

Research Paper

Slow Sand Filtration: A Cost-Effective and Straightforward Approach for Water Purification

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ABSTRACT

Slow Sand Filter (SSF) is an economical and manageable technique for water purification. Consumption of untreated water gave rise to major health issues and infection. In underdeveloped countries, clean and consumable water is the biggest problem. SSF system is one of those techniques used in several countries for water treatment to improve its quality and make it safe for drinking. In this study, tap water was treated via SSF and then tested for efficacy of the filtration system. Naturally existing materials like gravel, pebbles, and sand were used in the design. SSF can filter pollutants, bacterial contamination, and fecal contamination. In its assembly, the first layer was made up of gravel with a median size of 6.3 cm. The second layer was made using pebbles with a median size of 0.32 cm. The third and fourth layers were made from fine sand particles having a median size of 0.2 mm. After the construction of the sand filter, the quality of filtered water (i.e. the water obtained from the filtration) was assessed in comparison with unfiltered water by physicochemical parameters i.e. TDS, TSS, and hardness of water as well as microbiological methods. The sand-filtered water showed promising results, thereby indicating the efficiency of the Slow Sand Filter system.

KEYWORDS: Water Contamination, Fecal contamination, Drinking water, Waste-water treatment, Tap water treatment

INTRODUCTION

Water is a primary resource for the presence of life on earth and access to clean water is critical for humans and the ecosystem. Nonetheless, during the last decades, water quality has been negatively influenced by a continuously increasing population, rapid industrialization, increasing urbanization, and careless utilization of natural resources.

Even though industrialization has brought about uncountable merits, but has also been recognized as one of the major contributing gases, toxic material, solid waste, and even microbes to our surrounding environment that involves land, and water [1]. Among them, water pollution has piqued people's interest the most, as it has become a global challenge that is severely affecting developing countries [2].

On the other hand, nutrients, pharmaceutical, and personal care products, organic matter, poly- and perfluoroalkyl substances, heavy metals, biocides, radionuclides, plastics, dyes, nanoparticles, and pathogens, are among the pollutants that are of major concern [3]. Heavy metal ions are included among the most released contaminants, and due to this very reason, they are quite worrisome. Heavy metals and metalloids include silver (Ag), mercury (Hg), arsenic (As), chromium (Cr), cadmium (Cd), zinc (Zn), copper (Cu), lead (Pb), iron (Fe) and platinum (Pt) group elements [4]. These metallic toxic elements are daily released into the water from diverse natural and anthropogenic sources. In several places around the world, the average concentrations of Cr, Mn, Fe, Co, Ni, As, and Cd found in surface water bodies are well above the

maximum allowed values for drinking water [5-6]. This represents a public concern.

According to the suggestion of the United Nations, the upcoming two decades will bring serious water quantity and quality challenges to the countries in South Asia particularly, Pakistan, which stands at the top of the list of critical water shortage and pollution [8-9]. In addition, various reports on the national level agreed on the fact that the water quality of cities in particular will exacerbate and result in serious consequences on urban health.

The polluted water's negative impacts on health are widely acknowledged these days [10]. However, these effects can be recognized instantaneously while some take time to appear. The drinking water quality has deteriorated due to viruses, bacteria, etc. These bacteria spread through the fecal-oral route.

From either of the natural or anthropogenic sources, water can easily be polluted. Many of the sources of water, importantly, surface water bodies, are polluted due to industrial growth; urbanization as well as man-made problems. Both solid and sewage waste & industrial waste & effluents are the leading causes of water pollution on the surface. A study conducted in the Mardan district of Pakistan suggested that higher level of modification in the physico-chemical parameters and heavy metals (HM) in water and workers' blood will have a great impact on freshwater resources and human health in the study area [11-12].

