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Research Article

Applicability of Biological Sand Filters (BSF) in Water Decontamination: A Systematic Literature Review

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Water is a vital resource, but its increasing scarcity and deteriorating quality pose a global challenge, especially in developing countries, where the lack of adequate sanitation contributes to the high incidence of waterborne diseases. In this context, biological sand filters (BSFs) are emerging as a low-cost solution for water treatment in communities without access to conventional systems. This systematic literature review aimed to evaluate the effectiveness and applicability of BSFs in water decontamination, based on scientific articles published between 2015 and 2024. The search for articles was conducted in the PubMed database, using the keywords: biosand filter, evaluation, and efficacy. Ninety-eight articles were identified, of which nine were selected for analysis after applying inclusion and exclusion criteria. The studies analyzed demonstrate that BSFs are effective in removing microbiological contaminants, such as bacteria and protozoa. Efficacy is significantly enhanced by the addition of materials such as zero-valent iron (ZVI) and activated carbon, which can remove protozoa and chemical contaminants such as arsenic and fluoride. The formation of a biologically active layer is crucial for oxidation and contaminant removal. Beyond the technical aspects, the research highlights that the successful implementation of BSFs depends on social, cultural, and operational factors, for which mitigation strategies include community participation, health education, and training of local health promoters. In conclusion, BSFs represent a promising and affordable technology for improving water quality in vulnerable contexts. However, to maximize their impact, public policies must adopt an integrated approach, combining the technology with health education and community engagement programs. Future research should focus on optimizing filter materials and exploring socioeconomically viable implementation models.

Key-words: biosand filter; evaluation; efficacy

1. Introduction

Water represents a natural element of fundamental importance for life. It was through water that the existence of life on planet Earth and the emergence of the first civilizations became possible, by providing the necessary conditions for survival, the transportation of goods, and the development of agriculture[1].

One of the most important challenges for contemporary society is related to the sustainable use of water; however, despite efforts to store and reduce consumption, water is becoming an increasingly scarce resource, with a progressive deterioration of its quality[2].

In developing countries, there are still regions with precarious sanitation conditions and poor water quality, which allow waterborne diseases—such as typhoid fever, cholera, salmonellosis, shigellosis, and various other forms of gastroenteritis, as well as protozoan infections such as amebiasis and giardiasis—to remain significant public health problems and causing several epidemic outbreaks, leading to high morbidity and mortality rates[3].

Despite global efforts to control social inequalities, there are currently about 750 million people worldwide without access to improved water sources, problem that is more evident in developing countries[4].

According to the National Sanitation Information System (SNIS), in Brazil, in 2014, 93.0% of the urban population was already served by a water supply network. However, there is a disparity among the regions of the country in terms of sanitation, with the North and Northeast regions being the most deficient in sewage and water treatment systems, respectively. Thus, there is an imminent need to combat the sanitary exclusion of minority groups, represented by rural inhabitants and the poor population in general[4-5].

The difficult access to treated water in rural areas contributes to a high morbidity associated with waterborne diseases, which are part of the daily reality of the population. Therefore, it is crucial not only to promote access to water from public treatment systems but also to develop strategies for access to non-conventional treatments that may be effective for ensuring water potability[6].

Among the available alternatives, the biosand filter stands out. Like other slow filtration techniques, it acts as a physical barrier with outflow to provide water of adequate quality for consumption. In places where large-scale treatment is not available, slow filtration may be a favorable option[7].

The biosand filter consists of a tank filled with sand and gravel and, in some cases, activated carbon and/or other additives, which enable the removal of pollutants and infectious agents through physical and biological processes[7, 8].

Determining the effectiveness of the biosand filter may be a strategy of interest to promote its use as a tool for water treatment and to provide better quality of life for rural communities without access to conventional water treatment systems. Therefore, the present study aimed to evaluate the applicability of the biosand filter (BSF) for decontaminating water through a systematic literature review on this subject.

2. Method

Exploratory and qualitative research will be conducted, searching for information on the topic in the Medline scientific database using the following descriptors: "biosand filter," "evaluation," and "efficacy."

This is an integrative review, including articles published in English from January 2020 to December 2024 witch evaluated the effectiveness of biological sand filters for water decontamination.

