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The Effect of Slow Sand Filtration (SSF) on Water Quality: The Case of Usuthu Forest Company Water Scheme, Eswatini

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The demand for safe drinking water is continuously increasing globally, a situation that has led to the use of technologies that are safe, simple, efficient, and more importantly reduce the cost of water treatment. Slow Sand Filtration (SSF) is one of such technologies, which has attracted a lot of research interest from researchers. An experiment was conducted to determine the effect of SSF on the water quality of the Usuthu Forest Company Water Scheme in Eswatini (UFCWS). The experiment had the Usuthu Forest Water Scheme's slow sand filtered water, as the treatment with three replications. Tap water from Eswatini Water Services Corporation (EWSC) was used as a control. Water samples were taken from the inlet and outlet of the SSF treatment unit for testing physical, bacteriological and chemical quality on the same day. Data analysis was conducted using standard error bars, compared against World Health Organization (WHO) drinking water quality guidelines. The results reflected that the mean pH of the SSF UFCWS was 7.14, 6.72, 6.80 before the SSF, after SSF, and the control, respectively. The turbidity was 24.00 NTU, 1.00 NTU and 4.47 NTU before SSF, after SSF and for the control, respectively. The colour also followed the same trend, as expected. The biological quality of the SSF water indicated that the total coliforms was 1001 counts per 100 ml before SSF, 10 counts per 100 ml after SSF, and the control had 3.39 counts per 100 ml. The faecal coliforms (*E. coli*) in the SSF water were 80 counts per 100 ml before SSF and 0.0 counts per 100 ml after SSF and the control. The chemical SSF water results indicated that the nitrates level was 2.73 mg/L before SSF and 2.43 mg/ L after SSF, whereas the hardness was 58.5 mg/L, 55.3 mg/L and 53.7 mg/L before SSF, after SSF and the control, respectively. It was concluded that the physical water quality of the SSF UFCWS was of acceptable quality. The bacteriological quality was also found to be acceptable as evident by the values that were below the WHO guideline (5 NTU) for drinking water quality. The chemical quality of the SSF water was acceptable as evident by the values, which were lower that the WHO guideline values for both parameters in question.

Keywords

Effect, Slow Sand Filtration, Water Quality, Usuthu Forest Company Water Scheme, Eswatini

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1. Introduction

Water pollution is a global threat to the availability of potable water for a wide variety of socio-economic utilization. To free the water from the pollutants, often demands treatment. To provide the treatment, a number of technologies that could be used are available. Selection amongst these technologies, which are not by any strength of imagination cheap, entails a high degree of competence. The water treatment technologies comprise amongst others; activated sludge process, up-flow anaerobic sludge blanket, etc. The cost of water treatment is a burden that poses serious impediment to development,

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particularly in developing economies such as Eswatini. This has, as such led to the investment in cheaper and simple to operate but effective water treatment technologies such as Slow Sand Filtration (SSF).

Slow sand filtration is the oldest and simplest technology used for water treatment [3; 13]. One of the most significant advantages of SSF is its simplicity, which also lends the misperception of it being an irrelevant and antiquated technology. Slow sand filtration has the advantage over other methods in that it utilizes local skills and materials [7]. Some of the advantaged of slow sand filtration comprise the following [2]:

i. Very effective removal of bacteria, viruses, protozoa, turbidity and heavy metals in contaminated fresh water.
ii. Simplicity of design and high self-help compatibility: construction, operation and maintenance only require basic skills and knowledge and minimal effort.
iii. If constructed with gravity flow only, no (electrical) pumps required.
iv. Local materials can be used for construction.
v. High reliability and ability to withstand fluctuations in water quality.
vi. No necessity for the application of chemicals.
vii. Easy to install in rural, semi-urban and remote areas, simplicity of design and operation.
viii. Long lifespan (estimated >10 years).

Traditional SSFs can remove microorganisms in existing chlorine disinfection plants using relatively high quality raw water, but are not recommended for influent water with turbidities greater than 5 NTU [4]. Slow sand filtration is generally considered to be one of the most efficient and at the same time very favourable technology for the reduction of pathogens, particulate organic substances and turbidity [11].

