

Analysis of the Effectiveness of Sand Filters for Raw Water Treatment in Brackish Water Aquaculture Environments

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ABSTRACT

Brackish water used in aquaculture often contains high levels of contaminants that require treatment to make it suitable for farming. This study evaluates the effectiveness of sand filters in improving raw water quality at the Brackish Water Aquaculture Fisheries Center in Takalar, South Sulawesi, over a two-month monitoring period. A pre- and post-filtration analysis was conducted on key water quality parameters, including Total Organic Carbon (TOC), Ammonia (NH₃), Nitrite (NO₂), and Total Bacterial Count (CFU/mL). Results indicated that the sand filter system effectively reduced TOC by 20.99% and bacterial load by 13.18%. However, ammonia removal was minimal at 1.04%, and nitrite levels rose significantly by 23.93% after filtration. These findings indicate that while sand filters effectively reduce organic and microbial pollutants, they are inadequate for managing nitrogen compounds. The novelty of this study lies in its use of sand filtration in operational, high-salinity aquaculture environments, a context that remains insufficiently explored in existing research literature. Further integration with biological filtration systems is advised to boost nitrogen removal and enhance overall treatment efficiency.

Keywords-sand filter; raw water treatment; sustainable aquaculture; filtration effectiveness

I. INTRODUCTION

Environmental sustainability is now a significant concern in different sectors, leading to innovations focused on minimizing ecological impact and encouraging resource recycling. Recent studies, such as those utilizing landfill waste incineration ash and incineration residue ash, demonstrate how industrial by-products can be turned into value-added materials that reduce carbon emissions and promote sustainable infrastructure [1, 2]. These innovations exemplify a broader effort to reduce environmental degradation using life cycle-based approaches. However, similar attention should be given to aquatic environments, especially brackish water aquaculture systems, which are increasingly threatened by pollution, eutrophication, and intensified farming practices. As global demand for sustainable food production increases, maintaining the ecological integrity of these systems becomes more essential to achieving broader environmental resilience.

Brackish water aquaculture is vital for food security and coastal economic growth by supplying protein and numerous livelihoods to millions [3-5]. Nevertheless, its sustainability relies on water quality, which is often compromised by pollutants such as suspended solids, organic matter, nitrogen compounds (e.g., ammonia and nitrites), and microbial contamination [6-8]. These pollutants not only harm water quality but can also lead to eutrophication, disease outbreaks, and death in aquaculture species [9-11]. Therefore, it is

essential to develop effective raw water treatment technologies tailored to the specific conditions of brackish environments.

Among the treatment options available, sand filtration has garnered increased interest owing to its cost-effectiveness, simplicity, and environmental suitability [12, 13]. However, most of the current research has concentrated on the implementation of sand filters within domestic, drinking water, or low-salinity wastewater treatment systems. This focus has resulted in a notable deficiency of empirical data regarding their efficacy under the distinctive, high-salinity, and high-organic-load conditions characteristic of brackish aquaculture. For example, unlike previous studies that examined performance in potable water systems with moderate pollutant levels, this study explores the performance of sand filters in saline aquaculture ponds where biological fouling and complex organic inputs are more prevalent. While some evidence indicates that Slow Sand Filters (SSFs) can promote beneficial microbial communities and decrease biomass in general settings [14], there is limited quantitative data regarding their effectiveness in aquaculture-specific environments.

This study aims to fill this gap by evaluating the operational performance of sand filters in brackish aquaculture ponds, a setting frequently neglected in existing filtration research. Unlike traditional studies that analyze TOC, ammonia, and bacterial levels in municipal water systems, the current research focuses on a field-scale application in an aquaculture hatchery using seawater affected by organic waste and

biological activity. Furthermore, the utilization of varied filter media (e.g., glass pearl, zeoplus) within multi-unit configurations provides an opportunity to evaluate not only removal efficiency but also performance variability under aquaculture stressors. Therefore, this study has both theoretical and practical importance. Theoretically, it adds to the limited knowledge on filtration dynamics in saline aquaculture systems and emphasizes the role of organic-biological interactions in filter performance. Practically, it provides data-driven recommendations to aquaculture practitioners, offering insights into optimizing sand filter systems for sustainable application in coastal hatcheries. Specifically, this study aims to (1) analyze the effectiveness of sand filters in reducing TOC levels, (2) evaluate their capacity to remove NH₃, (3) assess their performance in lowering NO₂ concentrations, (4) measure impacts on total bacterial load, and (5) identify operational and environmental factors influencing filtration efficiency in brackish aquaculture environments.

