammonium $(NH_4 - N)$, pH, Dissolved oxygen and Organic Content (OC) in soil after the experiment.

According to the definition given by WHO, safe water is the one which cannot harm the consumer when utilized. It may be colored, hard, with unpleasant odor, bitter, salty but as long as the values are within the threshold limits, it is considered "safe" or "portable" hence SSF can make the water safe if it is properly or effectively treated. SSF has been widely adopted since within a single unit, it incorporates settlement, filtration, organic removal and inactivation, and partly chemical and physical change.

From to Huisman I and Wood (1974) and Logsdon S.G et al, (2002), the principle of SSF is simple in such a way that a layer known as schmutzdecke which is a bio-film develops with microbes such as fungi, bacteria, protozoa, rotifers and other aquatic animals such as bryozoa, snails, annelid worms, insect larvae which break down the organic compound in the waste water. In addition, McMeen and Benjamin, (1997); Ellis (1985) states that the sand grains of the filter bed provide additional biological and physical mechanisms that contribute to removal efficiency. Therefore in the experiment, four PVC columns were used containing fine, course and mixed types of sand sizes; of which all of them had schmutzdecke grown for 7 days before commencing treatment except the forth column which was used as a control.

2. Materials and Methods

2.1. Wastewater and sand origin

The waste water used was obtained from the Eastern side of China University of Geosciences' Lake, of which it is the domestic influent from the staff as well as students apartments and from literature, concentration values (mg/L) of COD, TP, TN, DO, normally ranges from 100 to 400, 2 to 12, 20 to 75, 0.1 to 10, respectively and pH of 5 to 8, Temperature of 15 to 25 ℃, Chen H.Q et al (2008). The sand used was quartz type which is from Yangtze river in Wuhan hence comprise minerals such as K^+, Na^+ Ca^{2+}, iron, oxides, others, Achak M et al, (2009).

2.2. Sand and column characterization

Column 1; 0.075-2mm (mixture of fine and medium sand hence termed as mixed sand), Column 2; 0.075-0.5 mm (fine sand), Column 3; 0.5-2mm (course sand), Column 4; 0.075-2mm mixture of fine and medium sand- mixed sand which begun to treat water without pre-growth of schmutzdecke and this was just used as a control to show the importance of micro-organisms.

Columns used were of 100 cm in height, 3cm in diameter, and the sand was filled to a depth of 80cm. Using Darcy's law of which

$$Q = \frac{KA(H_1 - H_2)}{L}$$

Where by; Q= Volumetric flow rate (m^3/s or ft^3/s), K= hydraulic conductivity (m/s or ft/s),
A= surface flow area perpendicular to L or direction of flow (m^2 or ft^2)
H= average depth of water above the filter (m or ft), L= length of the medium (m or ft)

The permeability (K) and porosity (n) of mixed sand is: L =30cm, A=7.065 × $10^{-4}m^2$ H_1 =75cm, H_2 =47.5cm, ΔH=27.5cm=0.275m

Q= $KA\frac{\Delta H}{L} \Leftrightarrow K = \frac{QL}{A(\Delta H)}$ = 0.242

For (n); Volume of medium= 50 mℓ, Initial volume of water = 20 mℓ, absolute volume of water = 17.15; $\frac{V\,of\,water}{V\,of\,sand} = \frac{17.15}{50}$ = 0.343

For Fine sand:
L = 0.3m, A= 7.065×10^{-4}, H_1 = 78.5cm, H_2 = 47.3cm, ΔH=31.2cm=0.312m

$$K = \frac{QL}{A(\Delta H)} = 0.207$$

(n); V of water = 21.5, V of sand = 50 then n =0.43

For course sand:
L = 0.3m; A= $7.065 * 10^{-4}$, H_1 = 85cm, H_2 = 80cm, ΔH=5cm=0.05m
K = 5.6619
n; V of water = 17.5, V of sand = 50 then n = 0.35

2.3. Experimental set-up

Three columns were filled with mixed sand, fine sand and course sand as shown in fig.1 and trickled with water for 7 days to allow the micro-organisms to grow and form the bio-film layer. All the columns were filled with 74 cm of pure sand and 3 cm of gravel at the top and bottom. An average of 3.5L of influent was trickled through the columns using a pump at a rate of 2 rounds per meter (rpm). After the elapse of this first phase, water was being filled following 7days wet/ 3 days dry cycle. The water was made to pass through the column by gravitational flow. The forth column was used as a control hence started treating wastewater influent without the first phase of growing the microbes and it used the mixed sand.