Inclusion criteria: articles exclusively in English, addressing evaluations of biosand filters. Articles that did not directly address the topic were excluded.

3. Results

After an extensive search for articles on the PubMed website, 98 articles were initially identified and, based on the exclusion and inclusion criteria selected for this research, only 9 were selected to compose the results. 73 articles were excluded because they did not directly address the topic, and 16 were literature review articles, as shown in the flowchart in Figure 1.

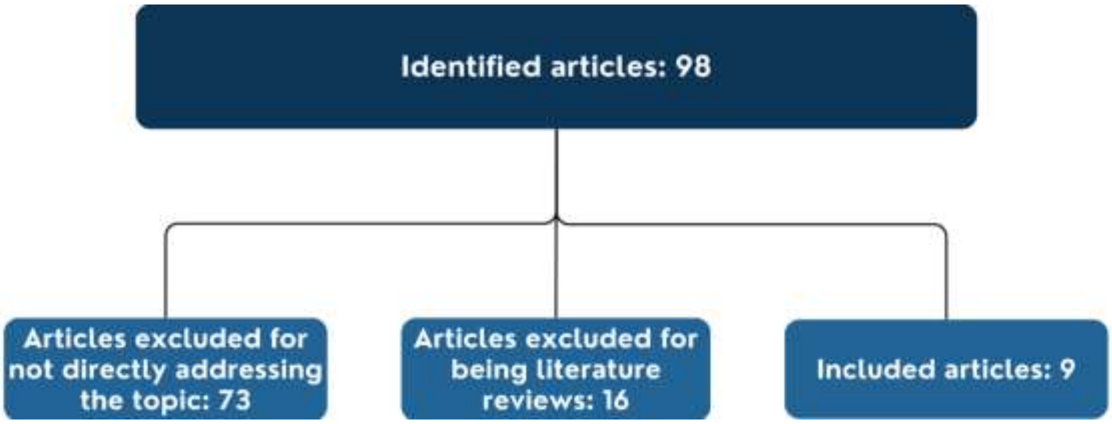

Figure 1: Flowchart of articles selection

Based on the 9 articles selected for final composition, a table was created which includes the authors, year of publication, main experimental design and main results/ conclusions of those studies.

Table 1: Synthesis of the analyzed articles

Authors	Year	Main experimental design	Main results/ conclusions
Alan Gutierrez,Matthew S Tucker,Christina Yeager,Valsin Fournet,Mark C Jenkins,Jitender P. Dubey,Kalmia E. Kniel,Benjamin M. Rosenthal,Manah Sharma[9]	2024	Sand filters and mixed filters with ZVI (zero-valent iron) were evaluated for the removal of *Eimeria* and *C. cayetanensis oocysts*, using minifilters and pool filters in laboratory and simulated agricultural water conditions.	The results showed that filters with 50% ZVI exhibited significantly higher efficiency in oocyst removal compared to filters with 100% sand: reduction of *E. tenella* by 99.9% versus 55.3% and *E. acervulina* by 70.5% versus 54.5%. Backwashing also indicated greater recovery of oocysts in the filters with ZVI. These findings confirm that the addition of ZVI significantly increases the efficiency of oocyst filtration, representing a promising strategy for agricultural water decontamination and parasite transmission prevention.