All around the world, groundwater is one of the main sources of supplying fresh water. The intrusion of saline water in the freshwater is a serious threat to groundwater resources. Furthermore, the reduction in groundwater quality is due to the over-pumping of saline as well as freshwater. About 70% of drinking water in Pakistan comes from aquifers. The groundwater quality is saline-distant from the main rivers

and freshwater close to the main rivers. Whereas, the places where the freshwater source is not available and groundwater is saline, people have no alternative other than to drink saline water [13]. The districts Thatta and Badin of Sindh are largely affected because of the saline water intrusion, ruining water sources and people drinking brackish water; thus, suffering from various harmful diseases. Due to water pollution, over-extraction of saline water, inadequate canal water management, and outdated irrigation technologies, the supply of safe and fresh groundwater is decreasing. Pakistan lacks a systematic and efficient mechanism for assessing groundwater extractions and their consequences on natural resources [14]. In the country of Pakistan, fresh drinking water contamination makes it difficult for people to find supplies of clean water. Unhealthy water causes the spread of waterborne diseases like hepatitis, cholera, dysentery, giardiasis, and typhoid (Howell, 2001). Worldwide, pathogens are the most serious pollutants in terms of human health. Pathogens can cause diarrhea, cramps, nausea, vomiting, headaches, fatigue, fever, and death. Around the world, 25 million deaths occur due to these waterborne diseases per year. The basic hospital information and case studies indicate that most treated diseases are fecal contamination. Almost 25% of patients cured at different hospitals, clinics, or healthcare centers suffer from diarrhea, mostly children and adults [15-16]. Subsequently, in Pakistan, most of the health problems reported are caused by direct or indirect contact with polluted water. 45% of child deaths are linked to diarrhea and 60% to overall waterborne diseases [17]. Microbial contamination, toxic metals (Cd, As, Fe, Ni, and Cr), pesticides, and NO₃⁻ and F⁻ are the main threats affecting the water quality. Contamination in drinking water has been reported in many areas of Pakistan, specifically in the provinces of Sindh and Punjab [18]. It was also reported that in

Pakistan arsenic pollution, there are risks of about more than 50 million people's lives by drinking groundwater. In Bobak village near Manchar Lake Sindh, exposure to the high As concentration over a long period has overwhelming effects on community health. Cancer, skin lesions, discolouration, and cardiac disorders are common. In Harnai, Balochistan, the high concentration of NO₃⁻ in spring water has resulted in blue baby syndrome in infants [20]. Whereas, in the Peshawar district, KPK, most drinking water samples were found to be severely contaminated with Fecal coliform and *E. coli* bacteria, posing serious health risks to public health. The presence of coliform bacteria in drinking water could contribute to sewage pollution. Acute gastroenteritis was reported in Rawalpindi, Pakistan, in children ≤ 5 years of age. In Karachi, drinking water samples were also found heavily contaminated with total coliform and fecal coliform (*E. coli*), which might have led to the prevalence of waterborne diseases like Diarrhea. Lastly, in Pakistan, the presence of pesticides in drinking water is another serious risk to human health. Additionally, in 2013, it was reported that the usage of pesticides in agriculture is significantly increasing over the last four decades for crop protection. The migration of pesticides in drinking water has remained a global concern [21]. Headache, dizziness, vomiting, burning of the urinary tract, muscle weakness, skin irritation, and breath shortness led to pesticide exposure have been reported in the country [22-23]. Consuming unhygienic and untreated water is the most common reason for Water-borne Infections. The treatment of water to make it pure and drinkable is always been a decisive topic among researchers. Some of the most commonly used methods of Water Purification are such as Filtration using cheesecloth, boiling, or with the help of chlorination but these techniques don't show us any reliable results.

Sand filtration is the oldest method for water purification that is performed around the world where no alternatives are available. The present study was aimed to design an economical and easily maintainable water purification system.

MATERIALS AND METHODS

The raw materials required for the construction of the slow sand filter included two container taps and pipes, which were made from plastic and were purchased from the local market. Similarly, pebbles, sand, and gravel were collected from the construction site.

The design of the sand filter (SSF) was carried out by following the two-bucket model. The assembly of the sand filter was done simply to avoid any complexity in the purification of water. In this assembly, first of all, 2 vessels were used. Those vessels consisted of sand, gravel, and pebbles. The first among the two vessels consisted of small holes at the bottom. The holes were of diameter of around 0.5 mm, through which, the water was collected.