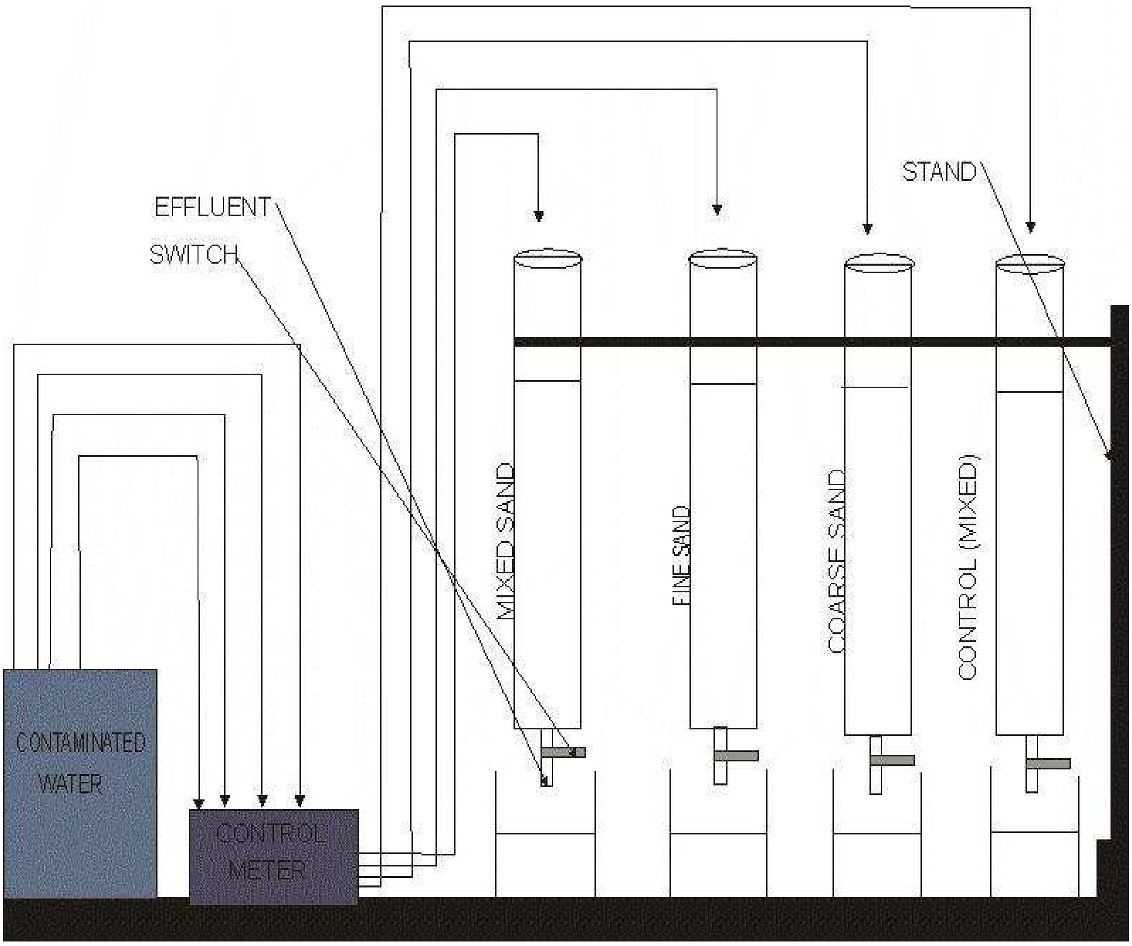

Fig. 1. Schematic diagram of the experiment with 4 columns.

