Exploring the Efficacy of Slow Sand Filtration for Sustainable Water Purification

Brickhill G and Sheridan C.*

School of Geography, Archaeology and Environmental Science, University of the Witwatersrand, South Africa

*corresponding author:
E-mail: craig.sheridan@wits.ac.za

Abstract

Slow sand filtration (SSF) demonstrates adaptability and resilience when applied to variable river water sources, making it a promising potential solution for sustainable water purification. This study investigates SSF's ability to remove *E. coli*, nitrates (NO_3), and phosphates (PO_4) over 12 weeks, with a focus on its performance under fluctuating water quality conditions. Results reveal progressive improvements in contaminant removal. Notably, SSF maintained consistent performance across varying river samples, showcasing its robustness against changes in turbidity, nutrient concentrations, and organic loads. SSF not only improves microbial water quality but also mitigates nutrient pollution, reducing risks of eutrophication in downstream ecosystems.

Keywords: *E. coli*, Microbial Resilience, Variable Water Quality, Biofilm Development, Nutrient Concentrations, Sustainable Filtration

1. Introduction

The challenge of ensuring access to safe drinking water in South Africa is compounded by the variability of surface water quality, particularly in regions where agricultural runoff, urban waste discharge, and seasonal changes significantly influence river systems. SSF has emerged as a natural and sustainable method for addressing this issue, offering a cost-effective alternative to energy-intensive or chemically dependent water treatment systems (Abdiyev *et al*., 2023). The SSF primarily relies on the Schmutzdecke (SCM) for microbial filtration; the active biological layer, or biofilm, that forms on the surface of the sand, trapping and metabolising microbes (Maiyo *et al*., 2013).

2. Methodology

The experimental design involved a controlled 12-week evaluation of a SSF using raw river water samples characterised by diverse contaminant and microbial profiles. These samples were loaded into a constructed 1m x 30cm SSF with a young, developing SCM using a 25L water supply bag. The influent water storage was placed above the filter to make use of gravity as a pump.

The filter consisted of a plastic cylinder containing densely compacted layers of media. The media consisted of a 15cm layer of fine sand, porosity (0.3-0.4), 5cm of activated charcoal porosity (0.45-0.6), and another 15cm of fine sand.

Flow adjusters were used on the tubing to ensure a sufficient hydraulic retention time (HRT) of 6 hours for microbial growth and contaminant exposure time. These samples were randomly selected to replicate *in situ* water source variability in turbidity, organic matter content, and nutrient concentrations.

Samples of influent and effluent were taken weekly. Effluent samples were taken 6 hours after influent samples to account for the throughput lag time (HRT). IDEXX Colillert 18 was used to analyse E. coli samples, and nutrient-specific MERCK Spectrophotometer test kits were used alongside a spectrophotometer to assess nutrient concentrations.

Key parameters monitored levels of *E. coli*, nitrates (NO^{3-}), and phosphates (PO_4^{3-}) (Tallon *et al*., 2005). The study aimed not only to quantify removal efficiencies but also to assess the system's resilience under variable conditions.

3. Results

3.1. Overall System Performance

Over a 12-week study, SSF showed progressive improvements in contaminant removal, achieving *E. coli* reductions from 34% to 61%, nitrate removal from 12.03% to 29.86%, and phosphate removal from 6.45% to 14.29% (Figure 1). Crucially, the SSF maintained consistent performance despite fluctuations in river water quality parameters.