Potable water treatment in small communities is challenging due to a complexity of factors starting with generally poor raw water sources, a smaller tax and consumption base that limit capital and operating funds, and culminating in what is typically a less sophisticated and robust water treatment plant for production and delivery of safe, high quality potable water [18]. These challenges are more pronounced in small communities and small water supply schemes such as the Usuthu Forest Company Water Scheme in Eswatini. As such appropriate technologies such as slow sand filtration are more appropriate in such communities.

Slow sand filtration is a technology that has been used for potable water filtration for hundreds of years [1, 8]. Slow sand filtration is still widely used. The removal process of particles and microorganisms is highly dependent on the buildup of the *schmutzdecke* at the filter surface. The *schmutzdecke* is a thin slimy layer of organic material, comprising algae, plankton, diatoms, protozoa, rotifers and bacteria. It is formed in hr first 10 – 20 days of operation of the SSF and is responsible for entrapping, digesting and breaking down of organic matter contained in the water [12].

The lack of access to clean drinking water in developing countries is still a great hindrance to socio-economic development. With the current drought conditions in Southern Africa, the situation is aggravated. The benefits of slow sand filtration have driven the ease of the availability of potable water to poor communities in developing countries. Potable water is the water that is free from pathogens, colourless, odourless and the chemicals composition are within the acceptable limits which is safe for consumption without causing any disease to man [20].

The contribution of potable water supply schemes to rural communities in Eswatini through Rural Water Supply Scheme (RWSS) is one of the strategies which are invaluable in alleviating this condition [5]. The use of simple technologies such as SSFs to purify water increases the country's coverage of potable water supply. However, maintenance of such schemes, once they are handed over to the communities, brings about challenges. The responsibility bestowed upon communities to ensure good maintenance of water supply systems is of utmost importance as the quality of the water is highly dependent on it, hence this study. The objectives of the study were (i) to determine the physical quality (pH, turbidity and colour) of the Usuthu Forest Company Water Scheme's slow sand filtered water, (ii) to assess the bacteriological quality (total coliform and faecal coliforms) of the Usuthu Forest Company Water Scheme's slow sand filtered water and (iii) to determine the Chemical quality (Nitrates and hardness) of the Usuthu Forest Company Water Scheme's slow sand filtered water.

2. Methodology

2.1. Description of the Study Area

Water samples were collected from the Usuthu Forest Company Water Scheme at Bhunya. The water was abstracted from the Great Usuthu River and treated using slow sand filtration. Bhunya is located under the Manzini region at $26^{0}33"0'$ South and $31^{0}1"0'$ East. The area has a moderate climate prevailing with the highest average temperature being 27°C in January and the lowest being 24°C in July. The average annual temperature is 24°C and the annual rainfall is about 639 mm. The predominant economic activity in the area is forestry, where a majority of people gain employment from the plantations with livestock and crop production at subsistence level.

2.2. Research Design

The research was an experiment in which the Usuthu Forest Company Water Supply Scheme's slow sand filtered water was the treatment with three replications. The Eswatini Water Services Corporation (EWSC) tap water was used as a control.

2.3. Sampling Procedure

Sterilized 500 ml polyethylene bottles were used to collect the Usuthu Forest Company Water Supply Scheme's slow sand filtered water from two sampling points. These were before slow sand filtration (inlet) and after slow sand filtration (outlet).

2.4. Data Collection and Analysis

The slow sand filtered water samples were transported to the laboratory in a cooler box with ice cubes, on the same day to avoid decomposition. The samples were tested for physical (pH, turbidity and colour), bacteriological (total coliforms and faecal coliforms) and chemical (nitrates and hardness) quality. The data were analysed using Microsoft excel computer software, utilizing standard error bars, which were compared against EWSC treated tap water and WHO drinking water quality guidelines.