II. LITERATURE REVIEW

Water quality is a key factor for success in brackish water aquaculture, as poor parameters can harm the health, growth, and survival of cultured species [11, 14, 15]. Common water quality concerns in such environments include high levels of suspended solids, organic matter, ammonia, nitrites, and bacterial contamination [10, 16, 17]. These pollutants can cause eutrophication, harmful algal blooms, and disease outbreaks, while factors like extreme pH, low dissolved oxygen, or unsuitable salinity can worsen stress on aquatic life [18-23]. To mitigate these risks, various water treatment technologies have been explored, with sand filtration emerging as a cost-effective and straightforward method for improving water quality [7, 12, 13]. Sand filters operate by trapping particulates mechanically and using biofilm-based biological filtration [24-26]. Two main types, SSFs and Rapid Sand Filters (RSFs), provide different benefits based on filtration rate, maintenance needs, and system complexity [8, 27]. SSFs, in particular, depend on a biologically active surface layer (schmutzdecke) for improved purification and have shown strong results in removing organic biomass and microbial contaminants in non-aquaculture environments [14, 26].

Research on filtration systems like Pontoon Mesh Rotary Filters (PMRFs) highlights the need to optimize flow rate, media grain size, and operational time to enhance filtration efficiency [26, 28]. Other research has highlighted the role of microbial communities, including fungi and bacteria, in enhancing the biological filtration capacity of sand filters [14, 29]. However, most of these studies focus on freshwater, domestic, or irrigation applications and do not address the specific conditions encountered in brackish water aquaculture, such as high salinity and increased organic loads. Although sand filtration has well-known benefits, its practical evaluation in brackish water aquaculture is limited. Previous research has not thoroughly examined how effective sand filters are in lowering major pollutants like TOC, NH₃, NO₂, and bacterial levels under saline conditions. Additionally, there is a lack of discussion on how factors such as media composition, flow rate, and water chemistry interact in these environments. Therefore, this study aims to fill this gap by examining how

effective sand filtration systems are in real-world brackish aquaculture environments. By focusing on pollutant reduction and operational conditions, the research helps improve treatment techniques and promotes sustainable management of aquaculture water quality.

III. RESEARCH METHODOLOGY

This study was conducted at the Brackish Water Aquaculture Fisheries Centre (BPBAP) in Takalar, South Sulawesi Province, over a period of three months. The experimental setup included a seawater reservoir pond (0.5 hectares, 2 meters deep), which served as the raw water intake. This above-ground pond was bordered by cement walls and stocked with *Caulerpa* algae and several species of brackish water fish. The seawater was allowed to settle for 24 hours to facilitate initial sedimentation before treatment. Water from the reservoir was filtered through five parallel sand filtration units (MICRON S-900), each with the following specifications: valve diameter 50 mm, internal diameter 900 mm, filtration surface area 0.64 m², bed depth 420 mm, maximum flow rate 509 L/min, and medium capacity 322 L. The filter media consisted of a layered mixture: 520 kg of glass pearls, 435 kg of EcoPure (0.815–1.5 mm), 470 kg of silica sand (16/30 mesh), and 386 kg of ZeoPlus (1–2.2 mm). Water was pumped through the filters into a nursery pond for post-treatment use. The intake area was observed to be partially obstructed by green mussels, which may have influenced microbial activity at the inflow site. Water samples were collected with 5-liter sterilized buckets at two fixed locations:

1. Immediately before filtration, from the reservoir pond, and
2. Post-filtration, from the outlet of the nursery pond. Sampling occurred biweekly on Mondays and Thursdays at 07:30 WITA.

Water quality parameters measured included: TOC - titrimetric method (SNI 01-3554-1998), NH₃ - colorimetric method (SNI 06-2479-1991), NO₂ - colorimetric method (SNI 06-2480-1991), CFU/mL - Total Plate Count (SNI 6989.72:2009). All analyses were performed at the BPBAP Takalar Laboratory using standard reagents and calibrated instruments. To evaluate filtration effectiveness, data were statistically analysed using paired t-tests comparing pre- and post-filtration concentrations. Significance was determined at the 95% confidence level, with results supported by p-values, confidence intervals, and standard error values. Additionally, water quality changes before and after treatment were visualized using box plots and bar graphs with error bars. Statistical analysis was carried out using SPSS or Microsoft Excel software.

$$SF = \frac{(C_{in} - C_{out})}{C_{in}} \times 100\% \quad (1)$$

where SF is the efficiency of sand filter, C_{in} is the value before the sand filter, C_{out} is the value after sand filter.