2.4. Physical-chemical analysis of wastewater samples

All the samples were being analyzed on daily basis using the US-EPA standard methods. COD was measured using titration method with potassium dichromate, sulphuric acid, ammonium ferrous sulphate and phenanthroline indicator. Total phosphorous (TP) and total nitrogen (TN) was analyzed using DRB200 reactor machine through Test 'N Tube procedure for PhosVer with Acid persulfate Digestion and TNT Persulfate Digestion Method respectively. For TP, Total and Acid Hydrolyzable Test Vial, Potassium persulfate Powder Pillow, 1.54 N sodium hydroxide, Phosver 3 Phosphate Reagent Powder Pillow, were used. For TN, Total Nitrogen Persulfate Reagent Powder Pillow, Total Nitrogen Hydroxide Reagent Vials, TN Reagent A, B and C powder Pillow chemicals were used. pH was determined using a pH meter and DO also used a DO machine. All the chemicals were supplied by Chinese company known as Wuhan Heng Ling Technology and Tianjin City Fuchen Chemical Reagents Factory.

2.5. Physical analysis of sand

Sand samples were weighed before and after heating for organic content. The crucibles for drying were pre-heated for 4 hours at 400℃ and after putting soil, they were then put in first furnace for 4 hours at 105 ℃ and second furnace at 650℃ for 4 hours, as in ohlinger, (1995). For all columns, three points were taken at the top (0-7cm), middle (35-42cm) and bottom (70-77cm).

3. Results and Discussion

3.1. COD Removal

World Health organization, US-EPA and other UN organizations have proved that sand filtration can treat water from 80-90%. COD was measured every day for 20 days in 7days wet/ 3days cycle. On day 15, the columns were left to recover for one week. Table 1 shows the results for the analysis.

Table 1

Variations of COD in different columns (Mg/L)

DAYS	SAMPLE NAME CONTAMINATED WATER	COLUMN 1	COLUMN 2	COLUMN 3	COLUMN 4
day 1	133.90	23.34	22.25	30.64	35.32
day 2	140.08	20.69	19.94	26.69	32.91
day 3	191.86	20.98	20.34	25.42	40.03
day 4	162.29	11.84	8.19	13.48	37.12
day 5	196.00	19.2	16.00	22.40	33.60
day 6	128.39	16.46	14.23	29.63	19.75
day 7	123.20	18.8	15.20	32.00	28.80
day 8	139.68	12.90	11.68	17.74	15.65
day 9	115.66	20.88	17.43	25.70	22.49
day 10	124.80	19.20	12.80	27.20	20.80
day 11	177.24	27.27	26.02	33.55	27.77
day 12	199.19	31.16	30.52	33.19	32.59
day 13	222.16	32.74	33.31	26.06	31.94
day 14	209.32	33.26	36.23	21.48	24.19
day 15	214.61	39.61	40.13	29.36	36.45
day 16	179.20	45.6	46.20	27.60	40.60
day 17	199.18	49.64	49.89	36.02	42.76
day 18	150.00	48.2	49.40	40.00	43.40
day 19	127.42	39.39	44.42	38.41	39.01
day 20	151.97	47.14	50.02	44.88	59.89

