The Viability of Biosand Filters to Recycle Water in a School Environment

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Abstract: ***The biosand filter is a slow sand water filtration system that is widely used in developing countries. The filter works through the use of a biological layer to kill pathogens in the water. The focus of this research was to determine the effectiveness of a biosand filter in relation to its ability to filter greywater- contaminated water from sinks, showers, and dishwashers- from handwashing and create recycled water in a school. River water was put through the filter daily to build the biological layer, a layer of the filter with live bacteria. Bacterial samples concluded the biological layer took six weeks to grow resulting in filtered river water having the same number of small bacterial colonies as school water. The newly filtered water was placed into a female's bathroom and used as hand washing water. Hand washing greywater was collected from the bathroom to be recycled but, it contained a high concentration of all-natural soap which the biological layer was unable to process. To determine the number of female students who used the bathroom, data was collected on bathroom water usage over a 2-month period. Data on female bathroom usage showed that the females' bathroom sinks used 0.67% of the school water, resulting in an average of Rs.650 (INR) water cost and a Rs. 780 (INR) sewer charge over a 2-month period. Ultimately, it was found that implementing biosand filters in a female bathroom is beneficial. However, it would not be feasible to recycle greywater due to the soap harming the biological layer composed of pathogen killing bacteria. The inability of the filter to recycle greywater results in a sewer cost greater than the cost of the water itself, making the bio sand filter financially impractical.***

Keywords: Biosand Filter, Recycle Water, pathogenes

1. Introduction

This research will focus on the feasibility of using a bio sand filter to recycle greywater, contaminated water from sinks, showers, and dishwashers, in a school environment. Today, 1.5 billion people worldwide do not have access to clean drinking water.[1] With the development of new water filtering technologies, recycled water is now an applicable resource to supply water for a variety of uses, such as cooking, cleaning and drinking. Slow sand filtration systems, more specifically, bio sand filters, have been placed in developing countries to create potable water from local streams. These filters are able to reduce hazardous bacteria by 90-99%, and reduce more than 99.9% of harmful parasites, such as *Cryptosporidium* and *Giardia intestinalis,* in water. Bio sand filter systems have been implemented in many workplace buildings to save money and resources.[2]

A bio sand filter is a specific type of slow sand filtration system, where three layers: underdrain gravel, separation gravel, and filtration sand are accompanied with a specially grown bacterial layer called the Schmutzdecke, which kills pathogens in dirty water. It is used in many developing countries as an easily accessible source of clean water. School bathrooms create wastewater and in a time when water is becoming limited and many schools are in need of money saving options, there is a large demand for water recycling systems.

There are three aims of this research:

1) Recycle greywater produced from hand washing and test the ability of the bio sand filter to repeatedly clean that greywater
2) Track student usage of recycled water in a bathroom
3) Discover the benefits of recycling water in a school setting using a large scale bio sand filter.

Clean water is becoming less accessible; it is necessary to find natural systems that will filter and recycle water. Thus, there is the need to research bio sand filters' efficiency and explore why bio sand filtered water is being used in other countries.

To determine the effectiveness of the bio sand filter, the effectiveness of the filter (looking at the bacteria, chemicals and soap that remained in the water) and the longevity of the water were observed. To collect data, a sink was placed in a high school girls' bathroom which gathered greywater samples for filtering and testing. The contaminated water source was a local river: the Chambal River. The ChambalRiver contains water deemed clean by local water quality standards. It was hypothesized that the biosand filter would clean greywater to the point that it is able to be reused for multiple weeks, which would create a water recycling system. The main independent variable was the water collection, as the greywater continually came from the same contaminated water source. The dependent variable was the data collected from the water quality tests, which were conducted with each sample of water collected. Limitations to the research include: the students' comfortability to use the sink (which the water sample is dependent on), the contamination of the water by other students from unwanted waste (i.e. trash), and the maintenance of the bio sand filter (because it will not be used every day, and Schmutzdecke flourishes when water is filtered every day). However, regardless of the limitations, the bio sand filter should be capable of recycling water effectively.[3]

To account for the students usage of filtered water and recycled water sink, the volume of water used each day was measured. The sink contained greywater, and potentially deterred student use. However, the usage of the sink should increase the longer it is located in the bathroom. In this, the independent variable is the sink, which will consistently be located in the girls' bathroom, and the dependent variable is the student's usage of the sink. The constraint is not knowing of how many students are using the sink. The sink usage will be measured by the volume of greywater collected from the sink, which will be measured by mass, however, it will be considered that water use does not directly relate to student usage. Therefore, the volume of greywater created will be important to account for when testing the collected water, as more people can result in a larger range of different bacteria.

