Proceeding of 4th Pontianak International Health Conference
ISSN : XXXX-XXXX, Volume 01, Edisi 01, Pages 6-10

Combination of Upflow Aeration and Filtration for Reducing Iron (Fe) and Manganese (Mn) Levels in Shallow Groundwater

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Abstract: Water quality is essential for human health and ecosystem sustainability. Groundwater often contains elevated levels of iron (Fe) and manganese (Mn), leading to aesthetic and health concerns. This study investigates the efficacy of combining upflow aeration and filtration techniques to mitigate Fe and Mn concentrations in shallow groundwater. Conducted as a quasi-experimental Time Series Design, the research focused on shallow groundwater in Kantor Village, Delta Pawan District, Ketapang Regency. The treatment involves a combination of aeration and filtration using shell sand, zeolite, activated carbon, and various filtration media. The results showed a substantial reduction in Fe and Mn levels in across all treatments, particularly notable with the aeration and multi-media filtration combination (shell sand, zeolite, and activated carbon). The average reduction in Fe levels was 90.11%, and for Mn, it was 83.17%. These findings highlight the potential of this approach in enhancing water quality for human consumption and environmental sustainability.

Keywords: iron; manganese; aeration; filtration; shell sand; zeolite; activated carbon; groundwater

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A. Introduction

Water is an essential necessity for human life and ecosystems. To ensure the survival of humans and other living beings, it is crucial to protect water resources (Ali et al., 2013). The quality of water used for human consumption must meet established health standards (Zuhri, 2009). The existence of quality standards for water is essential given the vital role of water in human life (Hapsari, 2015).

Minister of Health Regulation No. 2 of 2023 regarding Clean Water Quality Requirements regulates various water sources including wells, which are still used by rural communities for daily needs (Hapsari, 2015). Wells are the main source of water for rural communities, typically with depths ranging from 2 to 10 meters and constructed using simple tools such as shovels and hoes (Sapulete, 2010).

In areas where clean water services are unavailable, communities often rely on well water, which frequently fails to meet healthy clean water standards. In areas where groundwater or surface water quality is inadequate, inhabitants may depend solely on rainwater to fulfill their need for clean water. The difficulty in meeting clean water needs leads to more complex issues, such as public health problems due to the spread of various diseases like typhoid fever and skin diseases, serving as indicators of poor environmental quality and the challenge in meeting clean water needs. The quality of well or shallow groundwater differs from surface water quality. Groundwater is generally clear but often contains high levels of minerals or salts, due to the influence of underground rocks. The quality and quantity of shallow groundwater are influenced by surface environmental conditions, with quantity heavily affected by local recharge areas and quality influenced by surrounding sanitation conditions. Groundwater often contains significant amounts of iron (Fe) and manganese (Mn) (Trigunarso et al., 2019).

The presence of Fe and Mn in water causes it to turn yellowish-brown upon contact with air, posing technical and physical challenges. Excessive Fe intake, as the body cannot secrete Fe, leads to accumulation and darkening of the skin in those receiving frequent blood transfusions. Drinking water containing iron tends to induce nausea and, in large doses, can damage the intestinal walls, often resulting in death. Fe levels exceeding 1 mg/L cause eye and skin irritation. High Mn levels (>0.5 mg/l) in drinking water are neurotoxic, manifesting as nervous system symptoms, insomnia, weakness in the legs and facial muscles, freezing of facial expressions, and the appearance of a mask-like face (Slamet, 2007). Other changes also cause unpleasant odors, yellowing of basin walls, and yellow stains on clothing (Widayat, 2018). Minister of Health of the Republic of Indonesia No. 2 of 2023 sets the maximum allowable limit for iron (Fe) (dissolved) for hygiene sanitation purposes at 0.2 mg/L, while manganese (Mn) (dissolved) is set at a maximum of 0.1 mg/L.

To treat poor-quality shallow groundwater into clean water that meets standards, communities typically build sand filtration units. Sand filters commonly used by communities operate on a gravity system, where water flows downwards based on gravitational force. In terms of quality, gravity sand filtration can produce treated water that meets clean water quality standards. However, the common issue encountered, preventing sand filters from operating continuously, lies in maintenance (Trigunarso et al., 2019).

A common maintenance issue arises when sand filters reach saturation after prolonged operation, necessitating cleaning. Cleaning usually involves removing the top layer of sand media for washing and then returning it to its original position. This condition is often challenging for communities due to time, energy, and resources that could be used for more productive activities. To address this issue, enhancing the filter's value involves not only operational and maintenance aspects but also aesthetic value. Thus, the filter can operate continuously without burdening users. One alternative solution is to improve the design of water treatment units with a combination of aeration and upflow filtration systems. With a bottom-up flow direction, backwash cleaning can be performed, facilitating maintenance. Consequently, water treatment tools for groundwater/wells must be easy to operate and produce treated water that meets clean water quality standards (Trigunarso et al., 2019).

