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Original Research

Two Models of Household Sand Filters for Small Scale Water Purification

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Abstract

Access to sufficient quantities of safe water is not just a public health issue but also a human right. Water pollution causes millions of deaths and illnesses every year. To solve the issue of water pollution at household levels and during emergencies, slow sand filters are suggested as good choices. This study aimed at designing small scale Household Slow Sand Filter (HSSF) with locally available materials. This experimental study was conducted under ambient weather conditions to test efficiency of two proposed filters in removing pollutants from source water. Natural water samples were collected from the Blue Nile, and the White Nile. The two filters were first cleaned up followed by a ripening period of two weeks to allow formation of the *Schmutzdecke* (the biological layer). Data were subjected to Hierarchical cluster analysis (HCA), ANOVA and Pearson correlation. The current research revealed that, both filters were highly efficient in removing E.coli and total coliform. The average $\log_{10}$ removal of total Coliforms and E Coli for the first filter ranged between 1.9 log and 1.7 log compared to a range of 1.1 log to 1.2 log for the second filter. The association of $\log_{10}$ total coliforms with turbidity and TSS has drastically changed after filtration. Overall, the best performance of filter 1 was reported for removal of bacteria, turbidity, iron (Fe), TSS, K and NO_2, and Zn, respectively, versus NO_2, Fe and Zn for filter 2, in the same order. The trend of ions removal assumed to be affected by both mineralization and oxidation which further supported by HCA results and it was differ than the pattern of heavy metals removal that was generally moderate not exceeded 65%. All soluble ions after filtration did not exceeded WHO guideline limits. The first proposed filter suggested to be efficient that need to be confirmed by further studies.

Keywords: household sand filter, efficiency, removal rate, HCA, $\log_{1o}$ total coliform

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Background

Drinking water is the most important element of life, however, it can be a source of exposure of pollutants such as pathogens, chemical, physical, and radiological pollutants [1]. The major categories of water pollutants are pathogens, grease and oil, plant nutrients, heavy metals, synthetic organic compounds and oxygen-consuming materials [2-4]. Drinking water is a significant contributor to human exposure to waterborne pathogens including bacteria, protozoa and viruses. Water pollution is a wide-scale problem and the global community is dealing with extraordinary health problems related to polluted water. Water is either polluted by point sources such as discharge of untreated municipal (sewage) waste, power plants, coal mining and industrial discharges, or non-point sources from agricultural activities, storm run-off, construction sites, and streets. Additionally, some natural sources of pollution include decay of organic materials in water, leaching of minerals from rocks , and salt intrusion into water [4, 5].

Worldwide, an anticipated 1.9 billion people use both an advanced water supply and an unimproved supply that is faecally-contaminated. While diarrheal diseases kill more than 1.8 million people every year [6], around 502,1000 of the diarrheal deaths in low- and middle-income nations may be attributed to insufficient and unsafe water. The extensive majority of these deaths arise in Africa and South-East Asia, specifically among susceptible populations, consisting of younger children, the malnourished and those living with the human immunodeficiency virus [7]. Unsafe water and poor sanitation accounted for 0·9% (0·4-1·6) of global DALYs (Disability-Adjusted Life Year (DALY) in 2010 [8]. Contaminated drinking water not only linked with diarrheal disease but also with a range of other diseases such as dysentery, typhoid [5], Hepatitis E [9], cholera [10], Escherichia coli O157:H7 Infection [11], schistosomiasis, hookworm infections, trachoma, ascariasis, [12, 13], and several other illness.

Despite the improvement that being made in water, sanitation and hygiene promotion (WASH) related services, there still discrepancies between rural and urban in accessibility to safe and sufficient water. The components of WASH are interconnected and taken together, where safe water is affect by personal hygiene, practices, life styles and behavior of people while hygiene is linked with sanitation, educational level and economic status [14, 15], in addition to the influence of technological, social, economic and political factors on the provision of sanitation facilities.

The importance of Household Slow Sand Filter (HSSF) emerged for several reasons, firstly, water handling and storage practices at the household level lead to high contamination unless some sort of treatment taken place such as the use of HSSF [16, 17]. Secondly, Studies have shown that, the usage of sand filters for water treatment reduce the spread of diarrheal diseases, one of major causes of death among people [6], and even cholera outbreaks [18]. Thirdly, as mentioned above, HSSF is simple in design, affordable and highly efficient that suggest its use at household levels, particularly in rural, peri-urban areas and in emergencies [19]. Fourthly, the biosand filter such as these two models tested in this study can be designed using locally available resistant plastic barrels, or simply be constructed with concrete. Last yet importantly, the slightly warm ambient temperature is suggested to favor the microbial growth which is the main mechanism of the treatment in the HSSF system [20], however, excessive temperature has negative effect on treatment by reducing the solubility of oxygen in water. Sudan, and many other countries like Saudi Arabia, Egypt, Kenya, etc. are located in warm weather zone, therefore the use of HSSF may show better performance in these countries.

HSSF vary from the other types of water filters due to the fact they uses biological films or bio layer that grows naturally, as a main mechanism for the removal of pathogens, with pathogens removal rate reaching 99% to 99.9% [21]. Although the Household Slow Sand Filter (HSSF) is very efficient technique for the removal of classical microbial and physical pollutants, it is not recommended for the removal of industrial pollutants such as arsenic, chromium, cadmium and others [19]. Last but not least, application of HSSF at the community level need community orientation about proper use and operation, with follow up at least from local health workers [22].