Phumudzo Budeli, Resoketswe Charlotte Moropeng, Lizzy Mpenyana-Monyatsi, Maggie Ndombo Benteke Momba[10]	2018	Ceramic filters impregnated with silver (0.18 and 0.101 mg/L) and filters composed of sand and zeolite were evaluated, both in a original version and in a modified version with the addition of a layer of clay impregnated with silver, were challenged with surface water.	The silver-free sand and zeolite biological filter proved to be less efficient in maintaining the absence of microorganisms in storage water than other filters evaluated.
Vahid Zarezadeh, Travis Lung, Troy Dorman, Heather J Shipley, Márcio Giacomon[11]	2018	Monitoring of a sand filter basin on the UTSA campus during 10 rainfall events (2016–2017), with analyses of TSS, VSS, nitrate, orthophosphate, copper, zinc, lead, pH, and conductivity. Results compared with data from 30 other basins in an international database.	Sand filter basins are highly effective at removing solids but are less efficient at removing nutrients and dissolved metals, requiring complementary practices in aquifer recharge areas.
J.C.J. Gude, K. Joris, K. Huysman, L.C. Rietveld, D. van Halem[12]	2018	The experiments were carried out using groundwater in two filtration columns with a diameter of 300 mm and heights of 2 and 3 m, filled with quartz sand (0.70–1.25 mm) up to 140 cm. Raw water was pumped and sprayed onto the columns, ensuring aeration and an average dissolved oxygen concentration of 6.6 ± 1.1 mg/L, sufficient to meet the demand of Fe(II), Mn(II), NH_4^+, and As(III). Samples were analyzed in three ways: untreated, filtered through 0.45 µm, and filtered with an anion exchange resin for arsenic speciation. Arsenic, iron, manganese, phosphorus, ammonium, nitrite, and nitrate were quantified by ICP-MS or spectrophotometry. The experimental design allowed for	Increasing the supernatant water level and adding Fe to groundwater biological filters can promote arsenic removal. The study also confirmed that arsenic oxidation is primarily biological, as oxidation almost completely stopped after disinfection of the columns with chlorine.

		the study of bed biological maturation, contaminant removal, and the effect of iron addition on column performance.	
José Lugo-Arias, Javier Burgos-Vergara, Elkyn Lugo-Arias, Audrey Gould, David Ovallos-Gazabon[13]	2019	The efficiency of two natural coagulants—*Moringa oleifera* and *Cassia fistula*—was evaluated, also the performance of biosand filters, in versions with and without activated carbon, was compared. In addition, low-cost water disinfection processes (SODIS and UV-C lamps) were investigated. The efficiencies of different combinations of purification processes were tested, always following the sequence: coagulation–flocculation, filtration, and disinfection.	*Moringa oleifera* proved to be an excellent coagulant, better than *Cassia fistula*. Regarding filter performance and water quality parameters after filtration, turbidity levels decreased from 633 and 662 NTU to between 6.9 and 11.7 NTU, with the lowest values obtained through the combination of coagulants and filtration, particularly with activated carbon. The efficiencies in total coliform elimination ranged from 54 to 76.9%. When filtered water samples were subjected to disinfection processes using UV lamps and SODIS, coliform removal ranged from 97% to 98.8%, resulting in values below 100 CFU/100 mL, though never reaching zero.
Eric Fung, Ken I. Johnson, Wenqi Li, William Borges, Kai Chi, Sunil K. Sharma, Yogita Madan, Priyanka R. Sharma, Benjamin S. Hsiao[14]	2021	The study evaluated the efficiency of a biosand bag filter with activated carbon and bone char in adsorbing fluoride at different concentrations and different amounts of carbon. These tests were conducted at three pHs: 3, 7, and 9. Static adsorption tests and spectrometric studies of the carbon properties were also performed.	The association of bone char and activated charcoal made the best adsorption efficiency.
Mark Elliott , Christine E Stauber , Francis A DiGiano , Anna Fabiszewski de Aceituno , Mark D Sobsey[15]	2015	Two laboratory experiments were conducted, Column Tests No. 1 and No. 2, each lasting eight weeks. The purpose was to compare the effectiveness of two materials—commercial sand (Accusand) and locally sieved granite—in reducing microbes.	It is conclusive that the growth of the schmutzdecke (biological layer) is crucial for *E. coli* removal but has only a minor impact on viral reduction. The type of filter medium does not affect *E. coli* removal. However, unsieved granite without backwashing showed greater effectiveness in viral reduction compared