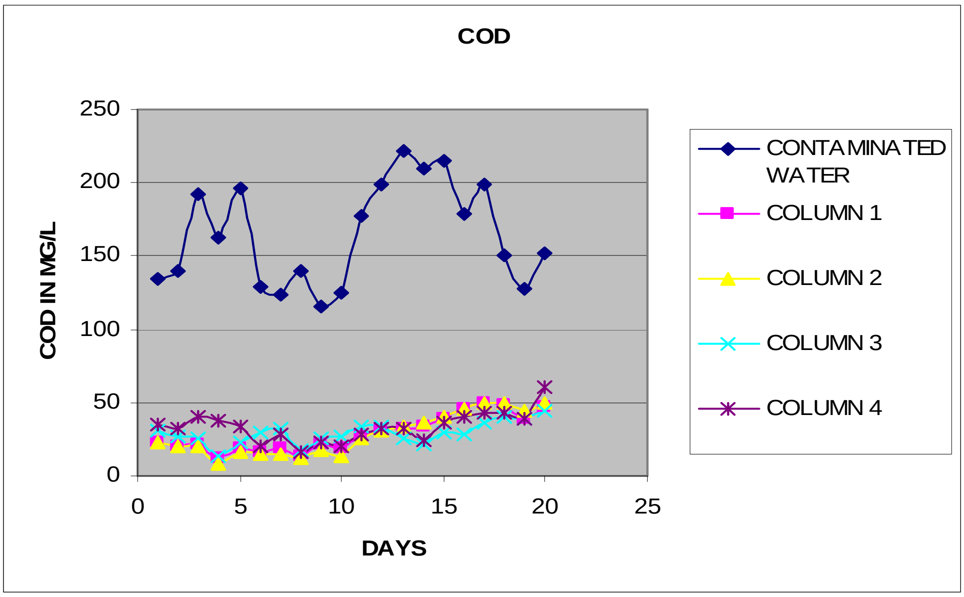

Fig.2. quantity of COD removal in different columns (mg/L)

The best results were obtained from the column with fine sand of 0.075-0.5 mm that is column 2. This is so because the there is little space in between the sand grain particles hence the organic compounds are easily trapped. Most of the COD is removed at the top of the column and the efficiency is reduced towards the bottom because of absence of oxygen. From fig. 2, fine sand column started with the efficiency of 83%. Unlike column 4 which was only 73% efficient for four days and its efficiency still remained below 79% due to insufficient micro-organisms since there was no pre-growth of the bio-film but on day 5, its efficiency increased to 82 % due to growth of microbes. In column 2, maximum COD removal was attained on day 4 at 94% and it was maintained between 80% and 90% until day 15 and this was found to be the best column with the best type of sand. After being left to recover again, the efficiency dropped to 67% hence it can be deduced that the life span of the column was 15 days. The overall COD concentration in filter effluent was measured as 28.21025 mg/L with min: 8.197mg/L; Max: 50.023mg/L. However, the efficiency of column 1 was not really significant from column 2. Column 3 was the third in its efficiency and column 4 was the forth for 5 days but the values interchanged with column 4 being the third since the microbes had grown by then and the values were close to the ones for column 1 since the same type of sand was used but the difference was in the amount of microbes which was lower in the column 4. Column 3 was most of the times the least efficient until day 12 since it had the highest sand size and this has an effect on filtration rate in such a way that it was high hence causing reduction in the organic loading and which reduced the removal rate of COD. Generally columns 1,2,3,4 were efficient in COD removal with ranges from 68 to 92%, 65 to 94%, 70 to 91%, 60 to 88% and average efficiency rates of 82%, 83%, 81% and 79% respectively. The efficiency was found by the formula $\frac{C_{in} - C_{out}}{C_{in}} \times 100$ whereby C represents concentration value. COD values from all columns were below 50mg/L which is the standard treated effluent in China. Achak M. et al, (2009) also found an efficiency range of 69 to 89%. Satoshi, (1998) in Achak M. et al, (2009) also reported as average of removal efficiency of 81.2% and similar results were experienced by Oladoja et al, (2006) who reported 80% COD removal. The removal efficiency for various days has been shown in fig.3.