This experimental study is aimed at designing an easy-to use HSSF with local materials for use in rural, peri-urban and emergency situations, with determination of the chemical, physical and bacteriological characteristics of water and measuring efficiency and removal rates be the main specific objectives.

Materials and Methods

Samples' Collection

A total of 66 samples were subjected to analysis, of which 22 are raw water samples that collected from the Blue Nile, and White Nile (11 from each Nile), 22 samples from effluent of filter 1 and 22 from effluent of filter 2, respectively.

Design Considerations

A. Materials used in the experiment:
- Two plastic Barrels with a height of 95 centimeters.
- Two PVC Hose of 70 centimeter length.
- Plumbing materials.
- Different sand beds as in Table 1.
- Fine sand the average of size 0.27 mm, and Uniformity Coefficient of 1.5-3.
- Gravel below sand bed to support the underdrain.

Table 1. The Layers of medium in the two system.

Layers	The first filter	The Second filter
Standing water	30 centimeter*	≤ 30 centimeter*
Fine sand column	40 centimeter	25 centimeter
Coarse (natural river) sand column	0.00	20 centimeter
Gravel	20 centimeter	20 centimeter

Note: *This level of water tested to maintain filtration rate that required for optimal operation

– Coarse natural river sand with the average of size 1.8 mm.

B. Setting up the two filter systems:

Firstly, the two filter containers (barrels) were washed with water and soaps several times followed by cleaning up with distilled water before placing the sand beds and the gravel. Secondly, the sand bed is washed with water only, therefore existence of mineralization could not be neglected, as indicated elsewhere [23]. Thirdly, after the filters fully set up, water is allowed to flow through the filters for two weeks as a ripening period during which, water is drained to waste. Fourthly, to avoid drying of the filter bed during the ripening and operation periods, the filter outlet levels are designed to be above the top level of the sand bed as in Fig. 1.

Filter Operation Conditions

– Filters are fed during daytime with at least 12-16 liter/day, with 6-8 hours pause periods at night.
– Uninterrupted flow was intended to assure constant input of oxygen and food for the microorganisms to avoid their die-off as indicated in the literature [20].
– Ripening period was two weeks as applied elsewhere [24].
– The filtration rates were kept between 0.09-0.3 $m^3/m^2.h$ by adjusting the level of standing water (i.e. the supernatant). The filtration rate adopted in this study was suggested by WHO and others [25, 26].

Laboratory Analysis

A. Quality control:

– A number of blank samples representing 5% of the total number of real samples followed the water samples during the whole process of sample collection and analysis. Thereafter, readings were adjusted based on trace concentrations of the blank samples.
– The filtered water is collected in hygienic water buckets that offered by Unicef for use during emergencies.
– All glassware and metallic tools used were sterilized by hot air oven at a degree of 160°C for 1 hour.

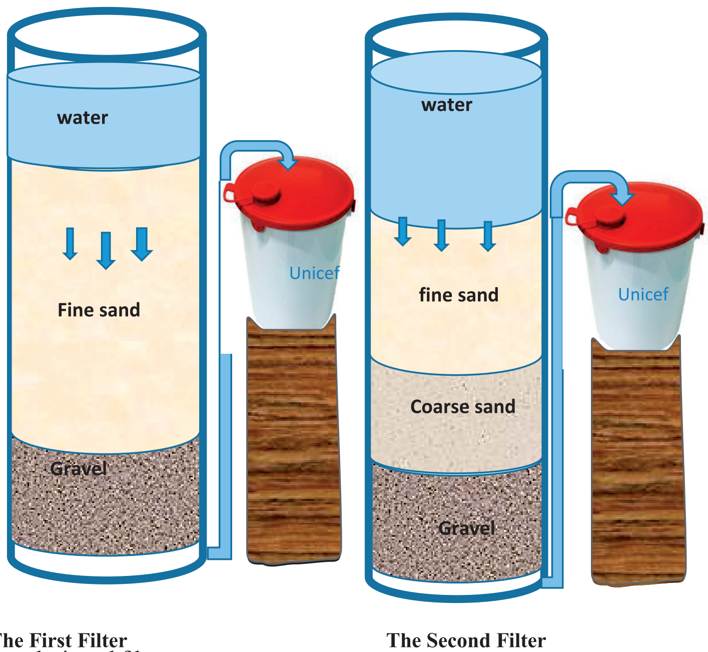

Fig. 1. An illustration of the two designed filters.

– Distilled water was obtained from a distiller and forceps were sterilized by flame.
– To ensure that oxygen supply is sufficient for aerobic treatment condition, dissolved oxygen (DO) has been measured several time and found to be above 1.5 mg/l.

B. Calculation of the efficiency of the two filter systems: the efficiency of removing pollutants is calculated using equation 1 below:

$$\text{The filter efficiency} = \frac{(A-B)*100}{A} \quad (1)$$

Where: A ≡ characteristics of sample before filtration and B ≡ characteristics of sample after filtration.

Physical Tests

Hydrogen Ion Concentration (pH)

A digital pH meter was used (Palintest® Co. LTD.), where the device is first washed with distilled water and calibrated before performing the measurement for the water that placed in a pre-cleaned glass beaker.

Turbidity

The turbidity was measured by Micro 950 Turbidity meter (Palintest® Co. LTD.), with measurements being done as in the user manual, and reported as NTU (Nephelometric Turbidity Unit).