Paired T Test

$$t = \frac{\sum d}{\sqrt{\frac{n(\sum d^2) - (\sum d)^2}{n-1}}} \quad (2)$$

where $\sum d$ is the sum of the differences between two observations, n is the number of samples, d is the difference

between two paired observations

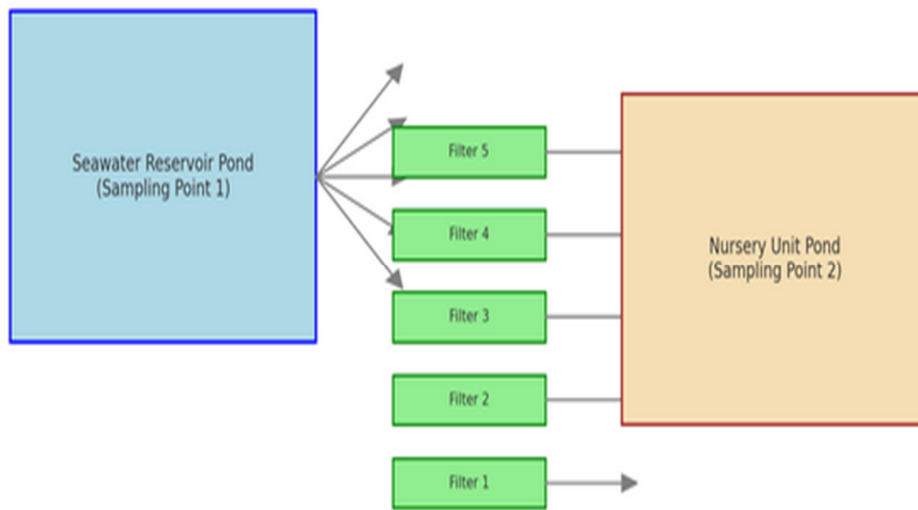


Fig. 1. Schematic Diagram of the Sand Filtration System and Water Sampling Points.

The schematic diagram shows the layout of the sand filtration system used in this study, clearly indicating the water flow and sampling points (Figure 1). Raw seawater from the reservoir pond (Sampling Point 1) is first allowed to settle for 24 hours before being pumped through five parallel filtration units (Filter 1–5) equipped with mixed filter media, including Glass Pearls, EcoPure, silica sand, and ZeoPlus. Following the filtration process, the treated water is discharged into the nursery unit pond (Sampling Point 2), where it is utilized for aquaculture activities. This setup allows for systematic monitoring of water quality before and after filtration. Using a clearly defined schematic improves the transparency of the methodology and increases reproducibility by visually illustrating the spatial arrangement and functional components of the filtration system.

IV. RESULTS AND DISCUSSION

A. Results

Across the three water sources, TOC before and after filtration varies markedly (Figure 2). Seawater has the highest mean TOC (37.48 mg/L; SD = 24.69; range = 15.01–75.05), indicating substantial variability in organic inputs. Reservoir water is slightly lower (33.25 mg/L; SD = 16.36; 15.01–57.04). The hatchery pond shows the lowest and most consistent values (29.61 mg/L; SD = 9.53; 17.82–45.03), suggesting more stable water quality.

Ammonia concentrations were uniform across all water sources, with a mean of 0.006 mg/L, a near-zero standard deviation, and no detectable variation over the sampling period (Figure 3). This consistency indicates negligible ammonia contamination, which is favorable for aquaculture operations, as elevated ammonia is harmful to aquatic species.

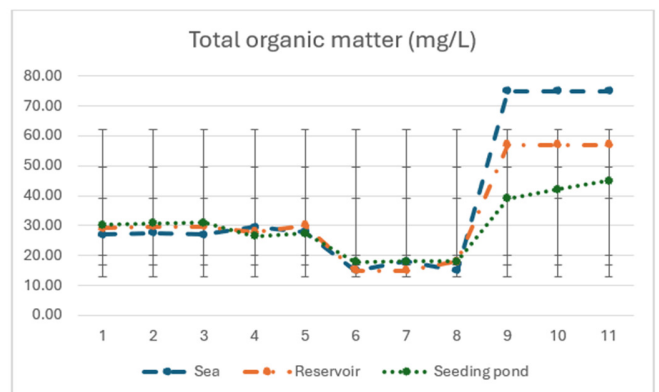


Fig. 2. Graph of total organic matter.