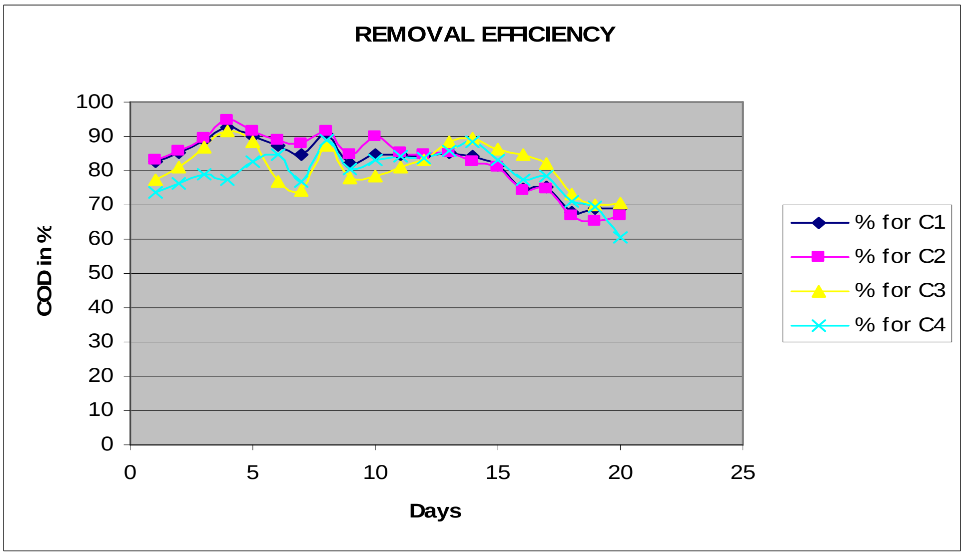

Fig. 3. COD removal in %

Achak M. et al, (2009) explains the removal of COD is eliminated through physical and biological phenomena. The particulate matter is filtered and sedimentation takes place and adheres itself to the sand grain particles. Biological degradation then takes place under oxygenated conditions. Jianmin Hua, et al (2003) reports that about 75 to 80 % of COD is removed in the first 25 to 30cm of sand in the column. The efficiency reduces due to clogging which reduces the filtration rate and the availability of the oxygen content.

3.2. Total Phosphorous (TP) removal

In this study, TP was measured every 2days and the removal capacity was the best and recorded data ranges with 0- 5mg/L as recommended by China Standards of surface water of which column 1- min: 0.04; max: 0.69, column 2- min: 0.08; max: 0.63, column 3- min: 0.25; max0.736, column 4- min: 0.1; max: 0.695 as shown in table 2 and the trend as shown in fig. 4.

Table 2
Variations of TP in different columns

DAYS	RAW WATER	COLUMN 1	COLUMN 2	COLUMN 3	COLUMN 4
day 1	2.18	0.11	0.16	0.25	0.20
day 2	3.36	0.04	0.08	0.39	0.1
day 3	2.42	0.06	0.19	0.3	0.21
day 4	2.8	0.12	0.34	0.39	0.35
day 5	2.54	0.25	0.33	0.45	0.38
day 6	3.58	0.36	0.41	0.46	0.39
day 7	4.02	0.45	0.46	0.51	0.48
day 8	4.28	0.52	0.58	0.67	0.59
day 9	3.89	0.57	0.55	0.68	0.58
day 10	4.7	0.69	0.63	0.74	0.70

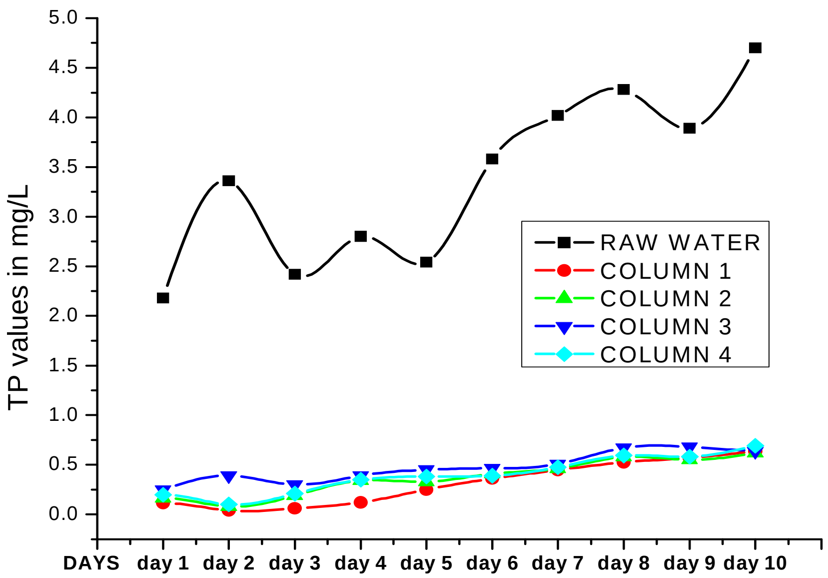

Fig.4. Quantity of TP removed (mg/L)