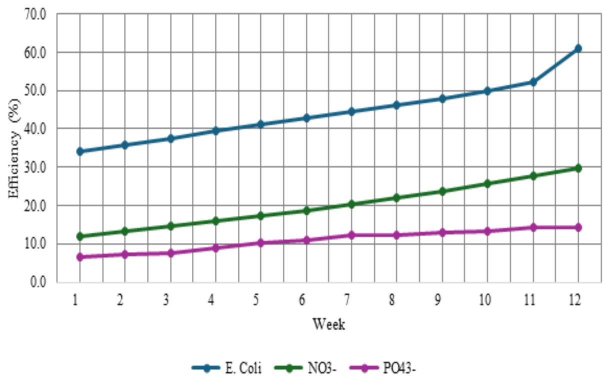

Figure 1. The graph shows t*rends in the removal efficiency of E. coli, nitrate (NO^{3-}), and phosphate (PO_4^{3-}) in slow sand filtration over 12 weeks*

3.2. Schmutzdecke Development

The formation and development of the SCM, the active biological layer on the sand surface, is a key indicator of SSF system performance. Initial growth was observed at 0.5 cm in week 1, increasing to an average depth of 8.24 cm by week 12. (Figure 2).

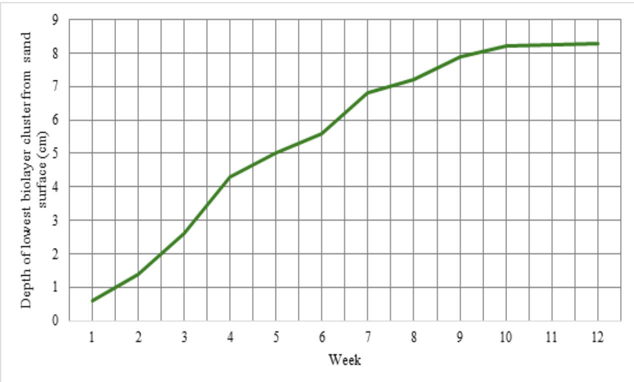

Figure 2. *Graph showing the development of the SCM over 12 weeks*

3.3. Microbial Removal Efficacy

The mean influent *E. coli* concentration was 971.4 ± 158.3 MPN/100 mL (mean ± SD), and the mean effluent concentration after filtration was 534.1 ± 81.9 MPN/100 mL. By week 12, the system reached its highest *E. coli* removal efficiency of 61.00%, reducing the influent concentration from 1203.70 MPN/100 mL to 469.40 MPN/100 mL (Figure 3).

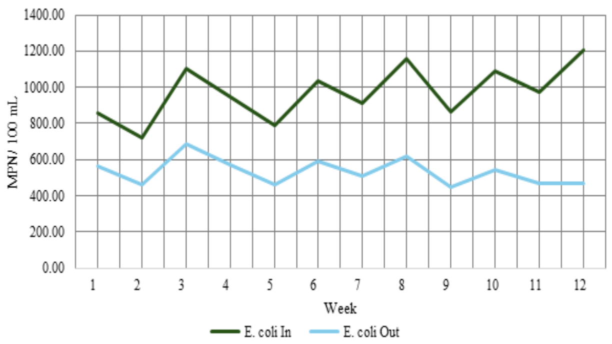

Figure 3. *Graph shows variation in E. Coli removal efficiency of a slow sand filter with developing biolayer over 12 weeks*

4. Discussion

The results of this study confirm that SSF is an adaptable and robust solution for improving water quality, even under fluctuating source water conditions. The progressive increase in contaminant removal-particularly for *E. coli*, nitrates, and phosphates-aligns with findings by Abdiyev *et a*l. (2023), who highlighted SSF's resilience and sustainability in diverse settings. The observed development of the SCM was consistent with the biofilm-driven filtration mechanisms described by Maiyo *et al*. (2023), emphasising the importance of biological processes in long-term filter performance.

5. Conclusion

Results of this study underscore the transformative potential of slow sand filtration as a resilient and eco-friendly solution for sustainable water purification under variable conditions, particularly within resource-constrained South African rural communities. To ensure successful implementation and long-term sustainability, future research should prioritise community participation through participatory action research and needs-based assessments. Further studies are also needed to investigate the relationships between specific microbiological contaminants (beyond *E. coli*) and other relevant water quality parameters such as turbidity, pH, and dissolved oxygen, informing tailored interventions. Such holistic and community-centred approaches will maximise the effectiveness and acceptance of SSF as a crucial tool for equitable access to safe and sustainable water in South Africa.

References

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