Large stones were used in the making of the first layer of the filter, which had a thickness of about 2 inches. The above-mentioned large stones had the size of (50-64 mm) approx. After that, there was the second layer, with a thickness of around 1 inch. The second layer was made up of gravel and had a size of around 20-30 mm approx. As for the third layer, it was made up of sand with the grain size of about 4-10 mm approx. and thickness of 1 inch, as well. The fourth and the final layer was about 5.5 inches in thickness, whereas, its grain size was 0.6-2 mm approx.

Other than that, the second container was used to store the filtered water. The container had the capacity of about 16 liters. For the filtration process, the first container was placed over the second container so that when the water was poured over the filter, it

passed through the filter and collected at the second container that was present at the bottom. The above-defined multiple layers are shown in the figure 1.



Figure 1: Multiple Layers of Sand were Sand Filtration System.

The optimization of the most significant steps in rendering the model more efficient and practical. At first, as the water was poured in the filter, 1 liter of water was filtered out around 1 minute. This depicted the presence of too much air in the filter column. For the sand to be settled and the columns to be packed, the air spaces from the column were required to be removed. Furthermore, for the packing of columns, tons of liters of water were poured in the filter, which also enabled the removal of air pockets. The water also helped in the sand becoming sediment to all the air pockets. The process was performed until the flow rate of 1.11 minutes per liter was obtained and the filtered water became transparent without there being any turbidity.

After the construction of the Slow Sand System design and its Flow Rate Optimization, the filtered water then proceeded for further physicochemical characterization to further understand the quality of filtered water to determine the

efficacy of the sand filtration system. For that purpose, estimation of Total Dissolved Solids (TDS), Total Suspended Solids (TSS), and hardness of sand-filtered water as well as unfiltered water were carried out.

Total dissolved solids (TDS) in water samples were determined through the gravimetric method.

For this purpose, a cleaned and thoroughly dried China dish was taken and weighed. Then a water sample (40 ml) was poured into the China Dish, which was then placed in the dry oven for about 2 h at 160 °C. After that, the china dish was taken out of the oven placed at room temperature, and then weighed again.

The TDS was then calculated using the following equation:

$$\text{Total dissolved solids (mg/L)} = \frac{A-B}{\text{Sample}} \times 1000$$

Where,

A= weight of dried residues + dish (mg)

B= weight of dish (mg)

Total suspended solids (TSS) in water samples were also determined through the gravimetric method.

For this purpose, the water sample (40 ml) was filtered via a pre-weighed 1.5 micron filter paper. The filter was then oven-dried at 104°C for an hour. After that, filter paper was taken out of the oven placed at room temperature, and then weighed again.

The TSS was then calculated using the following equation:

$$\text{Total dissolved solids (mg/L)} = \frac{A-B}{\text{Sample}} \times 1000$$

Where,

A= weight of dried residues + filter paper (mg)

B= weight of filter paper (mg)

The estimation of the amounts of divalent cations calcium (Ca^{2+}) and magnesium (Mg^{2+}) is a crucial step in the recognition of the hardness of water. Complexometric titration and other such techniques are used in the estimation of the concentration of the cations. During this complexometric titration process, complexes are formed using a chelating agent.

The solutions involved in this study were EDTA (ethylenediaminetetraacetic acid), ammonia buffer, and $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$, and an indicator named Eriochrome Black T.

A 0.005 mol L^{-1} EDTA solution was prepared via dilution of the 0.05 mol L^{-1} EDTA solution by the factor of 1/10.

The Ammonium buffer was prepared by dissolve about 7.0 g of ammonium chloride in a 57 mL concentrated ammonia. Distilled water was then used to dilute the ammonia to 100mL with in a volumetric flask. The resultant buffer's pH was found to be 10.5.

For the procedure a sample solution was prepared by adding a 100 mL of the water sample into a 250 mL conical flask. The 20mL of this diluted EDTA was then added to the water sample. A 10ml of the prepared ammonium buffer was then also added along with a 1ml Eriochrome Black T indicator.