Total Suspended Solid (TSS)

The TSS is determined following the *2540D* method of standard methods for the examination of water and wastewater [27]. Briefly, the apparatus used included Standard Glass Fiber Filters, Oven, Desiccator, sensitive Balance and Filtration. Water samples are well mixed then filtered via pre-weighted Glass fiber paper followed by drying in oven at 103ºC±2ºC for 1 hour, and finally placed in a desiccator before post-weighting in a micro balance.

Total Dissolved Solid (TDS)

Briefly, water samples are filtered through standard glass-fiber filter, followed by transferring the filtrate to a pre-weighed dish, evaporating to dryness, with subsequent drying in in an oven at 180±2ºC. The concentration of TDS equivalent to the increase compared to the weight of the empty pre-weighed dish [27].

Chemical Tests

All of the chemical parameters including Nitrate, Nitrite, Manganese (Mn), Potassium (K^+), Iron (Fe), Zinc (Zn), and Chromium)Cr(were measured using *Palintest*® Photometer 7500 (Palintest, Ltd, Gateshead, NE11 0NS, England), following instructions that given in the user manual. This photometer performs the testing based on scattering or absorption of the measured intensity of the incident light. The calibration is done by calibration tables and use of reference standards (Palintest reagents). The test methods are accessed through *ID phot Number* that showed on the main screen. For each batch of analysis, sample and Blank cuvettes are cleaned up and dried properly. Each screw cap is removed and wiped with a tissue free of impurities. For each parameter, there is a specific test tablet that is placed in the cuvettes and crushed followed by mixing and allowed 10 minutes before the analysis.

Biological Tests

Detection and enumeration of E. Coli and total Coliform were performed according to the standard methods for the examination of water and wastewater (section 9222) that set by the American Water Word Association (AWWA), with more details on the procedure are given in the indicated reference [27].

Statistical Analysis

Students t-test and ANOVA at 95% significance level were performed to investigate the correlation between the concentrations pre-and post-filtration and among quality parameters, which give an indication of possible alteration during filtration either due to existence of trace levels in the soil media or due to chemical reactions. Results were interpreted with values of Pearson's correlation coefficient; R^2 and p value.

Cluster analysis, an unsupervised learning technique is performed to explore proximities of the measured parameters. In brief, cluster analysis using ward linkage method is applied in which the sum of squares of "pooled within-group" is minimized. A Minkowski measure of interval is chosen. Since variables are not of the same units and having dissimilar variance, we applied standardization/transformation as an optional procedure during cluster analysis. More explanation on cluster analysis is provided elsewhere in the literature [28-31].

Results and Discussion

Overall, the performance of the first filter was better than that of the second filter as illustrated in Fig. 2 and Fig. 3, in the reduction of major parameters. This performance was possibly due to the suitability/sufficiency of fine sand bed in filter 1, with 40cm depth, diameters of 0.15-to 0.35 mm, and uniformity coefficient of approximately 1.5 to 3. Concentrations of all parameters after filtration in the first filter fulfilled WHO guidelines for drinking water quality. The best performance of filter 1 was reported for removal

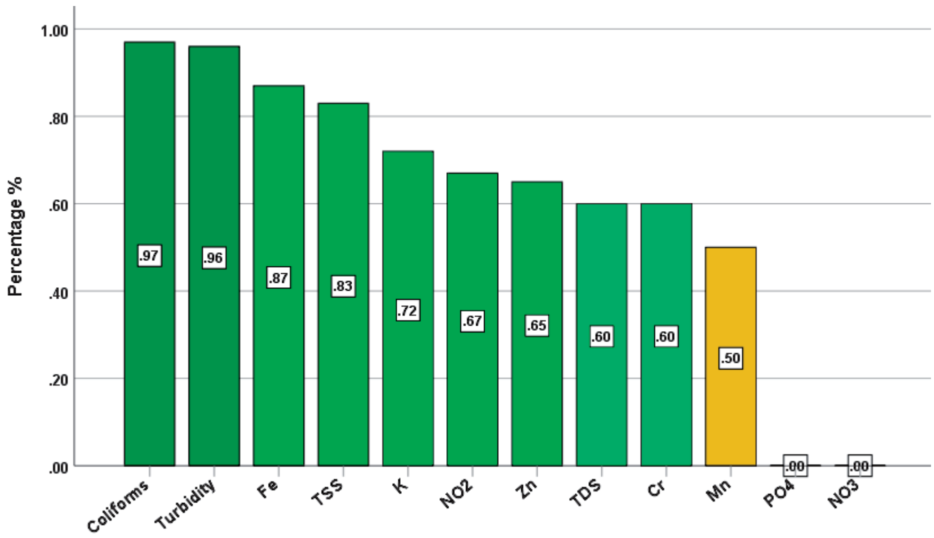

Fig. 2. Efficiency of filter 1 in removal of water pollutants.