2.4.1. Physical Quality Analysis Methods

i. pH

The table pH meter was used to measure the pH of the SSF water. The electrode was immersed in the sample. Readings were taken after 20-30 seconds after the water readings have stabilized. The electrode was rinsed with distilled water and wiped dry. The pH guideline for water is 6.5 – 8.5 [17].

ii. Turbidity

Turbidity is the cloudiness of water caused by particles and is a key parameter in drinking water quality analysis. Turbidity was determined using the Absorptiometry Method, adopted from FWPCA methods for chemical analysis of water and wastes, 275 (1969). The spectrophotometer wavelength was rotated until the small display showed 450 nm and 25 ml of the sample placed into the cell holder [6]. The turbidity guideline value for domestic water is 5 NTU [17].

iii. Colour

The colour of the slow sand filtered Usuthu Forest Company Water Scheme water samples was determined using a HACH DR6000 spectrophotometer tuned at 455 nm. Two hundred (200 ml) of the water sample was collected in a 400 ml beaker. Fifty (50 ml) of the deionized SSF water was then filtered through a 0.45 micron membrane filter and filled in a 10 ml sample cell to form a blank. Fifty (50 ml) of the SSF water sample was filtered through the membrane and filled in a 10 ml sample cell. The sample cell with the blank was wiped, inserted in the cell holder and was used to zero the spectrophotometer. The sample cell with the water sample was wiped, inserted into the cell holder and the results were read from the screen in mg/L Pt-Co.

2.4.2. Bacteriological Quality Analysis Methods

i. Total Coliforms

The coliform group is made up of bacteria with defined biochemical and growth characteristics that are used to identify bacteria that are more or less related to faecal contaminants. The total coliforms represent the whole group, and are bacteria that multiply at 37°C. Total coliform was determined using a reagents, dionized distilled water with the growth medium of 51 g of M-endo ager LES, 25 ml ethanol Abs. and 1000 ml of water. The media was the boiled. During boiling the media was stirred to avoid the burning of the undissolved media until the media was completely dissolved. The media was then allowed to cool to 45-50°C and dispensed ± 15 ml into each of the 65 mm plastic disposable petri dish. The media was then given 10 minutes to solidify. The freshly prepared plates were stored in an inverted position at 4°C in a dark area. Upon testing using the membrane filtration procedure discussed above, where 100 ml of the sample was used, all colonies that had a pink to dark-red colour with a metallic surface sheen were counted and the results expressed as Total coliforms per 100 ml.

ii. Faecal Coliforms

The term 'faecal coliforms', although frequently employed, is not correct: the correct terminology for these organisms is 'thermotolerant coliforms'. Thermotolerant coliforms are defined as the group of Total coliforms that are able to ferment lactose at 44-45°C. They comprise the genus *Escherichia* and, to a lesser extent, species of *Klebsiella, Enterobacter,* and *Citrobacter.* Out of these organisms, only *E. coli* is considered to be specifically of faecal origin, being always present in the faeces of humans, other mammals, and birds in large numbers and rarely, if ever, found in water or soil in temperate climates that has not been subject to faecal pollution.

The analysis of faecal coliforms was performed using deionized distilled water with the growth media being 50g m-FC broth and 100 ml water. The broth was boiled. During the boiling of the broth, constant stirring was done to avoid burning of the undissolved media. The broth was poured into a 47 mm filter culture plates. After testing using the membrane filtration procedure, all green colonies were counted and the results presented as faecal coliforms per 100 ml. The *E. coli* guideline value for domestic water is 0 counts/100 ml [17].

2.4.3. Chemical Quality Analysis Methods

i. Nitrates

The standard diazotization method using powder pillows was conducted to analyse the amount of nitrate in the slow sand filtered water. The nitrate guideline for the amount of nitrates in domestic water is 10 mg/L [17].

ii. Hardness

Hardness is the amount of calcium carbonate equivalent per litre [19]. It measures the capacity at which water will react with soap [11]. Excessive hard water cause excessive soap consumption, whilst soft water tends to be corrosive. Higher levels may cause incrustation of utensils and pipe works [11; 16]. Concentrations greater than 500 mg/L are considered undesirable for domestic use. The Titriemetric method was used to determine the amount of hardness.

3. Results and Discussion

3.1. Physical Quality Results

i. Ph

The results in Figure 1 indicated that the mean pH of the SSF water for the Usuthu Forest Company Water Scheme was 7.14, 6.72, 6.80 before the slow sand filtration, after the Slow Sand Filtration, and the EWSC tap water (control), respectively.