Previous studies have shown that aeration and filtration combinations can reduce iron (Fe) levels by 24.97% with a bound T-Test significance value of 0.005 and manganese (Mn) by 26.07% with a bound T-Test significance value of 0.010 (Aini et al., 2022). This study aims to develop a three-tube filter medium made of PVC pipes comprising sand, zeolite, and activated carbon filters, containing MnO_2 media to oxidize raw water with oxygen as the oxidizer, also serving as an ion exchange and adsorbent medium capable of absorbing Fe metal compounds.

Based on preliminary surveys in Neighborhood Association 019, Community Unit 005 Kantor Village, Delta Pawan District, Ketapang Regency, identified problems regarding changes in the condition of shallow groundwater at the research site. Initially clear, the water turns yellowish and turbid after a few hours of storage, with an oily layer forming on the water surface. Therefore, this study is necessary as an effort to improve raw water quality in areas reliant on shallow groundwater wells as the main source of clean water.

B. Materials and Methods

This research employs a quasi-experimental approach utilizing a Time Series Design, adopting a pre-test and post-test design without control. The tool utilized is a prototype designed applicatively to reduce the levels of Fe and Mn. The study location is situated at Pak Nibung II Street, Neighborhood Association 019, Community Unit 005, Kantor Village, Delta Pawan District, Ketapang Regency. The examination process is conducted at the local health laboratory of Ketapang Regency during July-August 2023.

The research object is the shallow groundwater in Kantor Village, Delta Pawan District, Ketapang Regency. The samples used are shallow groundwater from Neighborhood Association 019, Community Unit 005, Kantor Village, Delta Pawan District, Ketapang Regency, collected through grab sampling with five replicates with five repetitions of each treatment (aeration, combination of aeration with filtration of each media and combination of aeration with several filtration media).

This research involves several stages. Firstly, the collection of shallow groundwater samples is carried out to analyze the concentrations of Fe and Mn. Subsequently, the construction of the tool is done using PVC pipes with the assistance of tools and other materials. Once the tool is completed, the aeration and filtration process is conducted using the prepared tool along with the shallow groundwater samples. Finally, the concentrations of Fe and Mn are analyzed after the aeration and filtration process is completed.

The pre-test and post-test data were analyzed descriptively to calculate the average concentrations of Fe and Mn in mg/L, and then the average decrease in Fe and Mn concentrations was calculated in percent (%).

C. Result and Discussion

Construction of groundwater treatment equipment through aeration involves the use of PVC pipes measuring 30 cm in length and 4 inches in diameter. Subsequently, the pipes are perforated at the top with a diameter of ¾ inch to allow air entry, followed by the installation of two 4-inch diameter caps, each of which is punctured at the center with a ¾ inch diameter hole. Then, a tee pipe is inserted and connected between the air hole and the cap hole using a ¾ inch diameter PVC pipe, approximately 10 cm in length. Further, the lower part of the pipe is perforated along its length with a small drill bit. In the aeration flow, strong agitation or turbulence occurs, enhancing air transfer into the water. This vigorous turbulence can increase the air transfer coefficient compared to non-turbulent water reactions; the air bubbles formed will increase the water surface area for air contact (Aini, 2022). Following this, three 4-inch pipes with a length of 120 cm each are added, with the filtration media contained within a tube measuring 80 cm in height and lined with gravel, with a thickness of 10 cm both above and below the media, and 5 cm of fiber fill.

Pic 1. Aeration unit

Pic 2. Aeration unit (aerator and reservoir)

Pic 3. Upflow Unit with One Filtration Media

Pic 4. Upflow Unit with Three Filtration Media

The groundwater treatment equipment, employing a combination of aeration and upflow filtration, is utilized to reduce the levels of Fe and Mn, yielding outcomes as presented in Table 1, 2, 3 and Table 4.

Table 1. Reduction of Average Iron (Fe) Levels

Replication	Fe Level (mg/L)					
	Before Treatment	Aeration (A)	Aeration and Shell sand	Aeration and Zeolit	Aeration and Activated carbon	Combination Aeration and several filtration Media
1	4.6	4.04	1.60	3.90	3.57	0.58
2	4.73	4.13	1.61	3.95	3.71	0.54
3	5.89	5.24	1.94	4.84	4.59	0.56
4	4.84	4.29	1.55	4.02	3.82	0.53
5	5.04	4.44	1.63	4.14	3.89	0.25
Average	**5.02**	**4.43**	**1.67**	**4.17**	**3.92**	**0.49**

As evident in Table 1, the average level of Fe in raw water before treatment was 5.02 mg/L. This Fe level indicates a high value compared to the permissible standard stated in the Minister of Health Regulation No. 2 of 2023, which is 0.2 mg/L. After treatment, it is observed that the treatment involving a combination of aeration and filtration using three filtration media resulted in the lowest average Fe level, reducing it to 0.049 mg/L.