The third focus of the research is to evaluate the benefits of using a bio sand filter to recycle water in school. A cost analysis will be conducted comparing the sewer charge to the water cost. This will evaluate the justification of using a product and will compare the total expense to the future benefits of using a product. For this study the analysis will include: the pros and cons of recycling water in a school, the water and monetary savings recycling water can bring, the practicality of using a large scale biosand filter system to cover the whole school. The independent variable in this study is the school's usage of water, since it is set data collected from the school. The dependent variable will be the type of recycling system analyzed. Since this study is specific to Nalanda Academy Hostel, the results are limited to locations with conditions similar to Nalanda Group of schools which includes: small school size, small student population, and the four seasons climate.

2. Methods

In this study, the effectiveness of a biosand filter in a high school bathroom was tested regarding its ability to remove a variety of pathogens and soap. Specifically, the ability of the filter to clean greywater from hand washing water was tested. Greywater from hand washing was collected in the recycled water sink, tested for bacteria using agar plates, filtered, and tested again. The greywater was collected when the collection bin was full. Throughout this process the soap consisted of only the soap brand, Neem. This brand of soap was used because it contains all natural, biodegradable ingredients that do not directly attack bacteria like antibacterial soap. Multiple tests were conducted to evaluate the cleanliness of the filtered water as well as the ability of the biosand filter to clean greywater. Additionally, data on women's average water usage in the bathrooms was collected and used to determine any water and monetary savings that Nalanda Academy could receive from recycling handwashing water. Using this data, a comparison of the biosand filter to other water recycling systems as well as the current non recycling water system in the school was made to determine the financial feasibility of the biosand filter.

The biosand filter was constructed using a combination of 6 cm of underdrain gravel (6mm to 12mm), 5 cm of separation gravel (0.7mm to 6mm) and 37 cm of sand. ($\leq$ 0.7mm). The gravel was put through multiple size sieves to separate, and commercial sand was used. The biosand filter also included a 2 cm biological layer, which consisted of a live pathogens that killed the bacteria as water passed through. This was the first layer in the filter, and was fully submerged in water. The biological layer took approximately six weeks to create, and involved flushing on average four gallons of water from "Chambal River" through daily.

Effectiveness of the biosand filter was measured through three different tests: water quality, bacteria on hands, and bacteria in water. The water quality test consisted of testing levels of nitrates, nitrites, carbonated hardness, general hardness, and ammonia. To conduct the tests a generic fish tank titrating kit was used. This gave a range of levels of each of the components. The levels of Nalanda Academy's water, Chambal River water, and the biosand filtered water was tested and compared.

To determine how well newly filtered water cleaned someone's hands, a swab of students' hands before and after washing was done using school water and the average number of pumps of MMC soap was calculated to be 1.4. Then, a swab of students' hands before and after washing their hands with the filtered water and MMC soap was done. The swab samples of students' hands were swiped onto an agar plate and placed in an incubator for 48 hours at 90° F. The results were compared to determine how effective the filtered water was at cleaning.

Lastly, the number of bacteria in the water was tested. Unlike the other tests, this test was done frequently. Red Cedar River water, Williamston High School water, and biosand filtered water were tested. To sample the bacteria, a glass mixing tool was sterilized using hand sanitizer and dipped into the water sample. The sample was then swabbed in a straight line onto a petri dish filled with store bought agar. This was repeated two more times, ensuring that they are that the bacteria was placed in the same area each time. Next, a mixing tool was used to drag water perpendicularly to dilute the sample. The sample was diluted a third time and placed into an incubator at 90° for 48 consecutive hours. Bacterial samples of the filtered water were taken on average every week and qualitatively compared to the school water bacterial colonies and river water bacterial colonies.

In order to implement a recycling water system in the females' bathroom, a pair of tables with a five gallon tank was placed inside the bathroom. The five gallon tank contained a nozzle that was used as a faucet, and was placed on the larger table along with the MMC soap. The second, smaller, table sat next to the larger table where a large bin was set to catch the exiting greywater from the five gallon tank. To encourage students to use the sink, three posters were created to place into the bathroom with the sink; a warning poster stating the water is not potable, a persuasive poster discussing helping the environment, and a educational poster explaining the biosand filter.

Greywater was collected and measured by mass and the greywater was then put through the biosand filter to clean. Bacterial tests after the water was filtered were taken. pH tests were also conducted to determine if there was soap in the water after being filtered.

The final aspect of this research analyzed the benefits of recycling water specifically at Williamston High School. Data on the number of females who use the bathroom facilities was collected. Due to ethical reasons, the sink was only implemented in the female bathrooms, therefore, only data relating to the females' bathrooms was collected and used. The number of students who flushed the toilet and washed their hands during the school day was collected during sixth period, passing period, and lunch to account for the differences in bathroom use throughout the day. To determine the volume of water each hand wash created, the average time in seconds a female washes her hands was documented. The time was converted to milliliters of water using the average water flow from the sink faucet per second. 1.6 gallons of water was used per toilet flush.[4] To find the total daily water usage from the females' bathroom, the number of students who went to the bathroom during sixth hour was multiplied by the number of bathrooms in the school, and the number of hours in the school day. To find the total water usage of women during the passing period, the average water usage was multiplied by the total number of passing periods in the day. Lastly, to calculate the water usage during lunch the average volume of water used during lunch was multiplied by the number of lunches at Nalanda Academy High School. To determine how the water usage and cost in the females' bathroom compared to the total water usage and cost of Nalanda Academy High School, the total water usage and costs (including sewer charges) for Nalanda Academy High School were used from the two month-period of March and April. The proportion of water used by the females' bathrooms to the total volume of water used at Nalanda Academy High School gave the percentage of water the females use in the bathroom over a two-month period. The same process was used to determine the percentage of money spent on the females' bathrooms using values obtained against the table of monetary values that includes the sewer charges alongside the table of monetary values over a two month period (see Appendix).