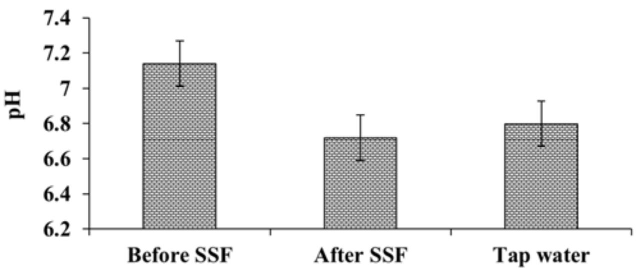

Figure 1. Slow sand filtered water pH.

The results indicated that the mean pH of the Usuthu Forest Water Company water was significantly different before SSF and both after SSF and the control. However, the mean water pH after SSF and the control was not significantly different.

ii. Turbidity

The results indicated that the mean turbidity of the slow sand filtered Usuthu Forest Company Water Scheme was 24.00 NTU, 1.00 NTU and 4.47 NTU before SSF, after SSF and for the control, respectively (Figure 2). It is worth noting that the turbidity was below the WHO guideline value of 5 NTU. This could be attributed to the effectiveness of the SSF.

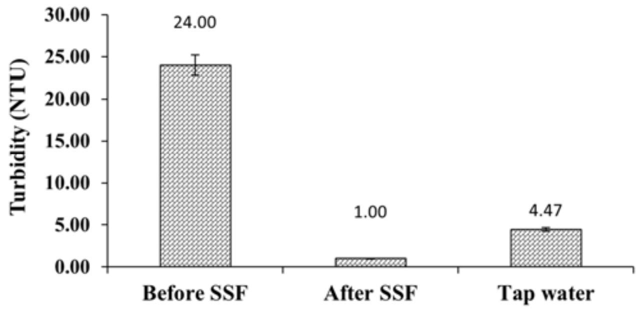

Figure 2. Slow sand filtered water turbidity.

The results indicated that the mean turbidity of the SSF water for the Usuthu Forest Company Water Scheme was significantly different between all the water quality attributes in question (before SSF, after SSF and the control).

iii. Colour

The results in Figure 3 reflected that the colour of the slow sand filtered (SSF) Usuthu Forest Company Water Scheme followed the trend of the turbidity, as expected. The water colour was 150 mg/L Pt-co before SSF and 7.00 mg/L Pt-co after SSF, while it was 9.00 mg/L Pt-co for the control. High levels of colour indicate the presence of organic molecules such as peat, leaves and branches in the water [17].

The results indicated that the colour detected in the Usuthu Forest Company Water Scheme was significantly different between all the attributes in question (before and after SSF). However, the colour of the water was not significantly different between the control and after SSF.

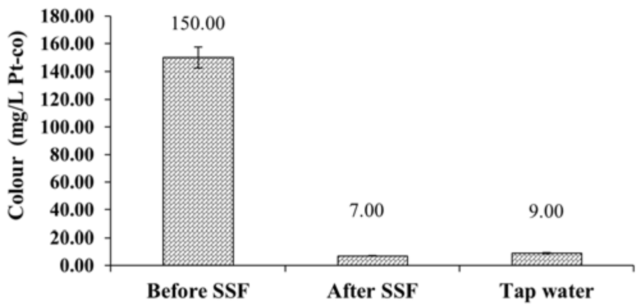

Figure 3. Slow sand filtered water colour.

3.2. Bacteriological Quality Results

i. Total Coliforms

The results showed that there were Total coliforms present in the water before the slow sand filtration treatment. Prior to treatment the water had 1001 counts per 100 ml, while it was 10 counts per 100 ml after SSF. On the other hand the control had 3.39 counts per 100 ml (Figure 4).