The preparation of a $0.0025 \text{ mol L}^{-1}$ magnesium chloride solution was then done by diluting the 0.025 mol L^{-1} magnesium chloride solution by a factor of 1/10. After that, the sample solution was titrated with the $0.0025 \text{ mol L}^{-1}$ magnesium chloride solution until a permanent pink coloration was achieved. The titration process was then repeated with further samples until concordant results (titres agreeing within 0.1 mL) were obtained.

Following the physicochemical tests, the water sample were then further proceeded for the microbiological analysis in order to determine the microbial load that might be

present in the water samples. For the determination of the said-factors in the water quality, standard plate count and Coliform count of the filtered and unfiltered samples were conducted.

The Standard Plate Count technique, sometimes referred to as the colony-forming unit (CFU) method, is a microbiological technique that is utilized for determining the number of viable bacteria present in a certain sample.

In aseptic condition, serial dilution was then done by transferring 1ml diluted sample from the first tub to the second, second to third, and so on using a sterile pipette. Each of the tubes was mixed vigorously. About 02 sterile nutrient agar plates were then taken and then labeled with the last two highest dilutions that were prepared in the end. A 1-ml of diluted water sample was taken from each tube and plated on the respective media plates, labelled as 1:1000 and then 1:10000.

After the transfer, the water samples were then spread via glass spreader to spread the samples evenly over the agar surface, meanwhile also maintaining aseptic technique. For the detection of fungal load, the same procedure was adopted, however, Sabouraud Dextrose Agar (SDA) was used instead of Nutrient Agar. All the plates of nutrient agar were placed upside down in an incubator for about 24-hours at 37°C for bacterial colonies. Whereas, the SDA plates were incubated at room temperature for 6-7 days. After the 24-hour time period, each Petri plate was then observed for bacterial colonies, where the number of colonies in each plate was counted manually. The counted colonies were in range of 30 to 300. Lastly, the number of Colony Forming Units (CFU) per ml was calculated for each plate. For the average of CFU, the sum of CFUs from the 2 plates was taken and divided by 2. Following the calculation of the bacterial colonies, colonial morphology and cellular morphology via gram-staining were

observed. Fungal cultures were also observed for colonial morphology and cellular morphology via tease mounting with Lactophenol cotton blue.

Coliform tests are an essential set of microbiological tests used to evaluate the water's hygienic condition and any potential faecal contamination. A class of indicator organisms known as coliform bacteria acts as a substitute for the presence of other pathogenic microorganisms connected to faecal matter. These tests are frequently used in many different industries, such as food safety, drinking water analysis, and environmental monitoring.

For this test, 3 Double Strength Lactose Broth [DSLb] and 6 Single Strength Lactose Broth [SSLb] in a test tube stand, where the 3 DSLb tubes were labeled 10 ml, 3 SSLb tubes were marked 1.0 ml, and the remaining 3 SSLb tubes were labeled as 0.1 ml. The bottle containing water sample was then mixed while shaking for an estimated of 25 times. After the shaking, 10 ml of water was then transferred to each DSLb tubes. Whereas, 1 ml of water was transferred via pipette to each of the 1.0 labeled SSLb tubes, and then 0.1 ml of water was transferred to SSLb tubes that were labeled as 0.1 ml. The transfer was then followed by an incubation at 37°C for 24 hours.

To confirm the presence of coliforms, in all the tubes that yield positive results, 0.1 ml of content of each tube was taken and plated onto the Eosine methylene blue (EMB) agar. The plates were incubated and examined after 24 hours of incubation for the appearance green metallic sheen.

RESULTS AND DISCUSSION

One of the earliest methods of treating water for drinking purposes was slow sand filtration (SSF). It is still a crucial step in the global water purification process. SSF has attracted renewed interest in recent years, in large part due to its effectiveness at removing

dissolved organic materials after pre-oxidation. SSF is often the third stage of water purification in traditional water treatment systems, coming after reservoir storage and quick filtration but before disinfection (Fogel D, Isaac-Renton J et al., 1993). Within specified turbidity and algal content water quality standards, slow sand filters can also offer a one-stage treatment for untreated raw waters [24]. Other key benefits of SSF over more complex water treatment techniques include simplicity and cheap capital and running expenses.