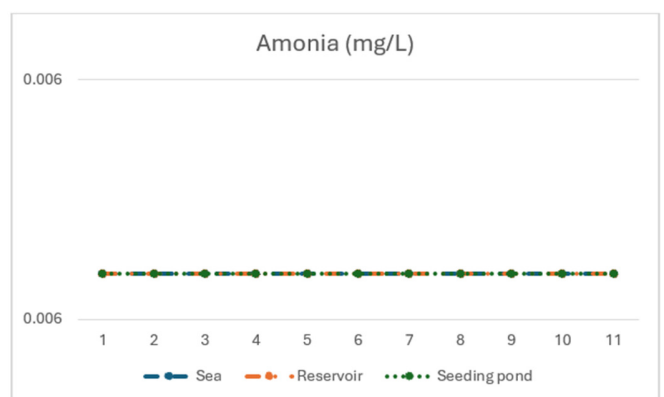


Fig. 3. Graph of water ammonia.

Nitrite concentrations in seawater and reservoir water remained low and stable, with a mean of 0.0223 mg/L, a negligible standard deviation, and no detectable variation

across measurements (Figure 4). This consistency indicates effective control or natural stability of nitrite levels in these water sources, reducing the risk of nitrite toxicity. In contrast, hatchery pond water shows much greater variability, with an average nitrite level of 0.1247 mg/L, a standard deviation of 0.0919 mg/L, and measurements ranging from 0.0223 mg/L to 0.2570 mg/L. This fluctuation suggests that nitrite levels in the hatchery pond are less stable, possibly affected by organic matter decomposition, feeding practices, or limited water exchange. Elevated nitrite levels in hatchery environments can be harmful to aquatic organisms, especially during early life stages. Therefore, close monitoring and proper water management strategies are necessary to maintain optimal water quality for fish health and growth.

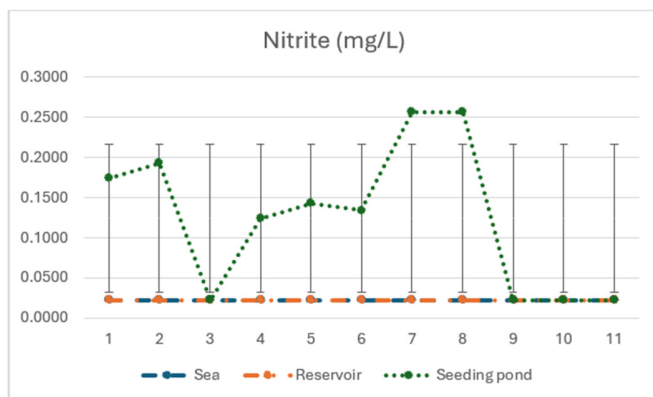


Fig. 4. Graph of water nitrite.

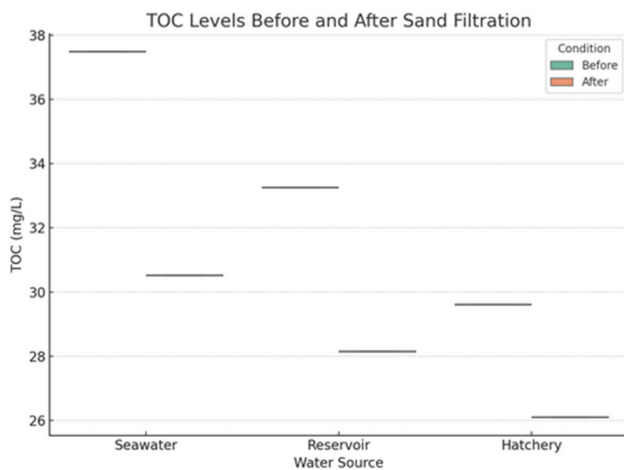


Fig. 5. TOC levels before and after sand filtration.

The TOC levels were notably reduced after filtration across all water sources. Seawater dropped from 37.48 mg/L to 30.52 mg/L, reservoir water from 33.25 mg/L to 28.15 mg/L, and hatchery pond water from 29.61 mg/L to 26.11 mg/L. A paired t-test showed this reduction was statistically significant ($t = 5.19$, $p = 0.035$), confirming that sand filtration had a meaningful effect on removing organic matter. The box plot illustrates this trend, showing consistent declines in TOC across all sample groups after filtration (Figure 5). These

findings confirm the sand filter's effectiveness in reducing suspended organic pollutants in brackish water environments.