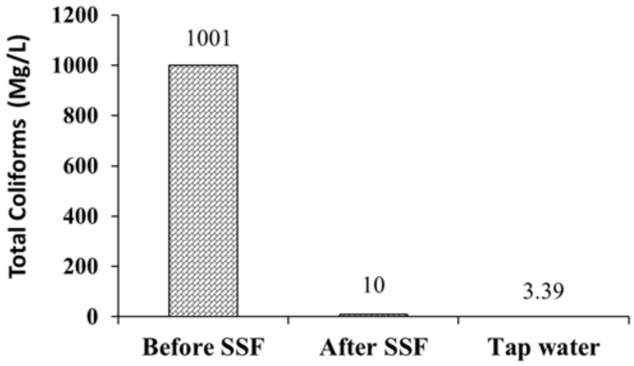

Figure 4. Slow sand filtered water total coliforms.

ii. Faecal coliforms

The results revealed that the water was contaminated with faecal coliforms before the slow sand filtration (Figure 5). The water came with 80 counts per 100 ml before the SSF and it was 0.0 counts per 100 ml after the SSF. This was the case even for the control (tap water).

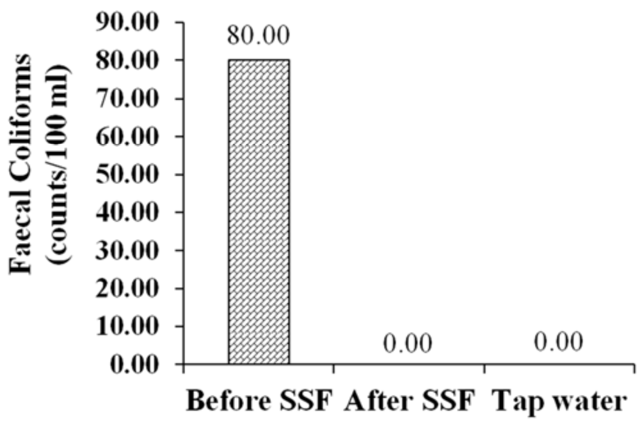

Figure 5. Slow sand filtered water faecal coliforms.

The results indicated that the amount of faecal coliforms detected in the Usuthu Forest Company Water Scheme was high (80 counts per 100 ml) prior to treatment, but was effectively treated by the SSF to the WHO guidelines, which state that the value of *E. coli* in drinking water should be 0 counts /100 ml, meaning that there should be no indicator of *E. coli* in water. It is worth noting that the amount of *E. coli* found in the Great Usuthu River water where the SSF water was abstracted from was earlier reported by researchers to be high [16]. This was attributed to the farming activities in the catchment area, especially livestock, which were reported as likely sources of the faecal matter.

3.3. Chemical Water Quality Results

i. Nitrates

The results indicated that there were nitrates present in the water samples before treatment that were effectively treated by the SSF as reflected in Figure 6. The nitrates were 2.73 mg/L before SSF treatment and 2.43 mg/ L after the Slow Sand Filtration. Both these values were slightly higher than the control (tap water), which had 2.05 mg/L.

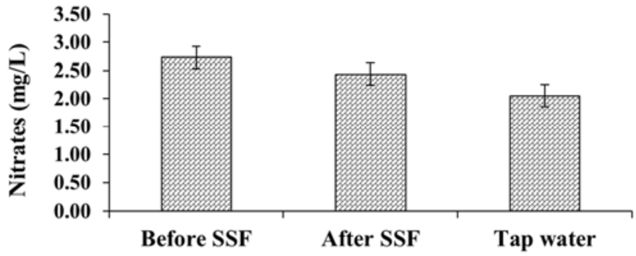

Figure 6. Slow sand filtered water Nitrates.

The results indicated that the mean nitrates detected in the SSF Usuthu Forest Company Water Scheme were all below the WHO guideline value for drinking water, which should be below 10 mg/L.

ii. Hardness

The results revealed that the mean hardness of the SSF water of the Usuthu Forest Company Water Scheme was 58.5 mg/L, 55.3 mg/L and 53.7 mg/L before SSF, after SSF and for the EWSC tap water (control), respectively (Figure 7).