The average efficiency rates were 91%, 89%, 86%, 89% respectively. Removal of phosphorous is complex and sand grain size is a component that has to be considered. Rehan Sadiq et al, (2002); Jenkins et al, (1971) in Andrew J Erickson et al, (2007) illustrate that to remove dissolved phosphorous, it has to be converted to a solid phase and be removed as a particulate matter as well as being removed by sedimentation and physical sieving for solids materials. Billore et al, 1999 in Achak M. et al, (2009) explains that phosphorous is removed by adsorption and precipitation, ionic exchange. However, in long term it can also be removed as substrate as a main sink. Andrew J Erickson et al, (2007); Stumm and Morgan, (1981); Reddy and D'Angelo, (1994) explain the actual process of adsorption and precipitation that in acidic soils, it is dominated by iron oxides and aluminum. Phosphorous gets adsorbed and precipitates, hence becomes immobilized by ferric oxyhydroxide and forms ferric and aluminum phosphates. In alkaline soils, phosphorous retention or precipitation is dominated by calcium and magnesium, Weber-Shirk, Monroe L. (1997b). It has to be noted that the adsorption and precipitation process is highest in acidic conditions which are close to neutral. However, some phosphorous can still be adsorbed with iron in alkaline conditions like pH 10. Since this requires the use of oxygen, most of the processes occur on top and the capacity to retain it, decreases with depth.

In this study, column 1 which had mixed sand had the best results as shown in fig.4 since there is need of pores to provide space for iron oxides for phosphorous adsorption and precipitation. This should go hand in hand with amount of microbes which are responsible for the uptake. Column 3 had the worst because the pores are large and lacks microbes hence the precipitates would easily fall back in the water. In other words, the positive retention suggests that the retention capacity still exists and after a couple of days, the retention capacity decreases as the precipitates clogs the filter and brings complication of adsorption sites. That suggests the need of backwashing in the field to be cleaning the soil after a specific period because if this is overlooked, the precipitates may fall back in the effluent when they have saturated.

3.3. Total Nitrogen (TN) Removal

TN was also measured every 2 days. According to China standards, recommended surface water to be disposed off is 15mg/L. The ranges were; column 1 – min: 6.3; max: 16.5, column 2- min: 6.1; max 15.9, column 3- min: 6.5; max 17.3, column 4- min: 6.8; max: 16.8 as shown in table 3. The average removal efficiency rates were 65%, 67%, 62%, 64% respectively.

Table 3
Variations of TN in different columns

DAYS	CONTAMINATED WATER	COLUMN 1	COLUMN 2	COLUMN 3	COLUMN 4
day 1	28.4	6.8	6.6	6.9	7.2
day 2	30.8	6.4	6.1	6.5	6.9
day 3	27.5	6.3	5.9	6.6	6.8
day 4	26.3	7.2	6.6	7.4	7.9
day 5	29.4	7.9	7.5	8.8	8.5
day 6	28.8	8.5	8.3	9.2	8.6
day 7	25.2	10.8	9.6	11.5	10.2
day 8	27.3	11.4	11.5	13.9	12.7
day 9	28.1	15	14.8	16.8	15.3
day 10	28.9	16.5	15.9	17.3	16.8