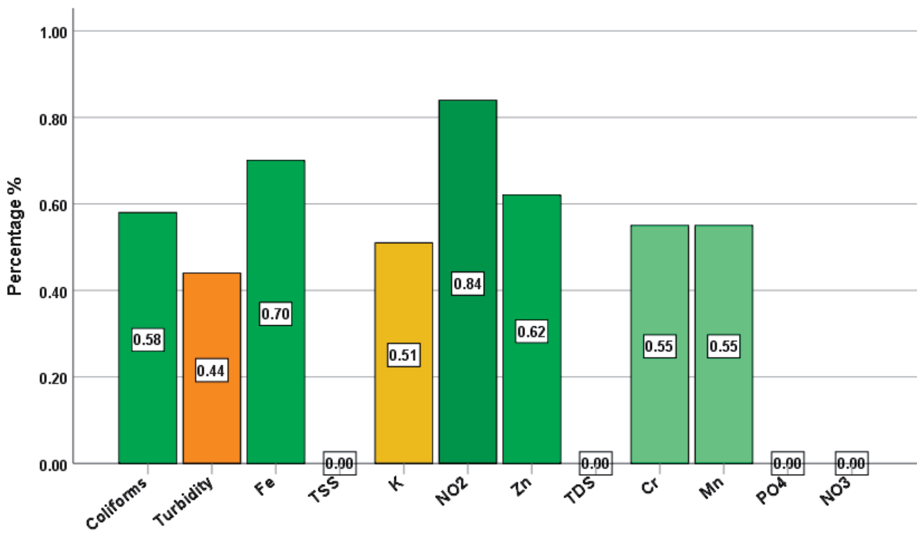

Fig. 3. Efficiency of filter 2 in removal of water pollutants.

of bacteria, turbidity, iron (Fe), TSS, K and NO_2 and Zn, respectively, versus NO_2, Fe and Zn for filter 2, in the same order. The large fine sand bed particularly of the first filter assumed to have increased the Solids Retention Time (SRT) and Hydraulic Retention Time (HRT) and improved the performance accordingly [24].

Bacteriological Characteristics

The major role of the household slow sand filter is to remove microorganisms as indicated by E Coli and total Coliforms where this issue has given special attention [24, 32, 33]. The removal of microorganisms is mainly due to the biological layer (i.e. schmutzdecke) that play the major role, with minor role for mechanical straining, however, there are other contributing factors such as predation by eukaryotic microorganisms and other life forms, starvation and lysis [34].

Due to possible great variability in the readings of bacteria in sample, geometric mean and log10 of removals are used to express the remove of bacteria using equation 2 [35].

$$\text{Log decrease} = 100 - \frac{log_{10}\ pre-filteration\ bacterial\ count)}{log_{10}\ post\ filteration\ bacterial\ count} * 100 \quad (2)$$

The average $\log_{10}$ removal of total Coliforms for filter 1 and filter 2 were 1.9±0.4 log, and 1.2±0.7 log, while for E. coli, the removal rates were 1.7±0.3 log, and 1.1±0.7 log in the same order. These values of log removal rates resemble those reported in similar recent research [36] and slightly greater than other results [37]. It is evident that the first designed water filter was very efficient for removing all (100%) of E Coli and around 97% of total coliform from the raw water, compared to low performance of the second filter that were below 60% for both total coliforms and E Coli. As expected, the removal of bacterial showed improvement with time, i.e. in samples collected during later days of filters' operation showed better removal rates compared to removal rates during earlier days of filters' operation [38]. This improvement of bacteria removal with time may be related to development of schmutzdecke layer over time through enhancing trapping of particles and reducing filtration rate [36]. Our findings found are also very close to findings of a similar study that shown removal of 98.9% [35], and 98.5% of fecal coliform [24].

There are two possible reasons behind the high removal of bacteria in the first filter. Firstly, the depth of fine sand that was 40cm, very close to what is being recommended [19, 24]. The larger volume of fine sand increases the efficiency through provision of extra residence time and more mechanical straining, as stated in the literature [24]. This result agree with Clark, et al., (2012) who stressed the importance of filter depth. The performance of fine sand bed is better than that of coarse sand, in consistence with a previous review [21]. Secondly, the sufficiency of ripening period that lasted for two weeks was enough for development of microbial community necessary for biological treatment. The influence of the schmutzdecke in filtration efficiency is greater than that of the mechanical straining [33].

The high efficiency of filter 1 for removal of total Coliforms and E Coli shown in this study support the usefulness of this natural purification system as an alternative to the household ultrafiltration and reverse osmosis units that may pose microbial risk as revealed in recent studies [39, 40]. Water from all filtration batches fulfil both WHO guidelines for drinking water (2011) and Sudanese Standards and Metrology Organization (SSMO), that each 100ml of collected water should be bacteria free particularly from E Coli.

Fig. 4, a contour map visualizes relationships between total coliforms, turbidity and TSS. Interestingly, for raw water (Fig. 4a), $\log_{10}$ total coliforms linked with low turbidity and low TSS, with the area of high coliform counts highlighted with red, orange and yellow color in the map. In effluent of the first filter (Fig. 4b), high coliform counts moved toward the center of x-axis and linked with moderate levels of turbidity but has no clear link with TSS. In effluent of the second filter (Fig. 4), apparently there were two trends for the association, the first trend resembles to some extent that for the first filter where high coliform counts linked with high turbidity (on x-axis) while the second trend is that high coliform counts centered the map and associated with both high turbidity and high TSS. When these apparent associations tested statistically, there were significant associations only when we applied Spearman correlation Coefficient (Nonparametric testing) that ranged between 0.52 and 0.54, with p values≤0.5, however, when we applied Pearson's correlation coefficient (parametric testing),