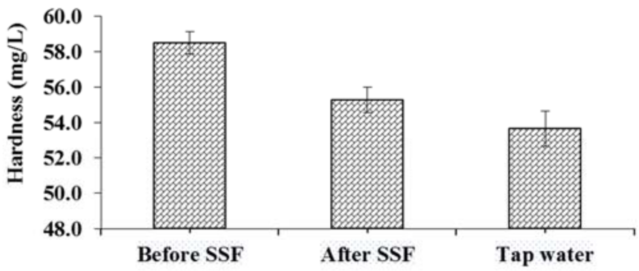

Figure 7. Slow sand filtered water hardness.

The results indicated that the slow sand filtered mean water hardness met the WHO guideline value of less than five hundred milligrams per litre (< 500 mg/L). This was the case for all the SSF water treatment attributes in question i.e. before SSF, after SSF and the control.

4. Conclusions

The physical water quality of the slow sand filtered (SSF) Usuthu Forest Company Water Scheme was determined with regards to pH, turbidity and colour and found to be of acceptable quality. The results indicated that the mean pH was 7.14, 6.72, 6.80 before SSF, after SSF and for the EWSC tap water i.e. control, respectively. The mean pH was significantly different between the water samples before SSF and after SSF. This could be attributed to the effectiveness of the slow sand filtration.

The bacteriological water quality of the SSF Usuthu Forest Company Water Scheme was assessed and found to be acceptable as evident by the values that were below the WHO guideline (5 NTU) for drinking water quality. However, the results indicated that the slow sand filtered Usuthu Forest Company Water Scheme was 24.00 NTU, 1.00 NTU and 4.47 NTU before SSF, after SSF and for the control (EWSC tap water), respectively.

The chemical water quality of the Usuthu Forest Company Water Scheme was determined with regards to nitrates and hardness and it was concluded that the slow sand filtered water was acceptable as evident by the values which were lower that the WHO guideline values for both parameters in question (nitrates and hardness). The nitrates were 2.73 mg/L before treatment and 2.43 mg/ L after the Slow Sand Filtration. Though both values were higher than the control, they were still below the WHO drinking water quality guideline value of 10 mg/L. On the other hand, the SSF water hardness was 58.5 mg/L, 55.3 mg/L and 53.7mg/L before SSF, after SSF and for the control (SWS treated tap water), respectively. These values were below the WHO drinking water guideline value of less than 500 mg/L (< 500 mg/L).

References

[1] Abushandi, E. (2021). Evidence of Improved Seawater Quality using a Slow Sand Filtration. *Advances in Science, Technology and Engineering Systems Journal* Vol. 6, No. 2, 359 - 367 (2021). https://www.astesj.com/publications/ASTESJ_060241.pdf. Accessed May, 2021.

[2] BOS, (2021). Slow sand filtration. https://www.best-osmosis-systems.com/resources/slow-sand-filtration/. Accessed March, 2021.

[3] De Souza, P. B.; Roeckera, D. D.; Silveuraa, M. L; Sensa, C. and Campos, L. C. (2021) Influence of slow sand filter cleaning process type on filter media biomass: backwashing versus scraping. *Water Research*. Vol. 189, 2021 116581. https://www.sciencedirect.com/science/article/pii/S0043135420311167?via%3Dihub. Accessed May, 2021.

[4] Gottiger, A. M.; McMartin, D. W.; Price, D. and Hanson, B. (2011). The effectiveness of slow sand filters to treat Canadian rural prairie water. *Canadian Journal of Civil Engineering*. 38: 455 - 463 (2011). https://www.researchgate.net/publication/237189238_The_Effectiveness_of_Slow_Sand_Filters_to_Treat_Canadian_Rural_Prairie_Water. Accessed June, 2021.

[5] Government of Swaziland, (2009). *Final Draft National Water Policy*. Government of Swaziland, Mbabane, Kingdom of Swaziland.

[6] Hatch company, (1999) Hatch method 8195. Determination of turbidity by Nephelometry. Revision 2.0. Hach Company 5600. Colorado, USA. www.hach.com/asset-get.download. Accessed June, 2021.

[7] Huisman, L. (1974). Slow sand filtration. World Health Organization (WHO), Geneva. https://www.who.int/water_sanitation_health/publications/ssf9241540370.pdf. Accessed June, 2021.