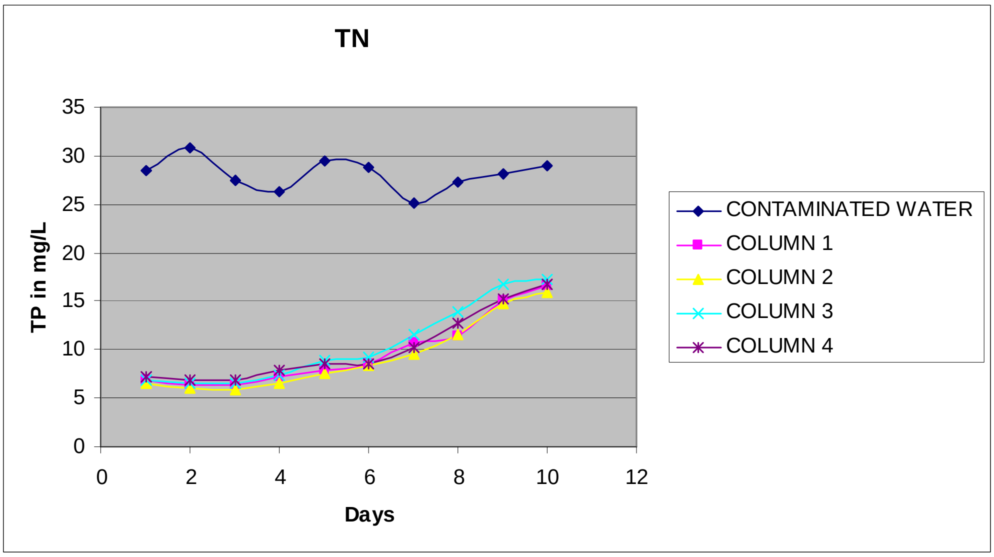

Fig. 5. Quantity of removed TN (mg/L)

The study of removal of nitrogen is complex and through literature, one of the removal process is through nitrification and de-nitrification though Gumes K and Tuncsiper B, (2009) states that the major removal mechanism is basically through de-nitrification of N-NO_3^+ by anaerobic bacteria. However, since the mentioned processes are achieved by both aerobic and anaerobic, the removal might have taken place from the top of the column to the bottom. The best type of sand was found to be column 2 with fine sand since it has a lot of microbes and the soil is compact which entails that the oxygen content would be lower than column 1 hence providing adequate growing and living conditions for anaerobic bacteria. In Achak M et al, (2009), it is explained that apart de-nitrification, microbes largely utilize nitrogen in form of NH_3 for the manufacturing of cellular components hence physical and chemical adsorption of NH_4^+ on organic matter. In nitrification, $N-NH_4$ is transformed into NO_2^- and to NO_3^- and in de-nitrification which occurs in anoxic zones, NO_3^- is changed to NO_2^- then to N_2O and to N_2. Hammer and Knight, (1994); Gumes K and Tuncsiper B, (2009), also explains that ammonium can be volatilized when NH4 is transformed to volatile NH3 especially when the pH is between 7.5 and 8.4 and in this study, this could be also the case as the pH had similar range. The fact that the efficiency of TP was better than TN, it indicates that the sand used was rich in iron and calcium. The overall procedure of nitrification, Davis L.M. and Masten J.S, (2008);

$$NH_4^+ + 2O_2 \Leftrightarrow NO_3^- + H_2O + 2H^+$$

De-nitrification;

$$2NO_3^- + organic\ matter \Leftrightarrow N_2 + CO_2 + H_2O$$

From fig.5, column 1 was the second, column 4 third because they might had relatively fewer organisms than column 2 and column 3 which had the least as well due to its large sand size hence bigger spaces in between the sand making the medium have less nutrients for the growth of bio-film.

3.4. Dissolved Oxygen (DO)

The DO of influent had arrange of 0.1 to 1.84 mg/L and after running through the sand filter, the effluent in column 1, 2, 3, 4 had a range of 5.42 to 9.23; 5.78 to 9.28; 6.6 to 9.3; 6.75 to 9.32; and an average of 7.00, 7.35, 7.91, 8.15 mg/L as illustrated in the fig.6. Column 4 had the best results due to few micro-organisms that use oxygen hence the bio-film took time to grow and column 1 did not have relatively good amount of DO as there was competition in the utilization of DO. The filter traps all the organic matter hence the DO is replenished in the process.