The slow filtration rate of slow sand filters (0.1-0.3 m) and the fine effective size of the sand (0.1-0.3 mm) are two factors that contribute to their high-water treatment efficiency. However, biological processes in the slime material that builds up above the sand surface (schmutzdecke) and in the upper layers of the sand bed are also responsible. Additionally, it is thought that the schmutzdecke is mostly to blame for the gradual rise in head loss that is seen throughout filter operation. The basic physical and biological principles governing water purification and head loss development during SSF remain little understood, despite its significance as a water treatment procedure in the present and in the past [25].

To assess the quality and other aspects of the filter, the above-mentioned methodologies were used. From those methods, certain results were obtained which further proved as to whether the filter is efficient or not.

Among the few materials that were collected and procured for the preparation of filter, large stones were of the most significance and also made the top-most layer. These water filter stones' minerals aid in converting acidic water into alkaline water. Minerals found in large stones, including calcium, iron, phosphorus, magnesium, potassium, and sodium, ionise the water, raising its pH and oxygenating it. These substances also

increase hydration and aid in cell absorption by lightening the water [26].

Other than that, pebbles and gravel were also used in the preparation of the filters. The use of these stones is to support the sand medium that is also being utilized in the filter.

Other than the pebbles and gravels, the filter medium for SSF was sand which was available locally. The media commonly used for SSF is coarse sand, fine sand, and combination of different sized pebbles and gravels. Sand used in SSF can be coarser, quartz/silica or accusand silica.

The design and construction of the filter that was done by adopting two-bucket model construction. Two buckets placed on top of one another were used to make the design. Five centimeters from the bottom of the bucket, a 20 mm hole was drilled, and into this hole, a tap was fixed to collect the filtered water. The top bucket was filled with the filter media, which was composed of a 20 cm layer of fine sand (0.3 mm) and a 5 cm layer of gravel (5 mm). In the bucket, the contaminated water was poured in the upper bucket, where it ran through the filter medium (i.e. fine sand). After passing through the medium, the filtered water was collected in the lower bucket through the perforations present at the base of the upper bucket [27]. Through the perforations in the gravel, filtration takes place through the heavy layer of fine sand, which keeps the fine sand from entering the collection vessel (Figure 2). One modification that was done to the system was the addition of a third bucket, that can be somewhat referred to as a reservoir bucket. A pipe was also added from the reservoir bucket to the other two buckets and a spray hose was attached to its other end. Furthermore, an addition of valve was also done to it so that there would not be any need to add the water manually, instead it could be added automatically via the third reservoir bucket and the valve.



Figure 2: Slow Sand Filter

The flow rate of the sand filter was optimized by passing the effluent through the filter and then the flow rate was noted in terms of time

As depicted in Figure 3 (a), the flow rate of 1L was 1:58 minutes. At 2L, the flow rate was found to be at 3:57 minutes, whereas the rate for 3L was at 4:52 minutes. Similarly, the increasing amount kept increasing with the volume of water. For instance, the rate was 7:46 minutes at 5L, whereas, at 6L, the time interval was 8:57 minutes. Lastly, at 9L, the flow rate was found to be at 17:39 minutes.

The Figure 3(b) represents the flow rate after the optimization and then the passing of the liquid. After the optimization, the flow rate of 1L was found at 5:28. Consequently, for 2L, the flow rate was at 9:37 minutes. At 13:45 minutes, the flow rate interval of 3L water was found. Along with that, for the volume of 4L, the rate was 19:22. The rate for 5L was 24:46 minutes. Similarly, the 6L flow rate resulted to be on a time interval of 30:7L. As for the flow rate of 7L, it was 34:25. Moving on along with that, for 8, 9, and 10L, the rates were respectively 40:51, 44:48, and 49:1.