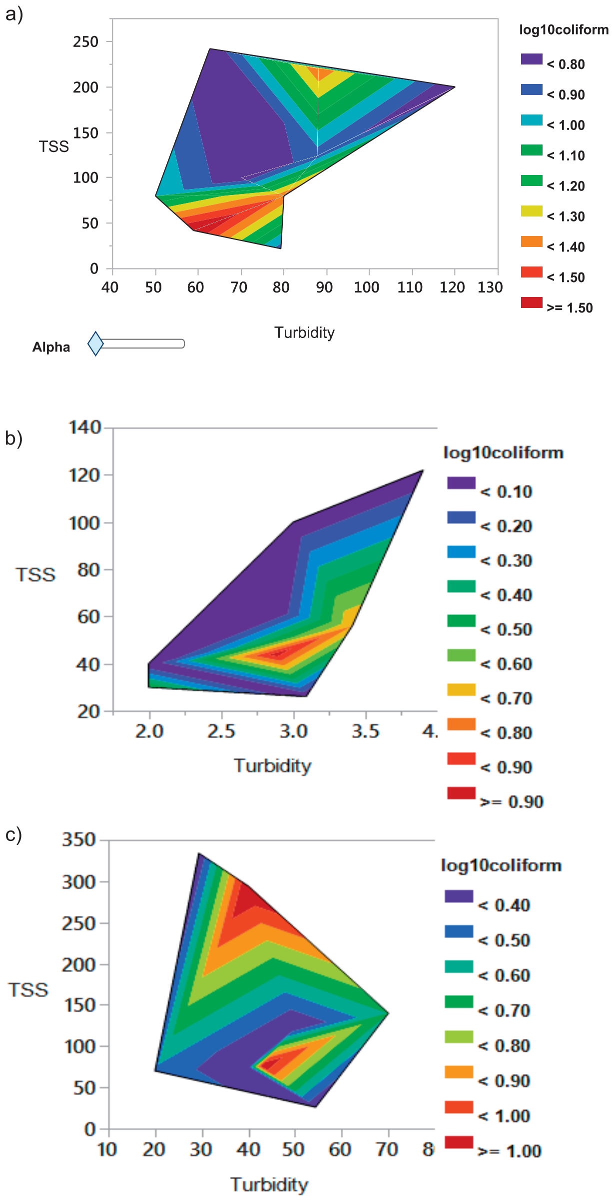

Fig. 4. Contour maps demonstrating relationships between total coliforms, turbidity and TSS. a) Raw water; b) Post filter 1; c) Post filter 2.

where were no statistically significant correlation (p≥0.5; r ranged between (-) 0.20 and (+) 0.54.

Physical Characteristics

Findings of analysis of soluble ions are shown on Table 2, the average levels of turbidity were 76.13±12.5NTU, 3.1±0.5NTU and 42.9±8.8NTU, for the raw water (pre-filtration), post filter1 and post filter 2, respectively. The removal rates were 96% and 44% for filter 1 and filter 2, in the same order. Even though the average turbidity of the raw water is high that may affect the efficiency [41, 42], the first filter showed better efficiency for removal of turbidity compared to the second filter. To be note is that, the removal rates for turbidity showed great variation, that may be attributed

Table 2. Basic statistics of physical parameters.

Statistics				
Physical parameters		Pre-filtration	Post -filter 1	Post-filter2
pH	N	22	22	22
	Mean	7.15	7.07	7.15
	Std. Deviation	.23	.15	.23
	Minimum	6.80	6.80	6.80
	Maximum	7.40	7.20	7.40
TDS	Mean	196.33	59.00	170.00
	Std. Deviation	36.47	45.22	20.44
	Minimum	166.00	96.00	174.00
	Maximum	254.00	220.00	234.00
TSS	Mean	121.67	20.20	154.67
	Std. Deviation	91.84	33.16	127.88
	Minimum	22.00	26.00	26.00
	Maximum	242.00	122.00	334.00
Turbidity	Mean	76.13	3.08	42.90
	Std. Deviation	12.50	.53	8.76
	Minimum	58.90	2.33	29.40
	Maximum	88.10	3.90	54.40

to variability in the turbidity levels of the raw water as indicated by its relatively high standard deviation, resembling a statement from literature [43]. Removal of turbidity is suggested to be a result of both physical mechanism and biological actions at the *schmutzdecke* layer [37]. The high turbidity of raw water presumably a result of two things; (1) water turbulence where some samples were collected during rainy season and (2) the fast flow of water in Blue Nile that lead also to high turbidity. Contrariwise, although low removal rate for turbidity is possible in the literature [23], the low removal of turbidity in filter 2 may reflect some defects in the design of the filter such as insufficiency of the volume of fine sand (height of 25 cm), and possible high mineral contents of the coarse sand in filter 2.

All samples showed low turbidity after filtration through the first filter that do not exceed the limits of 5NTU set by WHO [44] and the Sudanese standard for drinking water SSM, 2008. Surprisingly, turbidity in the influent showed no significant effect on the efficiency of the filter on removal of bacteria, with this finding accord with the literature [24].

The mean level of TSS in raw water before filtration was 121.7±91.8 mg/l, and after filtration with filter 1 was 20.20±33.16 mg/l while after the second filter was very high exceeding TSS levels of the raw water, accounting for 154.7±127.9. Meantime, removal of TSS for the first and second filters, were around 83% and 0.0% respectively. Since TSS is removed mechanically, the main reason for the variance in efficiency of the two filers could be the long depth of the fine sand of first filter (40 cm) compared to that for the second filter (25 cm). Theoretically, the smaller size of sand bed reduces the filtration rate by decreasing porosity and enhance larger surface area of biofilm. It is evident that there has been great heterogeneity in the readings of TSS where minimum level was 22 mg/l compared to maximum level of 334 mg/l. Although these levels of TSS may have no health implications, they affect the plausibility and acceptability of water by consumers. Finally, there has been overall similarity in the pattern of turbidity and TSS, i.e. levels of these two parameters were going up and down but not statistically significant ($p \geq 0.05$; r values$\leq$0.40). This result is further confirmed by cluster analysis and agree with statement from literature [45].