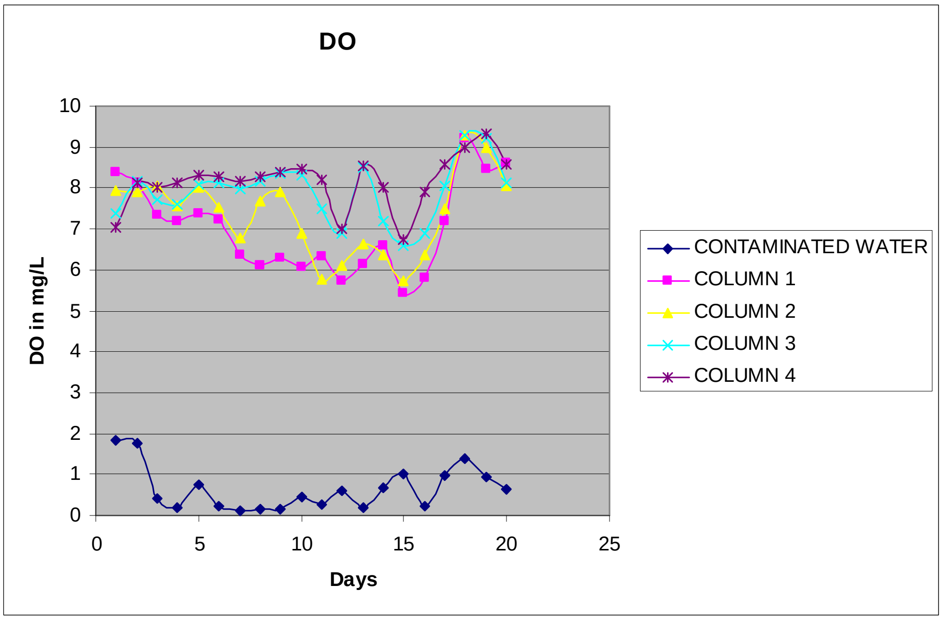

Fig.6. DO removal (mg/L)

3.5. Organic Content (OC)

OC in soil was weighed at the end of the experiment with column 2 having the highest mass and column 1 was the second as shown in table 4. This also entails why most parameters had good results in column 2.

Table 4

Organic compound from columns

Sample point (in cm)	Sand from columns (g)				
	Column 1	Column 2	Column 3	Column 4	Blank Sand
Top	4.14	4.87	2.49	3.29	0.26 (mixed)
Middle	4.81	5.61	3.45	3.32	0.34(fine)
Bottom	10.34	12.11	5.18	8.59	0.17(course)
Total	19.29	22.59	11.12	15.2	

4. Conclusion

Based on results, SSF has proved to be effective in treating light contaminated water in terms of its effluent quality with COD removal being the best in fine sand which was column 2 of 0.075-0.5 mm. TP removal was more effective in mixed sand column which was column 1 of 0.075-2mm, TN was best in column 2 just like COD. DO was effective in all columns though column 4 (0.075-2mm) outweighed with a marginal difference which comprised of mixed sand without pre-growth of micro-organisms and seconded by column 3 with course sand (0.5-2mm). In overall, fine sand should be regarded as the best because two parameters (COD and TN) studied in detail, proved more effective than in other types of sand, and for DO, the values were all in the accepted range and most of the results in fine sand were of good quality for many days as compared to other types of sand. The high amount of OC in column 2 also suggests the reason of it being more effective than other columns as it has been researched that OC is required in the treatment process of the water and growth of bio-film layer hence the higher the content, the better the efficiency but care should be taken, as too much of it would result to clogging of the column. Apart from its effectiveness, sand filtration should be promoted especially in developing areas due to its simplicity in its operation, cost effectiveness as well as being environmentally sound. Water from this system can be re-used for gardening, building, home use, and safety measures, chlorine ($C\ell$) should be added when drinking. The best efficiency rates were obtained within a period of 15 days hence it can be concluded that it was the maximum time to operate.

List of symbols

COD	=	Chemical Oxygen Demand
CUG	=	China University of Geosciences
DO	=	Dissolved Oxygen
$NO_3 - N$	=	Nitrate
$NH_4 - N$	=	Ammonium
NTU	=	Nephelometric Turbidity Unit
OC	=	Organic Content
PO_4^{3-}	=	Phosphate
RPM	=	Round per Meter
SSF	=	Slow Sand Filtration
TN	=	Total Nitrogen
TP	=	Total Phosphorous
UN	=	United Nations
WHO	=	World Health Organization

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