The analysis of TOC levels across the three water sources (seawater, reservoir, and hatchery pond) demonstrated a consistent decrease after filtration. The average TOC level in seawater declined from 37.48 mg/L (SD = 24.69) to 30.52 mg/L after filtration. Similarly, the reservoir water decreased from 33.25 mg/L (SD = 16.36) to 28.15 mg/L, while the hatchery pond water dropped from 29.61 mg/L (SD = 9.53) to 26.11 mg/L. A paired t-test showed that this decrease was statistically significant ($t = 5.19$, $p = 0.035$), indicating that the sand filtration system effectively removed organic contaminants from the raw water. These changes are shown in the box plot (Figure 4), which illustrates a decline in TOC concentrations for all three water sources after filtration. The distribution also became slightly narrower, especially for hatchery pond water, indicating improved consistency in water quality after treatment. Ammonia levels, on the other hand, stayed consistent at 0.006 mg/L across all sampling points, with nearly zero standard deviation, indicating minimal variation. This implies that the sand filter had no significant effect on ammonia removal, possibly because of already low initial concentrations. Since ammonia is toxic to aquatic species even at low levels, additional filtration strategies might be necessary to address this parameter better.

The total bacterial load differs among the three water sources, suggesting variation in microbial activity and contamination potential (Figure 6). Seawater exhibits the highest average bacterial concentration at 8.26 ln (CFU/mL), along with the broadest range (5.99–11.07 ln (CFU/mL)) and the highest standard deviation (1.26). This indicates more dynamic microbial conditions, possibly influenced by external environmental factors or organic inputs. Reservoir water has the lowest average bacterial count at 6.92 ln (CFU/mL) and a narrower range (5.70–9.05 ln (CFU/mL)), indicating relatively stable microbial conditions, possibly due to more controlled environmental factors. Hatchery pond water, with an average of 7.17 ln (CFU/mL) and the lowest standard deviation (0.90), indicates moderate bacterial levels with less fluctuation, suggesting consistent management practices in aquaculture systems. These findings emphasize the need for ongoing monitoring of microbial loads, especially in seawater sources, to maintain water quality and prevent potential risks to aquatic life.

B. Discussion

This study aims to evaluate the effectiveness of sand filters in treating raw water within brackish water fisheries environments. The results showed that sand filters effectively reduced TOC and Total Bacteria levels, but they were not effective in lowering NH_3 levels and increasing NO_2 levels. These findings suggest that the effectiveness of sand filters depends heavily on various factors, including raw water characteristics, filter design and operation, and microbiological processes occurring inside the filter.

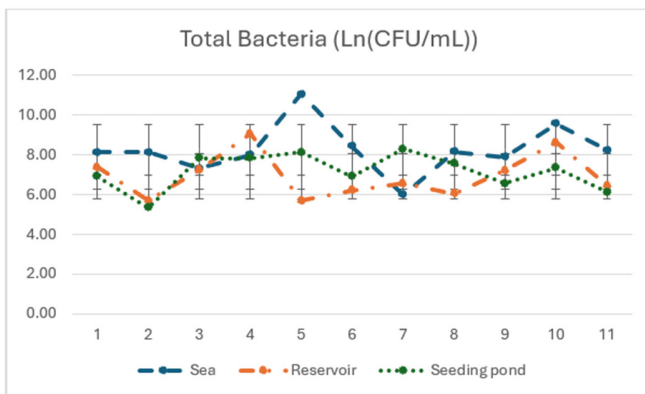


Fig. 6. Graph of bacterial spots in water.