3. Results

The biosand filter took six weeks to grow the Schmutzdecke. The filter did not effectively remove the soap from the bathroom greywater because the Schmutzdecke did not support the high concentration of soap. The soap in the biological layer could not be flushed out, requiring the top three inches of sand to be replaced in order to start the biological layer growth over.

Additional water quality tests showed that the biosand filter did not affect the levels of nitrates, pH, and general hardness in the water. Nitrate levels in the river water and filtered water were between 20 to 40 ppm, while the school water was only between 0 to 5 ppm. Carbonated hardness of the water decreased by 36 ppm after filtering from 268 ppm to 232 ppm. Ammonia in clean water should be zero and the biosand filter was able to remove about 0.25 mg/l of ammonia from the Red Cedar River water, rendering the level of ammonia in the water almost negligible.

Through multiple bacterial samples, the filter was found to be effective. Bacteria could not be grown using heat as the sterilizer. The Chambal River water was contaminated with multiple large colonies covering the majority of the petri dish. The biological layer slowly improved the filtered water as time went on. It took the biological layer six weeks to fully flourish and clean water well. Bacterial samples showed few, small, orange, colonies in filtered water. The number of bacteria in filtered water was similar to the number of bacteria in Nalanda Academy High School's water (Figure 1).

Figure 1: From left to right: river water bacteria, filtered water bacteria, school water bacteria

Additionally, the biological layer improved significantly as a result of having a flat top sand and biological layer compared to a non flat top sand and biological layer. Traditionally, the top layer of the biosand filter is level. However after large amounts of water had passed through the filter the top sand had formed a funnel from the water pressure. Bacterial samples taken before removing the funnel in the sand showed many medium sized colonies, with a few larger ones (Figure 2a). The samples showed very little improvement of river water. After the funnel was removed the bacterial colonies were reduced significantly to the same number of colonies as the school water (Figure 2b).

Figure 2 (a): Bacteria before top layer was flattened

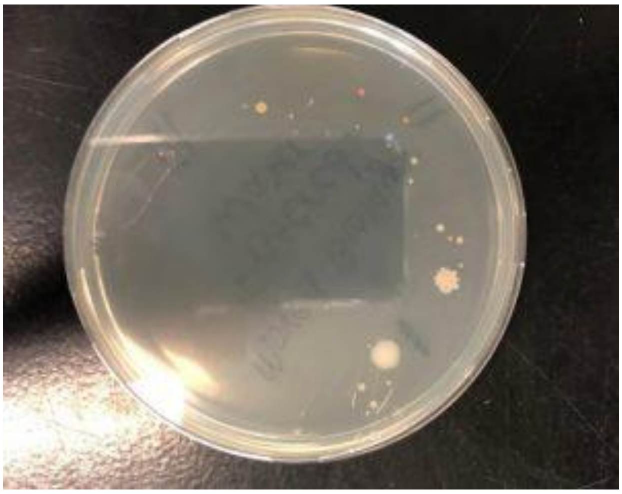

Figure 2 (b): Bacteria after top layer was flattened

Similarly, bacterial samples from washing hands showed an equal number of bacteria using either filtered river water or school water. Colonies before hands were washed were very large and frequent (Figure 3a). The number of colonies varied depending on how dirty the hands were. After hands were washed only a few, small colonies were left resulting in cleaner hands (Figure 3b).