The first filter exhibited fair removal (60%) of TDS compared to low removal (30%) for the second filter. In fact, average TDS after the second filter was high, accounting for 170±20.4 mg/l compared to 196.3±36.5mg/l for the raw water and 59.0±45.22 after the first filter. Fortunately, the TDS of all samples before and after filtration fall within normal range according to WHO guidelines for drinking water quality (4th edition,) which is considered safe for human consumption apart from creating objectionable taste to consumers. Since raw water samples are collected from rivers (Blue Nile and White Nile), the relatively low

Table 3. Basic statistics of water chemical constituents.

Points	Descriptive Statistics								
		NO_2	NO_3	PO_4	K^+	Cr	Fe	Zn	Mn
Pre-filtration	N	22	22	22	22	22	22	22	22
	Mean	.4298	.1477	.5016	6.9444	.0722	.0667	.0711	.0071
	SD	.0081	.0774	.1830	1.4638	.0244	.0850	.0298	.0054
	Minimum	.0176	.0300	.0740	5.7000	.0400	.0000	.0100	.0030
	Maximum	.0400	.2000	.6800	10.5000	.1100	.2500	.1100	.0200
Post filter 1	Mean	.1143	2.1599	.6944	1.9222	.0167	.0089	.0167	.0036
	SD	.1908	1.9996	.3421	.6037	.0200	.0093	.0430	.0075
	Minimum	.0070	.7700	.4000	2.4000	.0400	.0000	.0100	.0010
	Maximum	.6070	6.0000	1.5000	4.3000	.1000	.0200	.1500	.0210
Post filter 2	Mean	.0653	1.8109	1.1711	3.5111	.0278	.0200	.0589	.0032
	SD	.0365	2.8592	1.4153	.6827	.0311	.0166	.0386	.0029
	Minimum	.0260	.0890	.4000	2.7000	.0100	.0000	.0100	.0000
	Maximum	.1250	9.0000	4.8000	4.5000	.1100	.0400	.1100	.0100

TDS in raw water reflects low solubilities of minerals in the watershed/catchment area and Drainage Basins. Meantime, there were fair associations ($r = 0.72$); $P = 0.03$) between influent TDS and effluent TDS of filter 1 and between influent TDS and effluent TDS of filter 2 ($r = 0.76$); $P = 0.02$).

The pH levels showed no significant differences between pre-filtration and post filtration through the first and second filters, where the average values estimated to be 7.15±0.23, 7.07±0.15 and 7.15±22, respectively. While this normal range of pH evidently has no negative effect on microbial activity in the sand filter, it gives indirect indication about absence of anaerobic conditions that reduce pH through production of acids and other chemical species.

Chemical Characteristics

Average, maximum and minimum values of the tested chemical constituents are shown on Table 3. Iron (Fe) has undergone removal rates of 87% and 70 % for the first and second filters, respectively (see Fig. 5). However, both filter 1 and filter 2 showed moderate removal of Mn accounting for 50% and 55% respectively. This high efficiency of iron removal and moderate manganese removal compared to removal of other metals may be attributed to possible oxidation by bacteria [46]. Soluble iron (Fe) and soluble Manganese (Mn) may cause problems of taste and coloring of clothes if found in high concentrations that lead to consumer objection [47]. Slow sand filters are cost effective technologies for removing Fe and Mn via major mechanisms particularly aeration and existence of appropriate microbial communities for their oxidation [21, 48]. Mn does not exceed the health-based limit of 0.4 mg/l (WHO Guidelines 2011) while Fe has no health-based guideline limit set by WHO but if found in higher levels exceeding 0.3 mg/l may affect acceptability.

There has been a general trend of increase in concentration of Nitrate after filtration and decrease of Nitrite ($N0_2$) concentration which partially accord with results of a similar study [49]. Average level of Nitrate (NO_3) in the raw water was 0.148±0.077 mg/l, while after filtration in first filter was 2.159±1.99 mg/l and after filtering in the second filter was 1.811±2.859 mg/l respectively (see Fig. 6). Similarly, mean concentrations of NO_2 were 0.429±0.008 mg/l, 0.141±0.191 mg/l, 0.065±0.036 mg/l for raw water, effluent of filter 1 and effluent of filter 2, in the same order. In filtered water, NO_2 did not exceeded WHO exposure limit of 0.3 mg/l and NO_3 did not exceeded the limit of 50 mg/l. It is noteworthy that, these WHO limits for NO_3 and NO_2 are intended for protection against methaemoglobinaemia, a condition where the infant become hypoxic when nitrite in blood convert hemoglobin into methaemoglobin that hinder carrying oxygen into body tissues leading to other symptoms [26]. Solids Retention Time (SRT) and Hydraulic Retention Time (HRT) both claimed to influence the nitrification, an oxidation process through which ammonia is first converted to nitrite and the later subsequently converted to nitrate. In the same regard, the decrease of NO_2 along with the increase of NO_3 of the effluent water suggest appropriateness of SRT and HRT that allow oxidation, i.e. good aerobic condition throughout the filters.