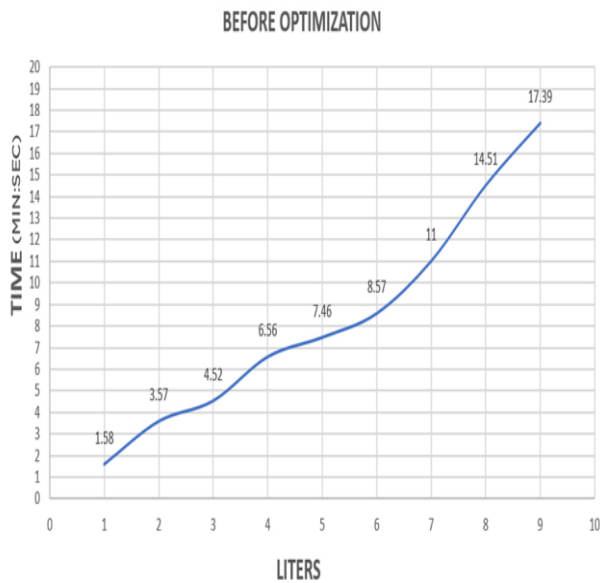


Figure 3(a): showing flow rate before optimization.

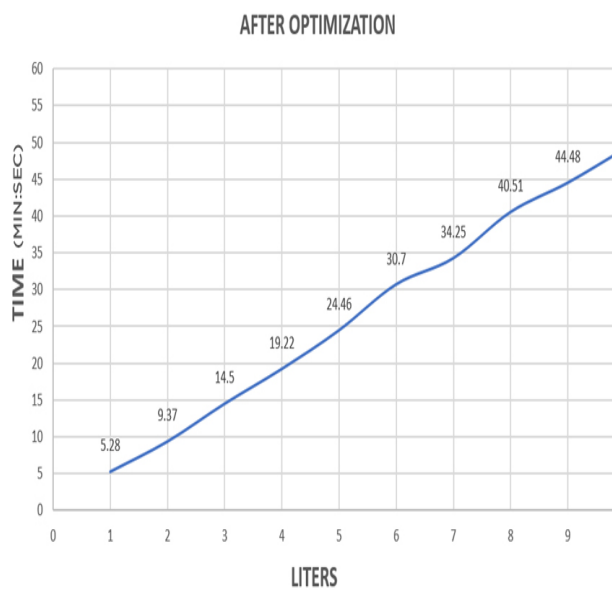


Figure 3(b): showing flow rate after optimization.

The TDS value of sand filtered water was significantly reduced as shown in Figure 4. The TDS of unfiltered water was estimated as 1.25 mg/L. The TDS of sand-filtered water was estimated as 0.875 mg/L.

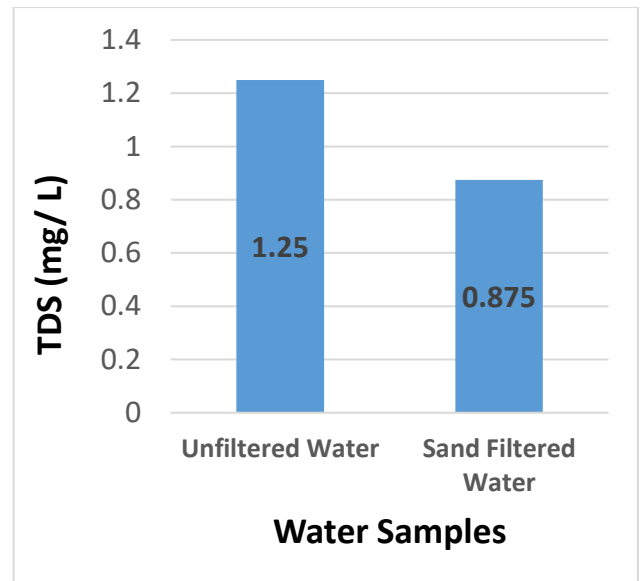


Figure 4: TDS values obtained of unfiltered water samples and Sand Filtered water samples

The TSS value of sand filtered water was significantly reduced as shown in Figure 5. The TSS of unfiltered water was estimated as 1.375 mg/L. The TSS of sand-filtered water was estimated as 0.625 mg/L.