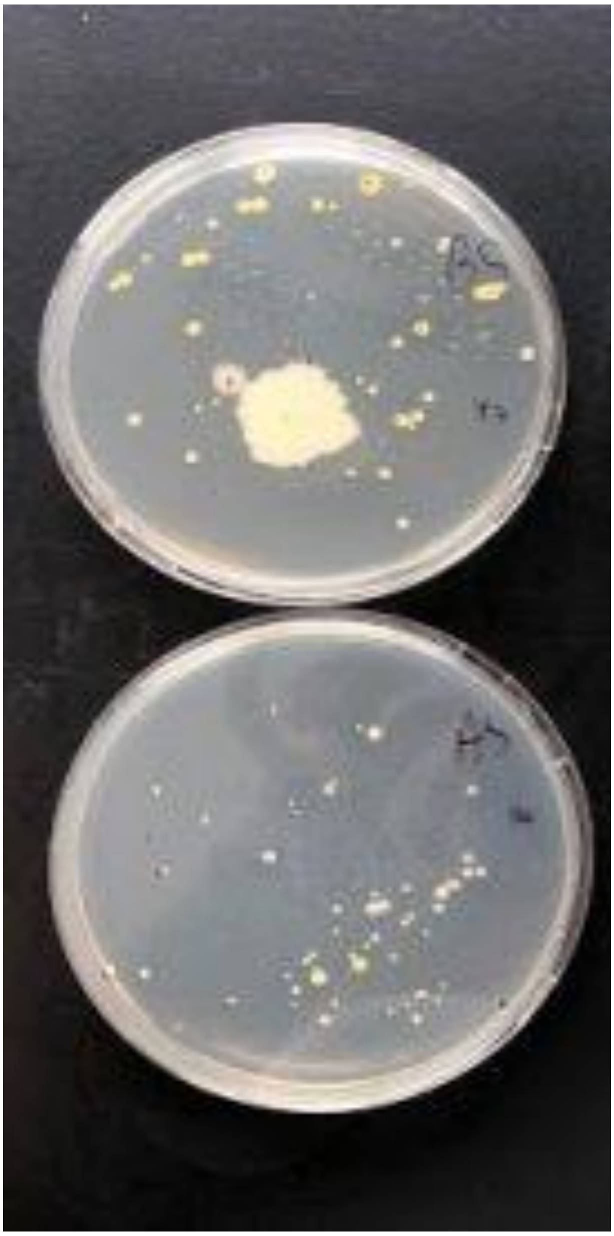

Figure 3 (a): From top to bottom: bacteria before hands were washed with sink, bacteria after hands were washed with sink

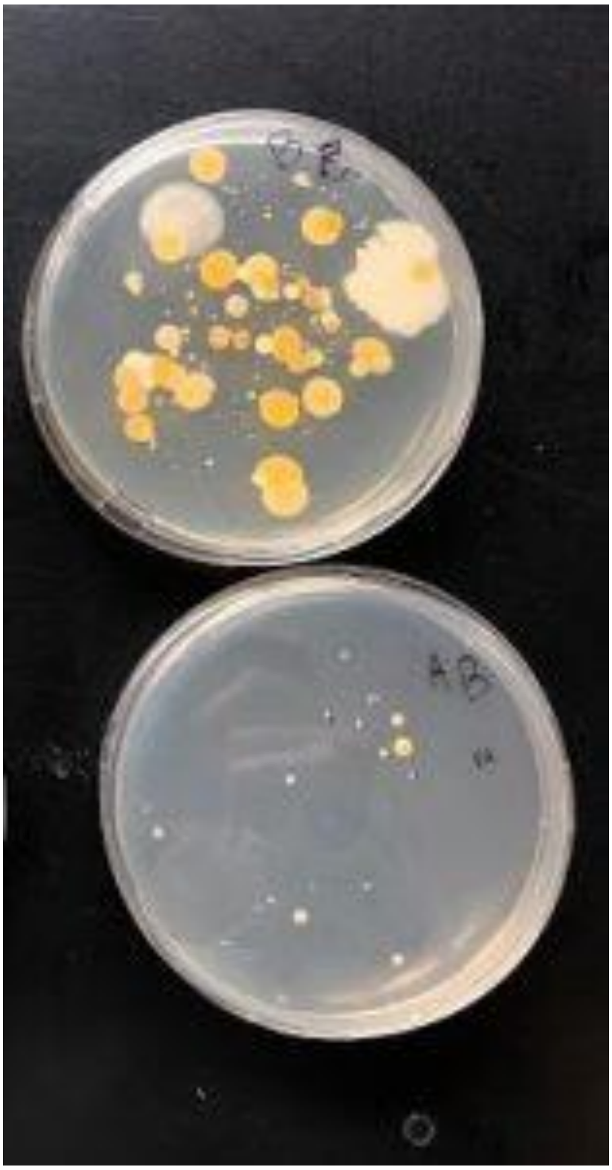

Figure 3 (b): From top to bottom: bacteria before hands were washed with biosand filtered water, bacteria after hands were washed with biosand filtered water

After placing the sink into the bathroom, only four days of water usage could be collected due to the inability of the filter to remove soap. Student's usage of the recycled water decreased substantially by 326.7 fl oz after the first day of recycling greywater. Additionally, students tampered with the filter by dumping the filtered water, as well as the hand soap (Figure 4).