			to Accusand, an advantage that was lost after backwashing the granite, suggesting that this process removes fractions important for viral sorption. Backwashing is inadequate for BSFs, as it can create preferential flow paths and reduce effectiveness. The observed viral reductions were minimal and did not meet WHO targets, highlighting the need to optimize filtration systems for virus removal.
Resoketswe Charlotte Moropeng, Phumudzo Budeli and Maggy Ndombo Benteke Momba[16]	2021	The cross-sectional study was conducted to evaluate how sanitation, hygiene, and storage practices influence the quality of household-treated water using biosand filters with silver-zeolite (BSZ-SICG) and silver-impregnated porous pot filters (SIPP).	The study demonstrated the effectiveness of the evaluated filters; however, it showed that the presence of *Escherichia coli* in treated water was significantly associated with hygiene practices, such as handwashing, and with the quality of water in storage containers, indicating the need for hygiene education to ensure the health benefits of water treatment.
Hayley E. Schram and Peter J. Wampler[17]	2018	The study evaluated total coliform and *E. coli* contamination in hand-dug wells and an ISF (Improved Sand Filter) well. The ISF well was constructed with local materials and hand-sieved filter sand, except for the imported pump, and the samples followed the same bacteriological procedures as the hand-dug wells.	Regarding bacterial contamination, of the 35 hand-dug wells sampled in 2016 and 2017, 30 wells (86%) exceeded the maximum detection limit for total coliforms (>2419.6 MPN/100 mL) and 4 wells (11%) exceeded the detection limit for *E. coli*. The geometric mean was calculated for *E. coli* tests due to the wide variation in MPN values (0–2419.6). Thirty-one of the 35 samples (89%) exceeded the World Health Organization (WHO) standard for *E. coli* in drinking water, which recommends no detectable bacteria in 100 mL of water. Furthermore, 23 of the 35 samples (66%) exceeded the geometric mean of 130 *E. coli*/100 mL established by the Michigan Department of Environmental Quality for recreational or body contact. These

			results indicate that most hand-dug wells in the region show significant contamination by total coliforms and *E. coli*, frequently surpassing international drinking water quality standards.

4. Discussion

Water, a vital resource for the existence of life and the development of civilizations[1], today faces one of the greatest sustainability challenges[2]. The scarcity and deterioration of water quality are global problems, particularly acute in developing countries, where precarious sanitation conditions persist, resulting in high rates of waterborne diseases[3- 5]. In this context, the development of effective and low-cost water treatment solutions is imperative, especially for rural communities and vulnerable populations without access to conventional treatment systems[6- 8].

Within this framework, biosand filters (BSFs) emerge as a promising alternative. Operating as a physical and biological barrier, BSFs are capable of removing pollutants and infectious agents from water, making it suitable for consumption[7-8]. The present article, through a systematic literature review, sought to evaluate the applicability and effectiveness of BSFs in water decontamination, gathering and analyzing studies that investigated their performance in different scenarios and configurations. This discussion deepens the findings presented, contextualizing them within existing literature and exploring implications for public health and future research directions.

The results reported[9] highlight the significant potential of modifying BSFs with metallic iron (ZVI) for the removal of protozoan oocysts, such as *Eimeria* and *C. cayetanensis*. The inclusion of ZVI substantially increased retention efficiency, with reductions of up to 99.9% in filters with 50% ZVI, compared to 55.3% in pure sand filters. This improvement is attributed to the strong adhesion of ZVI particles to the oocyst surface, suggesting a removal mechanism beyond simple physical filtration.

Consistency in oocyst retention in ZVI filters, even in tests with multiple species and simulated agricultural water conditions, reinforces the promise of this technology for preventing waterborne parasitic diseases. However, according to the authors, the partial recovery of oocysts during backwashing, regardless of filter medium, indicates that proper management of backwash residues is crucial to avoid environmental recontamination.

The study[10] analyzed ceramic filters impregnated with silver and a filter composed of sand and zeolite for the removal of physical and biological contaminants. Results showed significant turbidity reduction and absence of bacteria for a considerable period. However, coliforms and *E. coli* reappeared after the 14th day of water storage in ceramic filters and even earlier (3rd to 7th day). This finding underscores the importance of proper storage practices and the need for continuous user education. Silver leaching from the filters was also identified as a factor contributing to loss of efficiency over time, indicating that the sustainability of these impregnated materials may be limited.

Thus, it is remarkable that efficiency of BSFs in microorganism removal depends on multiple factors, such as filter media type, presence of additives (silver, zeolite, ZVI), filter usage time, and user hygiene practices. Although BSFs show good results in pathogen reduction, ensuring safe drinking water requires not only the technology itself but also community education and engagement to prevent post-treatment recontamination.