1) Characteristics of Raw Water and Its Effect on Filter Effectiveness

The consistently low NH_3 concentration in the raw water, measured at 0.006 mg/L, explains why there was no significant reduction after sand filtration. Since the initial value was already very low, there was little potential for measurable improvement. Although ammonia is toxic at high concentrations, its low baseline in this study indicates limited risk to both aquatic life and surrounding ecosystems. Nevertheless, ongoing monitoring remains essential, as environmental and operational factors—such as feed residue or seasonal shifts—could raise ammonia levels and cause environmental damage if not managed. In contrast, TOC showed a moderate reduction of 20.99%, indicating the filter's partial effectiveness in removing organic contaminants. TOC plays a crucial role in water quality management, as high levels can lead to oxygen depletion, algal blooms, and ecological imbalance. The observed reduction in TOC suggests that sand filtration can lower organic loading in aquaculture ponds, helping to maintain healthier aquatic conditions and reduce the risk of pollution in nearby ecosystems like estuaries and mangrove zones. These findings highlight the environmental benefits of using sand filters as a sustainable and low-energy water treatment option. By improving water quality and reducing pollutant discharge, sand filters support responsible aquaculture practices and help protect local environments. Future research should focus on analysing specific organic compounds and evaluating filter performance under different environmental conditions to improve both treatment efficiency and ecological impact.

2) Design and Operation of Sand Filter

The effectiveness of sand filtration is governed by design and operating parameters, including media type, bed configuration, and flow rate. In this study, a multilayer filter comprising Glass Pearls, EcoPure, silica sand, and ZeoPlus was used to treat raw brackish water. This configuration demonstrated moderate efficiency in reducing suspended solids, TOC, and bacteria levels, leading to better water quality suitable for aquaculture. However, the system had a limited ability to remove ammonia, and there was a slight increase in nitrite levels after filtration. This finding raises environmental concerns because higher nitrite levels can be harmful to aquatic

life and may indicate incomplete nitrification or biofilm-driven conversion processes within the filter.

While advanced mechanical systems like PMRF have demonstrated high filtration efficiency through controlled operational parameters such as sand dosage and flow rate, these systems are fundamentally different from gravity-based sand filters. PMRFs depend on active rotation and precise dosing, whereas conventional sand filters operate passively and rely more on media characteristics and microbial activity. Therefore, optimization strategies should be tailored to the specific context. In passive sand filters, factors like media grain size, development of the biological layer, and hydraulic retention time are more critical for removing pollutants, especially nitrogen compounds.

From an environmental management perspective, enhancing the efficiency of sand filters in removing nitrogen species—especially NO_2 and NH_3 —is essential for maintaining water quality in aquaculture systems and reducing nutrient runoff into nearby ecosystems [30, 31]. Excess nitrogen can lead to eutrophication, disrupt ecological balance, and harm sensitive habitats like estuaries and mangroves. Future design improvements should aim to improve biological treatment capacity within the filter media, possibly by adding bioactive layers or supporting denitrifying microbial communities. Such innovations will bolster the ecological role of sand filters as both a water treatment method and a preventive measure against environmental degradation in coastal aquaculture environments.

3) The Nitrification Process and the Role of Microorganisms

One of the notable findings in this study was the increase in NO_2 concentrations after sand filtration, suggesting a possible disruption in the nitrification process. Nitrification involves the biological oxidation of NH_3 to nitrite by ammonia-oxidizing bacteria (AOB), followed by the conversion of nitrite to nitrate (NO_3^-) by nitrite-oxidizing bacteria (NOB). When this process is incomplete, nitrite can accumulate and pose risks to aquaculture species, especially in enclosed or semi-enclosed brackish water systems. High nitrite levels can impair fish respiration and water quality, threatening the sustainability of aquaculture operations and the surrounding aquatic environment. The presence of biofilms and benthic organisms, such as green mussels (*Perna viridis*) observed near the intake pipe, may have contributed to this imbalance. These organisms can change flow conditions and oxygen levels, indirectly influencing microbial community structure and the effectiveness of biological filtration within the sand filter. Such environmental interactions highlight the importance of understanding the complex ecology within filtration systems and their potential to either promote or hinder complete nitrogen cycling. In this case, the biofouling observed may have encouraged partial nitrification by favouring AOB activity over NOB, leading to nitrite buildup.

From an environmental management perspective, the findings emphasize the importance of monitoring biological activity within treatment systems to ensure effective nutrient transformations [32]. Incomplete nitrification not only lowers treatment efficiency but also raises the risk of nitrogen

pollution in nearby water bodies if effluents are discharged untreated. Future studies should consider adding microbial assessments to understand the ecological balance within filters better and develop strategies—such as oxygenation control or biofilm management—to support complete nitrification and minimize nitrogen-related environmental impacts in aquaculture systems.