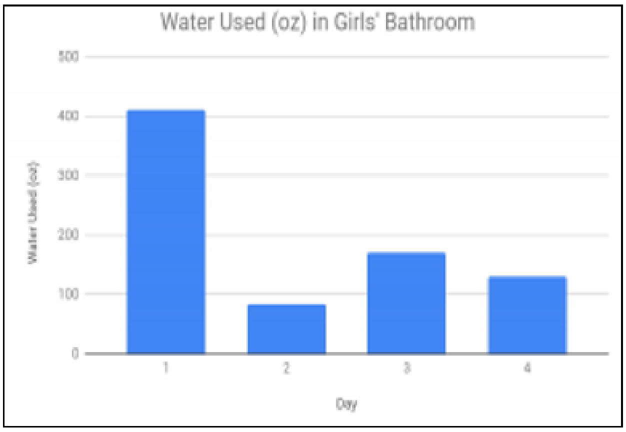

Figure 4: Recycled Water Sink Usage

From the data collected on female's water usage in the bathrooms, it was determined that more students use the bathroom during lunch than during passing period. Students on average flush the toilet more often at 18.5 flushes per hour compared to how often they wash their hands at 18 washes per hour (Figure 5). Depending on the day, the number of students who used the bathroom varied greatly.

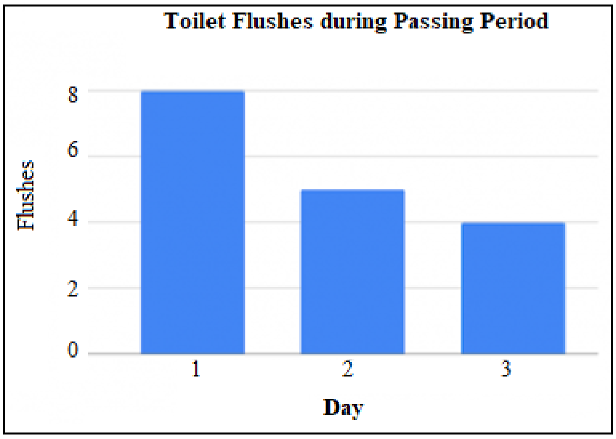

Figure 5 (a): Toilets flushed during passing period

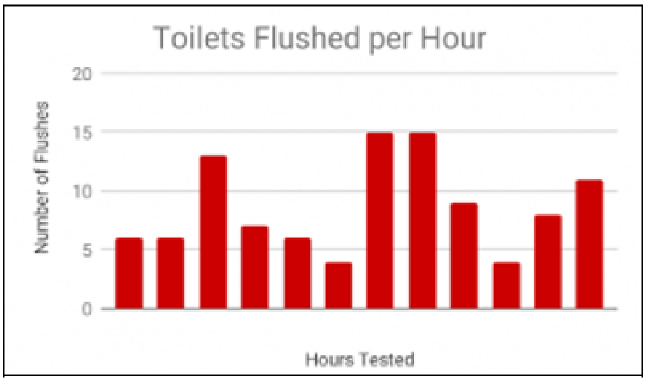

Figure 5 (b): Toilets flushed per hour

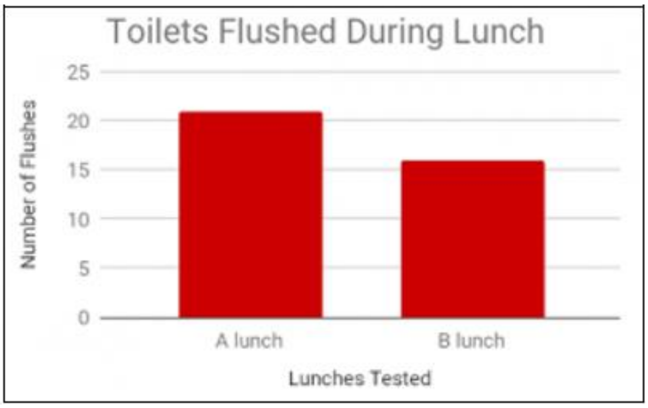

Figure 5 (c): Toilets flushed during lunch

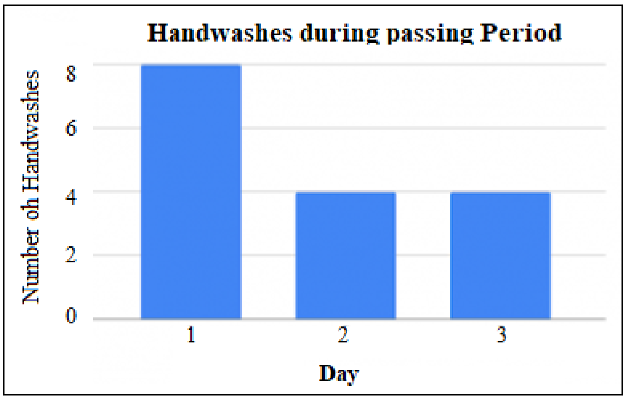

Figure 5 (d): Hand washes during passing period

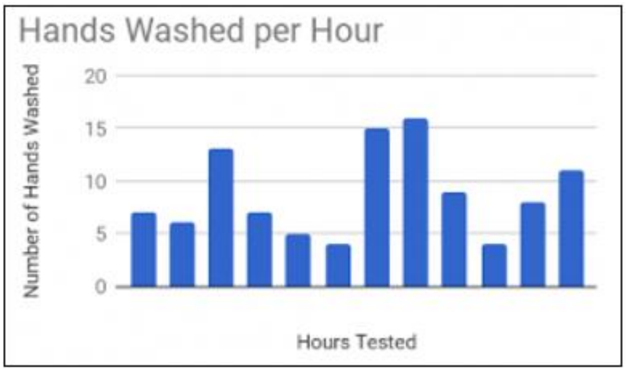