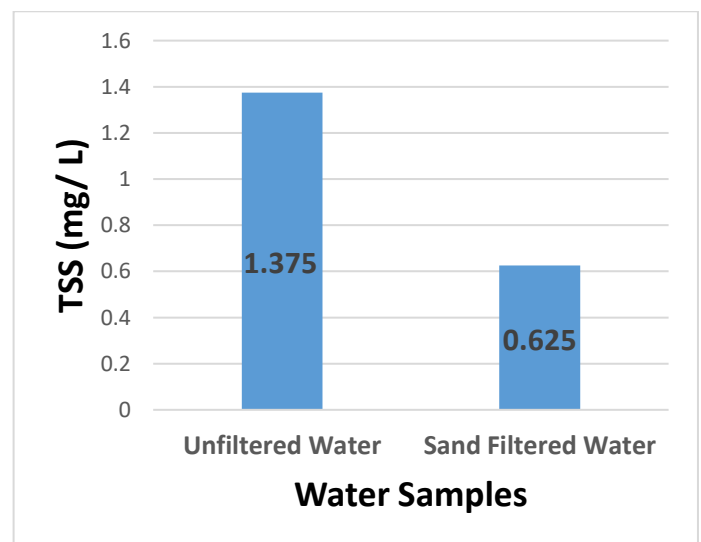


Figure 5: TSS values obtained of unfiltered water samples and Sand Filtered water samples

For the determination of the hardness of water, firstly, the total moles of EDTA that were added to the solution of the sample were calculated. Following the calculation of the total moles of EDTA, the calculation for the

moles of magnesium chloride solution that was utilized in the back titration from the results. The moles of Mg were equivalent to the moles of excess EDTA.

Keeping in consideration the ratio of $\text{Ca}^{2+} + \text{Mg}^{2+} : \text{EDTA} = 1:1$, the moles of those Ca^{2+} and Mg^{2+} were calculated, which might have been complexed with the EDTA via the subtraction of excess EDTA from the total number of moles of EDTA that were added to the sample. The obtained results were for the moles of Ca^{2+} and Mg^{2+} present in the sample solution.

Since 82 ml of Mg^{2+} was used for the neutralization of the 5ml of unfiltered water, therefore, it would be considered as:

The here-mentioned result indicated that there were about 410 mM EDTA ions present in 5ml of unfiltered water sample, which in consideration with eq 1.2, implied that there were exactly 410 mM ions of Magnesium were present in the unfiltered water sample.

This calculation was then proceeded by the calculation of Mg^{2+} ions in the filtrate.

Just like the result for the calculation of Magnesium in the unfiltered water sample, this results also indicated that 115 mM EDTA ions were present in a total of 5ml of filtrate sample, which in consideration with eq 1.2, implied that there were also exact 115 mM ions of Magnesium present in the filtrate.

So, upon comparison of resultant 410 Mg^{2+} ions found in unfiltered water sample with the 115 mM Mg^{2+} found in the filtrate, it can be clearly seen that the filtrate had lesser Mg^{2+} ions than in the unfiltered water. This difference in the concentration of the ions is because of the different ions also present in the filtrate, which attracts the Magnesium ions. The charges also play an essential role in the attraction as the negative Mg^{2+} ions charges that bind with the positive charges of

the filtrate and dilutes the ions of Magnesium in the water sample.

After following the protocol for the Standard Plate Count, as indicated above, the petri plates consisting of unfiltered water were observed. SPC analysis of unfiltered water samples showed the presence of numerous and uncountable bacterial colonies in water that can be indicated as Too Numerous to Count (TNTC) as indicated in Figure 6.