4) The Role of Organisms in the Sand Filter

The ecological dynamics within sand filtration systems greatly influence water treatment performance and have wider implications for environmental sustainability. In natural and engineered systems like SSFs, microbial communities—including fungi—play a key role in breaking down organic matter and aiding pollutant decomposition [33, 34]. Although this study did not directly measure fungal populations, prior research has identified dominant fungal taxa such as *Rozellomycota* in deeper sand layers, which help decompose complex organic compounds and possibly assist in removing micropollutants. This microbial activity is crucial not only for improving water quality but also for reducing the release of untreated pollutants into surrounding ecosystems.

The observed moderate reduction in TOC and bacterial counts in this study indicates that microbial interactions, including those involving fungi, may have supported the biological purification processes within the sand filter [35, 36]. Although specific microbial groups were not isolated or identified, their environmental role remains significant. A diverse and active microbial community helps reduce pollutant levels, which in turn lowers the risk of oxygen depletion and eutrophication in nearby brackish water bodies. This highlights the importance of maintaining microbial balance in filtration systems to support both aquaculture sustainability and downstream ecological health.



Fig. 7. The mouth of the sand filter is covered by green shells.

Additionally, the proliferation of green mussels (*Perna viridis*) around the intake system adds another ecological factor. These organisms can block flow, change hydraulics, and introduce organic residues, all of which may affect filter performance. Their presence emphasizes the importance of

ecological monitoring and preventive maintenance in filtration systems. Managing biofouling and reducing organism interference are crucial for maintaining treatment effectiveness and lowering environmental risks. Future designs should include biological exclusion methods or pre-filtration systems to improve environmental control and long-term efficiency.

5) Comparison with Previous Research

Numerous studies have evaluated sand filters for their effectiveness in reducing turbidity and suspended solids in various water treatment settings. In domestic wastewater treatment, sand filters have been shown to reduce Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) through mechanical filtration and microbial degradation mechanisms [23, 28, 37]. However, research has mainly focused on household or agricultural water treatment and often overlooks the challenges posed by brackish aquaculture effluents, which are high in salinity and organic loads. This study addresses this gap by examining sand filter performance under complex environmental conditions typical of aquaculture settings, where untreated discharges can cause eutrophication, sediment oxygen depletion, and harm nearby coastal ecosystems.

Studies on PMRF highlight how operational factors like flow rate and sand concentration greatly affect filtration efficiency [38-40]. For instance, an efficiency of 84.01% was achieved under optimal PMRF conditions with low hydraulic head loss. However, the gravity-based sand filter system used in this study responded differently, showing no improvement in efficiency at higher flow rates. This difference emphasizes the need for filter-specific design adjustments, especially when treating saline, organic-rich effluents that interact closely with sensitive aquatic ecosystems. Additionally, the biological contributions of fungi in SSFs demonstrate that stratified fungal communities can influence organic matter decomposition [41, 42]. These ecological interactions are vital for understanding filtration beyond just its mechanical function, especially in reducing environmental pollutants that cause ecosystem stress. In this study, a post-filtration rise in nitrite levels was observed, likely due to incomplete nitrification or biological activity near the intake system. This observation raises new environmental concerns, as nitrite accumulation in discharged water could harm estuarine biodiversity. By identifying these dynamics, the study offers new insights to the scientific community and emphasizes the importance of environmentally conscious filtration strategies that support both ecosystem health and aquaculture productivity.

V. CONCLUSION

This study confirms that sand filters can effectively reduce Total Organic Carbon (TOC) and total bacterial counts in raw water used in brackish water aquaculture. A decrease of 20.99% in TOC and 13.18% in bacterial levels was observed after filtration, aligning with previous findings on the effectiveness of sand filters in removing suspended particles and organic contaminants. These results support using sand filtration as a basic treatment step to improve water clarity and lower microbial loads. However, the filter system was found to be ineffective at reducing ammonia (NH_3) levels and instead

caused an increase in nitrite (NO₂) levels—an outcome that could endanger aquatic life. This may result from the low initial ammonia levels, the composition of the filter media, and incomplete nitrification processes. The accumulation of nitrites suggests that the biological processes within the filter, possibly influenced by microbial activity and organisms at the intake, require closer examination.

To improve performance, future studies should explore alternative filter media that more effectively target ammonia and nitrite, while also investigating microbial dynamics, including the potential role of fungi. Additionally, filter designs must be tailored to the specific characteristics of the raw water and operational goals. This study emphasizes the need for optimization and integration with other treatment systems to ensure safe and sustainable aquaculture water quality.

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