Figure 5 €: Hand washes per hour

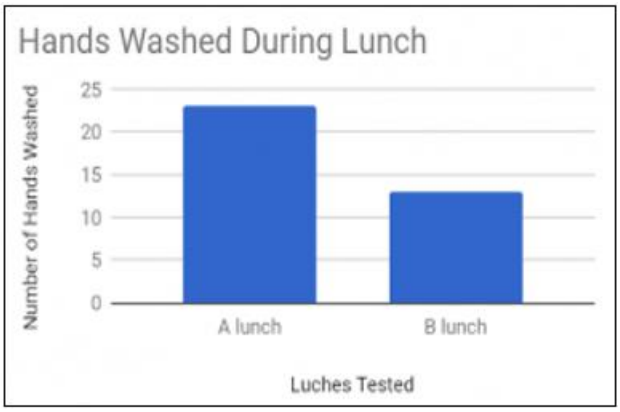

Figure 5 (f): Hand washes during lunch

The median flow rate of a sink in a female bathroom was 30 ml per second. The flow rate is consistent with a small range of 12 ml. The range reflects the slight difference in the faucet position during each trial (Figure 6).

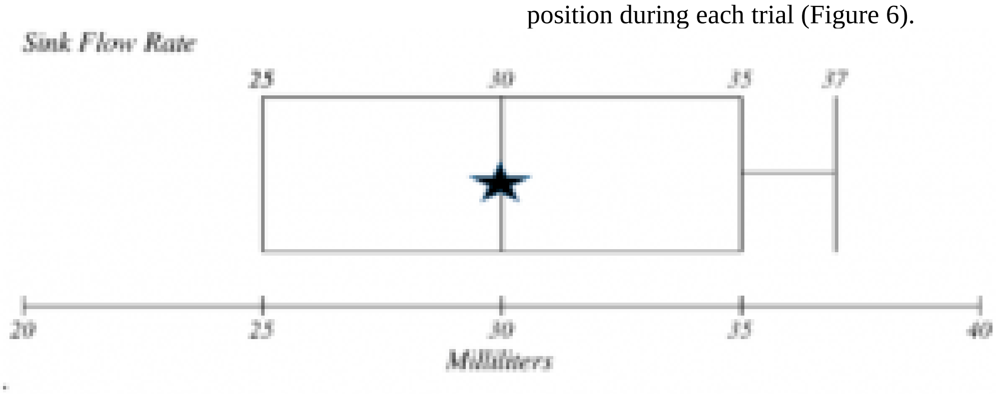

Figure 6: Sink flow rate (star represents the mean)

Females' length of time they wash their hands for determined on average females wash their hands for 11.125 seconds. The range was 22 seconds (Figure 7).

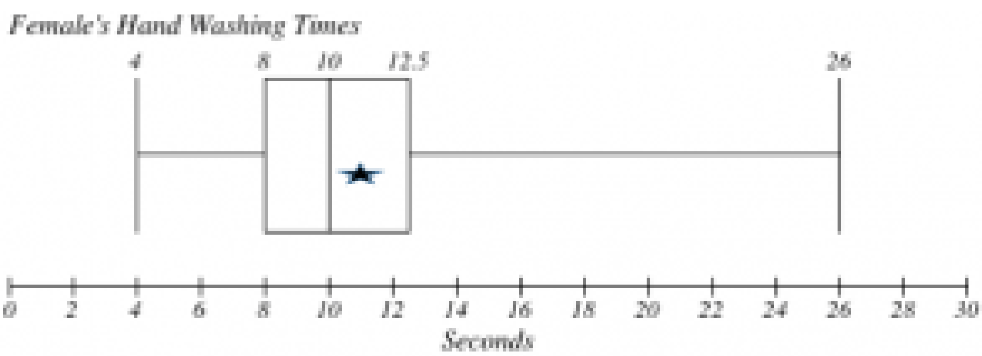

Figure 7: Female hand washing time (star represents the mean)

Female students use a large range of 660 milliliters of water to wash their hands with. The average volume of water a female used to wash their hands with is 335 ml (Figure 8).