[8] Matuzahroh, Ni'.; Nuriana, N; Fitriani, N.; Ardiyanti, P. E.; Kuncoro, E. P. and Budiyanto, W. D. (2020). Behavior of schmutzdecke with varied filtration rates of slow sand filter to remove total coliforms. 2020*Heliyon* 6 (4). https://www.researchgate.net/publication/340441098_Behavior_of_schmutzdecke_with_varied_filtration_rates_of_slow_sand_filter_to_remove_total_coliforms. Accessed June, 2021.

[9] Mophin-Kani, K. (2016). Efficiency of slow sand filter in wastewater treatment. *Journal of Scientific and Engineering Research.* Vol. 7, (4): 2016. https://www.academia.edu/26977045/Efficiency_of_Slow_Sand_Filter_in_Wastewater_Treatment. Accessed May, 2021.

[10] Ndlela, Z. P.; Vilane, B. R. T. and Nkambule, N. F. (2017). An Assessment of the Mvutjini Earth Dam Water Quality at Kalanga, Swaziland. *Journal of Agricultural Science and Engineering*. Vol. 3, (1), pp. 13 – 19.

[11] Oluk, I; Nagawa, C. B.; Tumutegyereize, P. and Owusum P. A. (2020). Slow sand filtration of raw wastewater using biochar as an alternative filtration media. *Water and Environment Journal* (2020) 10:1229 https://www.nature.com/articles/s41598-020-57981-0.pdf. Accessed May, 2021.

[12] Ranjan, P. and Prem, M. (2018). Schmutzdecke- A Filtration Layer of Slow Sand Filter. *International Journal of Current Microbiology and Applied Sciences* (2018) 7 (7): 637-645. https://www.researchgate.net/publication/326706835_Schmutzdecke-_A_Filtration_Layer_of_Slow_Sand_Filter. Accessed June, 2021.

[13] Urfer, D. (2016). Use of bauxite for enhanced removal of bacteria in slow sand filters. *Journal of Water Science and Technology: Water Supply.* Vol. 16 (6): 2016. IWA Publishing 2016. http://ws.iwaponline.com/content/early/2016/12/15/ws.2016.199. Accessed May, 2021.

[14] Verma, S.; Daverey, A.; Archana, D. and Sharma, A. (2017) Slow sand filtration for water and wastewater treatment – a review. *Environmental Technology Reviews* 6 (1): 47 - 58. https://www.tandfonline.com/doi/full/10.1080/21622515.2016.1278278. Accessed June, 2021.

[15] Vilane, B. R. T. and Gwebu, S. (2017). An Assessment of the Quality of Rainwater Harvested Using Rooftop Rainwater Harvesting (RWH) Technologies in Swaziland. *Journal of Agricultural Science and Engineering* Vol. 3, No. 6, 2017, pp. 55-64.

[16] Vilane, B. R. T. and Tembe, L. (2016). Water Quality Assessment Upstream of the Great Usuthu River in Swaziland. Journal of Agricultural Science and Engineering. Vol. 2, No. 6, 2016, pp. 57-65.

[17] WHO, (2008). Guidelines for Drinking – water Quality, Third edition incorporating the first and second addenda Volume Recommendations, Geneva. World Health Organization. http://www.who.int/water_sanitation_health/dwqfulltext.pdf. Accessed June, 2021.

[18] WHO, (Undated). TDS water quality guidelines. http://www.who.int/water_sanitation_health/dwq/chemicals/tds.pdf. Accessed July, 2021.

[19] Yusuf, K. O.; Adio-Yusuf, S. I. and Obalowu, R. O. (2019). Development of a Simplified Slow Sand Filter for Water Purification. *Appl. Sci. Environ. Manage*. Vol. 23 (3) 389-393. http://www.bioline.org.br/pdf?ja19058. Accessed. Accessed March, 2021.

[20] Zanacic, E.; Stavrinides, J. and McMartin, D. W. (2016). Field–analysis of potable water quality and ozone efficiency in ozone-assisted biological filtration systems for surface water treatment. *Water Research* Vol. 104, (1): 2016, pp. 397 - 407. https://pubmed.ncbi.nlm.nih.gov/27576158/. Accessed May, 2021.