The average concentrations of Potassium (K) were 6.944±1.46 mg/l, 1.92±0.60 mg/l, 3.511±0.68 mg/l respectively which are considered within normal range. According to WHO (2011) there is no need for

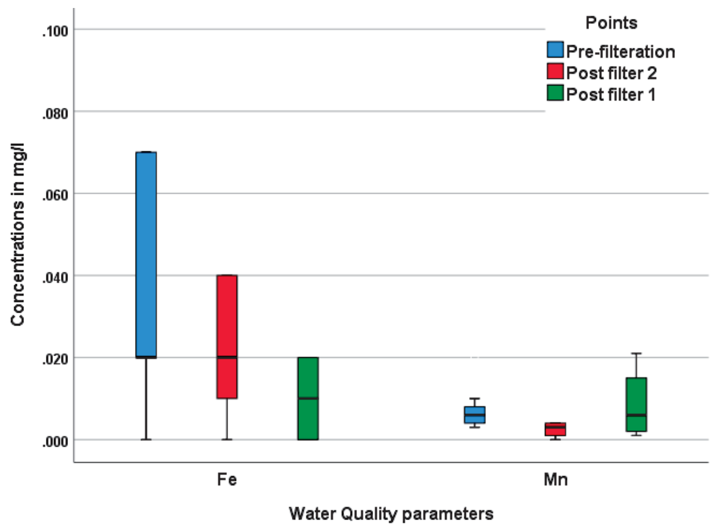

Fig. 5. Comparing Fe and Mn pre-and post-filtration.

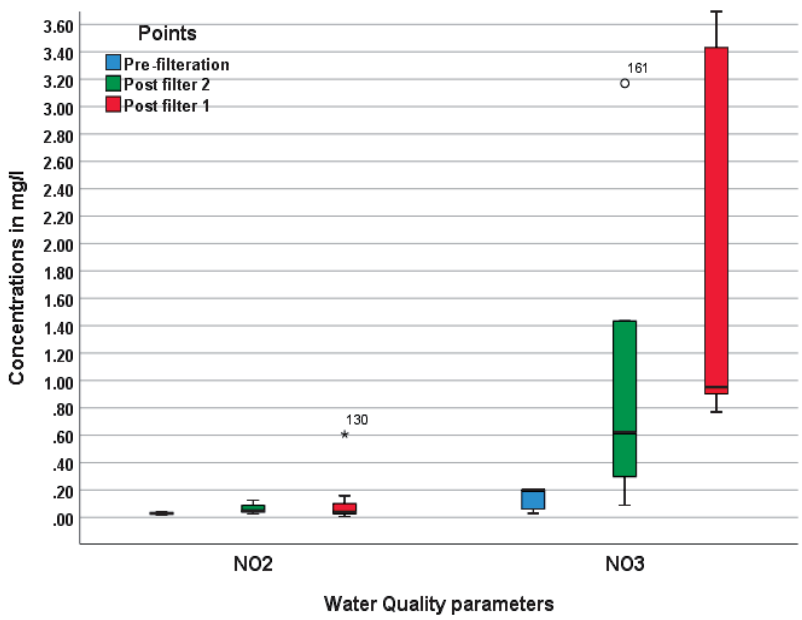

Fig. 6. Comparing NO_2 and NO_2 pre-and post-filtration.

setting health-based limit for potassium in water since its concentration in natural water pose no health risk to human. Phosphate (PO_4) followed the same pattern of NO_3 where its levels increased after filtration, with mineralization (dissolve of PO_4 in soil) be considered as the potential reason for its increase.

It was evident that the efficiency for removing some soluble ions was generally high for filter 1 and low for filter 2. This apparent low removal of some soluble ions may be affected by existence of mineralization, i.e. ions dissolved from the filter media as explained elsewhere [23]. Since filter 1 which is based on fine sand only has better performance than that of filter 2 which is consisted of fine and coarse sand, we assume that this mineralization is due to the coarse sand.

Heavy metals, a group of quality parameters represented herein by Zinc (Zn), Chromium (Cr) as most common chemical species that may reflect chemical contamination. Percentage removal rates of around 65% were reported for the aforementioned chemical species. Because of potential stochastic effects of persistent exposure to heavy metals in water, levels of Zn, Cr, and other similar metals are of public health concern. Expectedly, the efficiency of both filters considered moderate which partly agree with findings of similar study [50]. As a matter of fact the removal of heavy metals is commonly below 80% [51] and HSSF is not recommended for removal of industrial chemicals such as Zn, Cr,…etc., rather it is best for removal of pathogenic microorganisms [19].

Hierarchical Cluster Analysis (HCA)

Dendrogram (Fig. 7), visualizes results of HCA and summarizes the distance matrix of the quality parameters included in the study. It suggests that after filtration in the first filter (Fig. 7a), NO_3 become closer to NO_2 which confirms the idea of oxidation of NO_2. Manganese (Mn) and phosphate (PO_4) both linked with turbidity suggesting that residues/deposit from oxidation of Mn and PO_4 may have caused little turbidity. Unlike samples of raw water, TSS in effluent of filter 1 formed a single separate cluster that ultimately joint the above cluster of turbidity, Mn and PO_4. That means the link between turbidity and TSS in effluent of first filter become weak. Iron (Fe) showed strong link with TDS as shown on the dendrogram. On the contrary, nether K nor Zn has shown any link with any other parameter, implying that their removal is affected by other mechanisms.