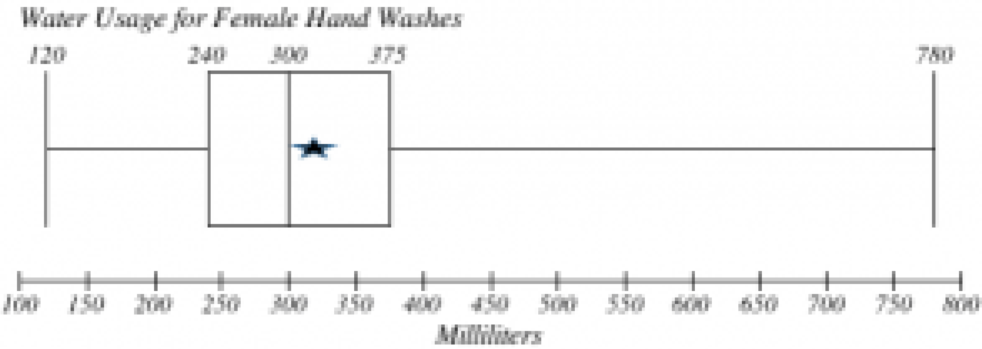

Figure 8: Water usage for female hand washing (star represents the mean)

The volume of water used in the bathroom compared to the total volume of water in the school showed that the females' bathrooms only account for a total 13.47% of the schools water usage over a two-month period (Figure 9). Toilets use much more water compared to hand washing greywater, which only accounts for 0.67% of the schools water usage over a two-month period.

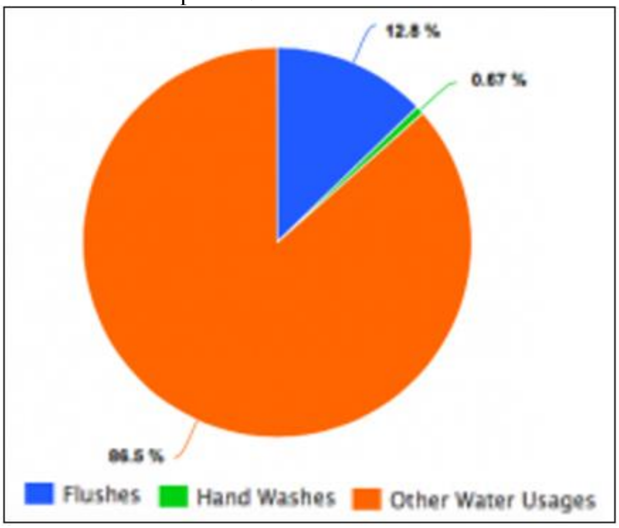

Figure 9: Female bathrooms water usage compared to school's total water usage over a two month period

The water cost signifies the price of incoming water for the school. The sewer cost shows the cost of the drainage system for greywater for the school. For the school as a whole, the sewer charge is greater than the incoming water itself (Figure 10a). The same is true for the sewer charge of females' sinks. The water cost for the females' bathrooms sinks is Rs.650 INR, while the sewer charge is greater at Rs.780 INR (Figure 10b).

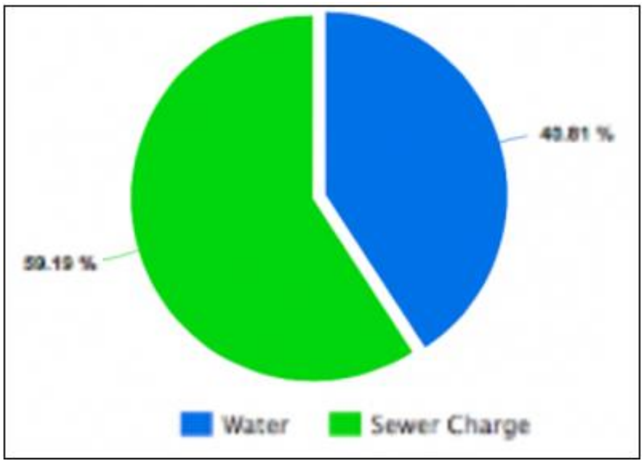

Figure 10 (a): Sewer charge compared to incoming water charge over two month period (percentage of combined cost)

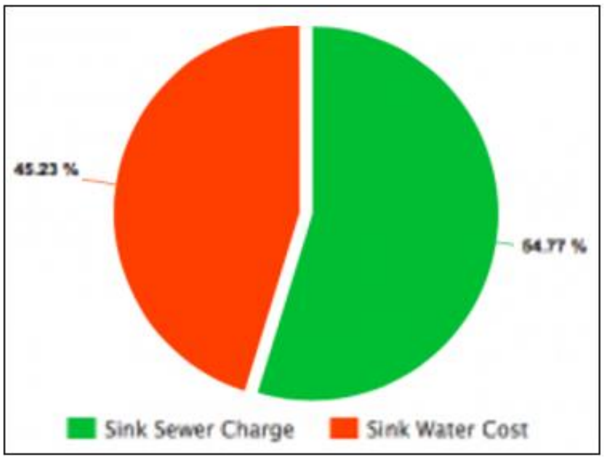

Figure 10 (b): Sewer cost compared to water cost for female bathroom sinks over a two month period

4. Discussion and Conclusions

The hypothesis stated that the biosand filter would be a feasible method to recycle river water and greywater in the school's bathroom. However, the bacterial results concluded that the biosand filter would only be feasible to recycle river water, and not greywater. It is not practical to use this type of filter for long term use in the school.