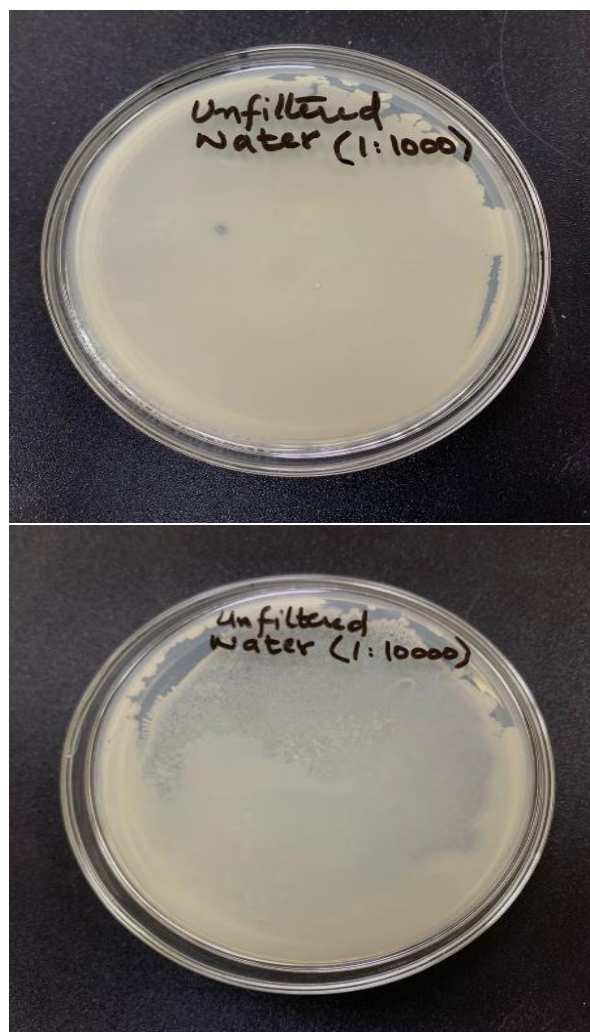


Figure 6: SPC analysis of unfiltered water samples

SPC analysis of sand filtered water samples showed 8.8×10^4 and 5×10^4 CFU/0.1ml in 1:1000 and 1:10000 times diluted samples and were found to be 8.8×10^5 and 5×10^5 in terms of CFU/ml respectively, thereby approximately 6.9×10^5 colony forming units (CFU) were found per ml of sand filtered water samples as indicated in Figure 7.



Figure 7: SPC analysis of Sand filtered water samples

SPC analysis of unfiltered water samples showed the presence of 5.5×10^4 CFU/ml fungi in water as indicated in Figure 8.

SPC analysis of sand filtered water samples showed absence of colony forming units (CFU) i.e spores were found per ml of sand filtered water samples



Figure 8: SPC analysis of unfiltered water samples

MPN analysis was carried out to determine the load of coliforms as per the protocol mentioned above.

As per the MPN index, the coliform count of sand filtered water sample was found to be 460/ 100 ml of water. Whereas, the coliform count of the unfiltered water sample was found to be ≥ 2400 coliforms per 100 ml of water

Further confirmation was made by observing green metallic sheen on EMB agar when the content (0.1ml) from each tube yielding

positive results was plated on EMB agar (Figure 9).

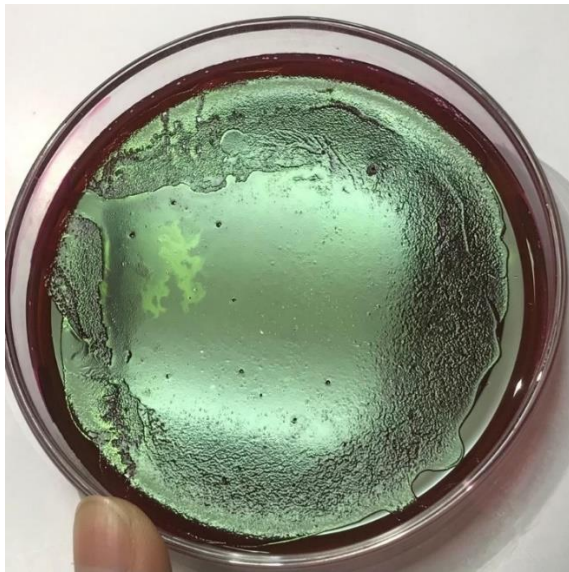


Figure 9: Green metallic sheet on EMB agar as confirmation of coliform test.

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