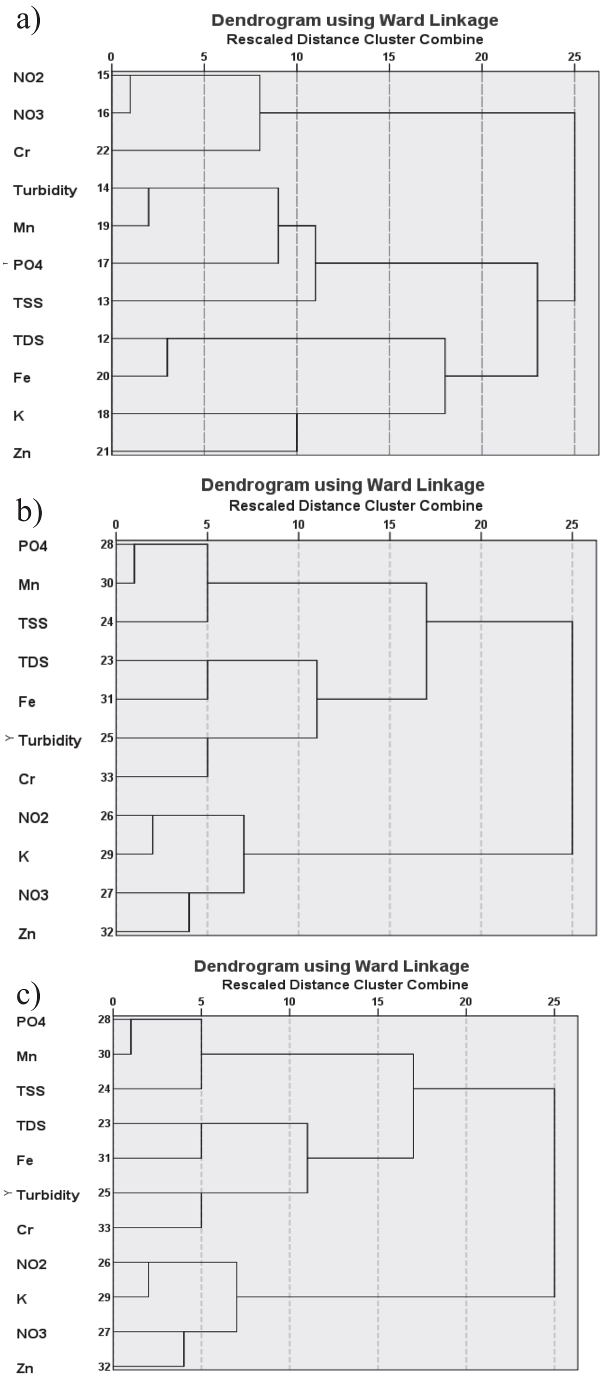

Fig. 7. Dendrogram illustrating results of HCA. a) Dendrogram Post filter1; b) Dendrogram Post filter2; c) Dendrogram Pre-filtration.

After filtration in the second filter (Fig. 7b), PO_4 and Mn linked with TSS in one cluster, for unclear reason. Following the same pattern as in filter1, Fe linked with TDS, while unexpectedly turbidity with Cr have aggregated in one cluster. Last but not least, NO_3, NO2, K and Zn all formed together in a separate cluster. It is evident that, concentrations of parameters in effluent of filter 2 are influenced by factors that differ than those of the first filter and that some chemical species aggregated tougher with no clear reason. This unusual pattern of distribution for the parameters in the effluent of the second filter may be attributed to possible effect of mineralization since we applied two different types of sand (fine and coarse) in the second filter.

For the raw water (Fig. 7c), Mn is found closer to NO_3 than to NO2 but all of which belong to the same cluster, i.e. possibly originated from same source. Phosphate (PO_4), Chromium (Cr), and Zinc (Zn) aggregated to shape a cluster that may indicate industrial source. Interestingly, TDS and Fe have formed a distinct cluster while turbidity, TSS and K have aggregated in a separate cluster.

Conclusion and Recommendations

This study revealed very high efficiency of the first designed filter system in the removal of E. coli, total coliform, turbidity and moderate efficiency in the removal of some soluble ions implying potential usefulness of filter 1 in rural water treatment and in emergency use in future. The general low efficiency of the second filter in removing any set of parameters, may reflect existence of some defects in the design such as insufficiency of the volume of fine sand that subsequently affect the flow rate and mechanical straining and possible high mineral contents in the coarse sand bed. On the contrary, both filters showed fairly low reduction in heavy metals and this is true and logic because the slow sand filters are biological filters that not primarily intended for the removal of heavy metals, rather they are mainly used to remove microbes and some ions from water. We recommend conducting further research that include more quality parameters and reconsider current study limitations. In line with previous studies, we suggest adding chlorine to the filtered water just in case of existence of quiet few coliforms and that local conditions cause elevated levels of nitrite that to be oxidized by chlorine.

Study Limitations

- The tested filters were supposed to run for several months before being confident about the development of head loss and its effect on the filter run.
- The possible effect of overnight pause on the filter efficiency is not test, although it is generally not assumed to cause noticeable bad effect.
- More water parameters were suggested to be tested to give a better picture about the filter efficiency.

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Conflict of Interest

The authors declare no conflict of interest.

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