From the data, it is concluded that the biosand filter is effective at filtering river water, but requires significant maintenance. River water must pass through the filter almost daily for six weeks to grow the biological layer. The top sand layer needs to be flattened regularly, and bacterial tests must be taken regularly to ensure the filter is working correctly. This size filter can only filter about four gallons of water at a time, and the water takes a considerable amount of time to go through the filter. To use biosand filters and keep up with school demands would require many large filters that would need to be closely managed.

Since the biological layer is not adequate for recycling greywater, sink water would need to have the soap removed before filtering. This would require an additional chemical filter along with the biosand filter system in the school. Using two different filters would not be beneficial, especially since a chemical water treatment filter is much more efficient. However, the biological layer is able to clean river water very well. This corresponds to the findings in "New Horizons for Slow Sand Filtration" which stated the biological layer is very sensitive to foreign water and does not filter chemicals well.[1]

Secondly, female students' usage of the recycled water showed students do not use recycled water when regular water is available. Water volume tracking concluded that after the first day, a small volume of recycled water was used compared to how much Williamston High School water students use daily. Students did not correctly use the recycled water and damaged the recycling sink. In order to create a school-wide recycling system, the behavior of the students in the bathroom would need to change to ensure the bathrooms stay clean and well-functioning.

Third, the research concluded using the biosand filter would only benefit the school's water savings by 0.67%. Water usage data showed female students use only a small fraction of the school's total water and an even smaller fraction of water is used for hand washing. Replacing only the sinks with recycled water in the female bathrooms would result in only a small volume of water savings. The biosand filter cannot recycle the water created from toilets, which account for most of the bathroom water usage. Additionally, due to its inability to recycle greywater, the biosand filter is not financially beneficial because the sewer charge is 54.77% of the school's water charges, making the sewer charge greater than the cost of water itself. Since the overall water savings are low, and there is no significant financial savings, it would be impractical to use biosand filters in a school setting.

The results of this research were concluded with only a small amount of data on water usage of the recycled water sink in the bathroom. Implementing the sink long term could affect the students usage of the sink. Not being able to collect data in the males' bathrooms limited the total water used in bathrooms to assumptions that females use the same volume of water as males. Future research on the water usage in the males' bathrooms compared to females' water usage could be done to further improve the experiment. In addition, when calculating water usage, the method used simply involved tracking one bathroom and then multiplying this result by the number of bathrooms in the school and the number of hours in the day. This assumes all bathrooms are used equally at all parts of the day, which is likely not the case. As such, this can be viewed as a limitation to our findings and point to an opportunity for improved procedures. After the filter was compromised as a result of the soap, no additional attempts to remove soap occured. The concentration of soap in the water was unknown in this study, but different concentration levels could affect the biological layer differently. Further research on the water flow rate through the biosand filter should be evaluated to determine how this affects the filtering abilities as well. Biosand filters have the potential to be beneficial with additional research.

References

[1] T. J. Kennedy, A. E. Hernandez, A. N. Morse, and T. A. Morse, "Hydraulic Loading Rate Effect on Removal Rates in Biosand Filter: A Pilot Study of Three Conditions", *Springer Netherlands* 223, 7 (September 2012): 4527–4537, https://doi.org/10.1007/s11270-012-1215-4.

[2] Christine E. Stauber, Gloria M. Ortiz, Dana P. Loomis and Mark D. Sobsey, "A Randomized Controlled Trial of the Concrete Biosand Filter and Its Impact on Diarrheal Disease in Bonao, Dominican Republic," *The American Journal of Tropical Medicine and Hygiene* 80, 2 (February 1, 2009): 286-293, https://doi.org/10.4269/ajtmh.2009.80.286.

[3] Sara Zadeh, Diane Lombardi, Dexter Hunt, and Christopher Rogers, "Greywater Recycling Systems in Urban Mixed-Use Regeneration Areas: Economic Analysis and Water Saving Potential." *The 2nd World Sustainability Forum Session Sustainable Urban Development*, October 29, 2012, https://doi.org/10.3390/wsf2-01021.

[4] "Wastewater Technology Fact Sheet: High-Efficiency Toilets", United States Environmental Protection Agency, September 2000, https://www3.epa.gov/npdes/pubs/hi-eff_toilet.pdf.

[5] David H. Manz, "New Horizons for Slow Sand Filtration", Solutions for Water, April 2004, accessed October 2017, http://purefilteredwater.com/docs/BSF/New Horizons for Slow Sand Filtration Full Paper.pdf.

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Special note: **Schmutzdecke** (German, "dirt cover", sometimes wrongly spelled schmutzedecke) is a hypogeal biological layer formed on the surface of a slow sand filter. The schmutzdecke is the layer that provides the effective purification in potable water treatment, the underlying sand providing the support medium for this biological treatment layer.