Sand filters, as designed by[11] in sand filter basins for urban stormwater runoff, have proven to be an efficient technology for removing suspended solids. The analysis in question, conducted at the main campus of the University of Texas at San Antonio (UTSA), monitored ten storm events and reported high removal rates of total suspended solids (TSS) and volatile suspended solids (VSS), with averages of 94% and 86%, respectively. These results exceed typical design criteria for TSS removal, which are generally around 80%. The potential for rapid particulate matter extraction is crucial, as many pollutants, including heavy metals such as lead, are often associated with these particles.

Beyond microorganism elimination, BSFs are also important for the treatment of chemical contaminants and metals[12-13], a crucial aspect for water quality, especially in regions where groundwater may be naturally enriched with toxic substances such as arsenic.

The study[12], which investigated the oxidation and removal of arsenic (As(III)), iron (Fe(II)), manganese (Mn(II)), and ammonium (NH_4^+) in quartz sand filter columns in Belgium, are particularly relevant. These studies demonstrated that biological maturation of the filter plays a fundamental role in removal efficiency. The gradual conversion of As(III) to As(V) and the complete oxidation of arsenic in filtered water, concentrated in the top 20 cm of the filter bed, indicate the formation of an active biological layer (schmutzdecke) that facilitates these processes. A deeper filter bed (120 cm) resulted in higher arsenic removal, highlighting the importance of contact time and surface area for biological activity. The sequence of biomass colonization—As(III)-oxidizers, nitrifiers, and Mn(II)-oxidizers—suggests a complex and adaptive microbial ecology within the filter.

The addition of Fe(II) or Fe(III) to water enhanced arsenic removal, with Fe(III) being more effective. This is due to the formation of ferric hydroxides (HFOs), which act as sorbents for arsenic. The oxidation of Fe(II) ensured complete iron removal, indicating that BSFs can effectively remove multiple contaminants simultaneously.

Fluoride adsorption capacity was also investigated by[13], who compared activated carbon and bone char. Bone char showed significantly higher adsorption capacity (9.13 mg/g) compared to activated carbon (6.23 mg/g), and the combination of both materials resulted in 100% fluoride removal during filtration, suggesting a promising synergy. However, removal efficiency decreased with increasing pH, an important factor for practical application.

This study also evaluated the efficiency of natural coagulants, such as *Moringa oleifera*, and their combination with BSFs (with and without activated carbon) for turbidity and coliform removal. *Moringa* showed strong coagulating performance, reducing turbidity by up to 96%. The combination of coagulants and filtration, especially with activated carbon, resulted in very low turbidity values. Although total hardness removal was low, total coliform elimination ranged from 54% to 76.9%, and the application of additional disinfection with UV lamps or SODIS (Solar Water Disinfection) increased coliform removal to 97–98.8%. These results demonstrate that ensuring drinking water safety may require a multifaceted approach that combines different treatment steps, especially for removing chemical contaminants and inactivating microorganisms resistant to filtration.

The article[14] studies the effectiveness of sand filtration and zero-valent iron (ZVI) in reducing *Eimeria spp*. oocysts, which serve as surrogates for *Cyclospora cayetanensis* in water.

The research confirmed that the addition of ZVI to sand filters significantly improves the removal of these parasites, both on a laboratory and field scale. This suggests that the unique combination of ZVI and sand may be an affordable and effective intervention for improving the quality of safe water and reducing the risk of contamination of fresh produce by waterborne parasites.

According to[15], a study of the influence of supernatant water level (SWL) on arsenic (As) removal in biological rapid sand filters, optimizing the oxidation state of iron (Fe) entering the filter bed, controlled by SWL, is important for effective arsenic removal. Therefore, it concludes that combining a higher SWL and/or the addition of Fe(III) with the biological oxidation of As(III) in the upper part of the filter bed significantly favors arsenic extraction, promoting improvements in groundwater treatment systems.

Adressing the relevance of integrated hygiene, sanitation, and storage practices for the microbiological quality of drinking water treated at the point of use, the study[16], conducted in Makwane Village, South Africa, analyzed the efficiency of silver-zeolite biosand filters and silver-impregnated porous ceramic filters. The studies demonstrate a significant association between the presence of Escherichia coli in the treated water and factors such as the age of caregivers, the number of children under five, and hygiene practices, particularly handwashing. The study emphasizes that, to ensure the health benefits of point-of-use water treatment, it is important to implement adequate hygiene education.