Table 2. Reduction of Average Manganese (Mn) Levels

Replication	Mn Level (mg/L)					
	Before Treatment	Aeration (A)	Shell sand	Zeolit	Activated carbon	Combination 3 filtration media
1	0.219	0.176	0.095	0.157	0.169	0.038
2	0.191	0.153	0.083	0.137	0.149	0.032
3	0.387	0.310	0.164	0.278	0.300	0.061
4	0.350	0.282	0.153	0.249	0.271	0.061
5	0.410	0,329	0.176	0.296	0.318	0.069
Average	**0.311**	**0.25**	**0.134**	**0.223**	**0.241**	**0.052**

Table 2 reveals that the mean concentration of Mn in untreated water was 0.311 mg/L. Following treatment, it was noted that employing a combination of aeration and filtration with three filtration media yielded the lowest average Mn concentration, reducing it to 0.052 mg/L.

Table 3. Percentage Reduction of Average Iron (Fe) Levels

Replication	Fe Level (%)				
	Aeration	Shell sand	Zeolit	Activated carbon	Combination 3 filtration media
1	12.17	65.21	15.22	22.39	87.39
2	12.68	65.96	16.49	21.56	88.58
3	11.04	67.06	17.83	22.07	90.49
4	11.36	67.97	16.94	21.07	89.05
5	11.90	67.65	17.86	22.81	95.04
Average	**11.83**	**66.77**	**16.87**	**21.97**	**90.11**

Based on the results in table 3, it is evident that the most significant reduction in Fe concentration occurred with the combination of Aeration and three filtration media, resulting in a decrease of 90.11%. The second most effective method was Aeration combined with shell sand filtration, which reduced Fe levels by 66.77%.

Table 4. Percentage Reduction of Average Manganese (Mn) Levels

Replication	Mn Level (%)				
	Aeration	Shell sand	Zeolit	Activated carbon	Combination 3 filtration media
1	19.63	56.62	28.31	22.83	82.64
2	19.89	56.54	28.27	21.98	83.24
3	19.90	57.62	28.16	22.48	84.24
4	19.42	56.28	28.85	22.57	82.57
5	19.76	57.07	27.80	22.43	83.17
Average	**19.72**	**56.83**	**28.28**	**22.46**	**83.17**

From Table 4, it is evident that the most significant reduction in Mn concentration occurred with the combination of Aeration and three filtration media, resulting in a decrease of 83.17%. The second most effective method was Aeration combined with shell sand filtration, which reduced Mn levels by 56.83%.

The measurements of Fe and Mn levels after treatment indicate fluctuating decreases, attributable to the presence of the shell sand media. The principle of shell sand operation is founded on physical filtration mechanisms, where water passes through layers of sand. As water flows through the shell sand media, solid particles dissolved in the water adhere to the surface of the sand grains. Additionally, physical filtration and adsorption mechanisms occur within the pore structure of the shell sand. During the filtration process, shell sand can trap solid particles such as mud, soil, organic matter, and suspended turbidity particles present in the water. This occurs because of the pore structure of the shell sand, which can filter these particles, thus retaining them within its pores. The shell sand layer also forms a filter cake layer, aiding in enhancing filtration efficiency by capturing finer particles. Shell sand is resistant to degradation by chemicals that may be present in the water requiring clarification, making it a durable and effective filtering material. Shell sand treatment results in an average reduction of 66.77% in Fe levels, while combination treatment shows a greater reduction of 90.11%, as illustrated in Table 3. Similarly, Mn levels demonstrate an average reduction of 56.83% with shell sand treatment and 83.17% with combination treatment, as depicted in Table 4. Past research employing aeration and filtration combinations has shown an average Fe reduction of 85.4% (Rasman & Saleh, 2016).

The decrease happens as a result of the shell sand media, as its pore structure enables the filtration of solid particles dissolved in water, which then adhere to the sand grains' surface. Throughout the filtration process, shell sand can capture solid particles like mud, soil, organic materials, and dissolved turbidity particles in the water. The utilization of three filtration media yielded superior results due to the synergistic combination of each filtration medium, facilitated by the upflow configuration aimed at simplifying the filtration media cleaning process through backwashing.

D. Conclusion

Based on the results of the research, there was a decrease in the levels of Fe and Mn in shallow groundwater after treatment using a combination of aeration and filtration, whether employing a single filtration medium or three filtration media arranged in an upflow configuration. Communities grappling with elevated Fe and Mn levels in their water sources can adopt the upflow aeration and filtration combination, particularly with shell sand as the filtration medium, to tackle these water quality challenges. This approach offers a slightly superior alternative compared to other filtration media. Moreover, the simplicity and cost-effectiveness of the tools and materials used make this design highly suitable for widespread community implementation.

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