Despite technological advances, the study[17] in Haiti serves as a critical reminder of the limitations of hand-dug wells and the persistence of bacterial contamination, even in wells protected by raised concrete collars. The high levels of total coliforms and *E. coli* in these wells, often exceeding international drinking water quality standards, highlight that basic infrastructure alone may be insufficient to guarantee water safety. This emphasizes the need for complementary approaches, such as the use of BSFs, and the importance of considering the local context and water use practices when implementing treatment solutions[18].

The implementation of BSFs in rural regions include the improvement quality of life of residents, especially women, that is harmed by the risks associated with fetching and transporting water, such as violence along the way and contact with wild animals at water sources; also, water collection activities imply a reduction in time dedicated to home, family, and studies. Trouble with water sources such as rivers commonly result from shared use by humans, livestock, and wild animals, as well as use for other activities such as laundry.

The lack of cooperation between stakeholders in plans to improve water access, the exclusion of communities from decision-making processes, the lack of innovation and substantial projects, in addition to the use of low-quality materials and services, are bottlenecks to changing this scenario. Another factor of influence is that population normally lack knowledge about health and techniques of prevention of diseases, like water treatment. The group studied in [18] demonstrated an understanding of the link between diseases and water quality, albeit in a simplistic way, despite not having strong water treatment habits and a common sense that water with low turbidity is safe.

The main problems and concerns related to the implementation of the biological sand filter are: neglect of the social context of the communities, particularly poverty, inequality, and long distances between communities; bureaucracy in accessing the materials required for filter installation; bureaucracy in permitting installation in certain areas; tensions regarding the distribution of filters to different homes; damage to the filter or its materials during transport or installation; lack of community trust in the policies and projects involved; lack of material, economic, and human resources for filter implementation and maintenance; water scarcity, which can lead to the loss of the filter's biological layer; lack of education and training on the use and maintenance of the biological sand filter, which can lead to misuse and even recontamination of the water; possible sale of low-quality filters; and the possibility that health promotion and improved water access policies can be limited to the short term.

The mitigation strategies for the problems and concerns surrounding the use of biological sand filters are: oversight and transparency in the equitable distribution of filters in communities; assessment of strategic locations or homes for implementation in communities; sharing treated water among neighbors; structuring project management including the participation of the community and local health promoters; quality education and training for health promoters and filter technicians, as well as educational activities in schools.

In synthesis, BSFs—particularly when optimized with adsorbent materials or combined with biological and chemical processes—show great potential in removing a wide range of chemical contaminants and metals. The biological maturation of the filter and the appropriate selection of filter media are critical factors for maximizing treatment efficiency.

5. Conclusion

The present systematic literature review demonstrated that biosand filters (BSFs) represent a low-cost and accessible water treatment technology with significant potential to improve water quality and public health in communities without access to conventional treatment systems. The analysis of the selected studies revealed that BSFs are effective in removing a wide range of microbiological contaminants, such as bacteria (including total coliforms and *E. coli*) and protozoa, and, when optimized with adsorbent materials or combined with biological and chemical processes, they can also remove chemical contaminants and metals such as arsenic and fluoride, contributing significantly to the improvement of drinking water quality[9-13].

However, the effectiveness of BSFs is not limited to their technical capacity. Social, cultural, and operational factors play a crucial role in their implementation and sustainability. Health education, community engagement, overcoming logistical barriers, and ensuring adequate practices of water hygiene and storage are as important as the design of the filter itself. Post-treatment recontamination and the misperception of water safety are persistent challenges that require multifaceted and continuous approaches[14-15].

Thus, biosand filters represent a valuable resource in combating drinking water scarcity and waterborne diseases, particularly in vulnerable contexts. To maximize the impact of BSFs, it is imperative that public policies adopt an integrated approach that combines the provision of technology with strong health education programs, investments in supporting infrastructure, and monitoring and evaluation mechanisms. In this regard, future research should focus primarily on optimizing filter media, deepening the understanding of biological processes, conducting long-term field studies, and, importantly, exploring socioeconomically viable implementation models. Consequently, by addressing these areas, biosand filters can consolidate themselves as an even more powerful, safe, and sustainable solution to guarantee the human right to drinking water for millions of people worldwide.

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