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Research Paper

Assessment of Groundwater Quality and Proposed Treatment using Aeration-Filtration Methods for Iron-Rich Groundwater at UPN "Veteran" Yogyakarta

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Abstract

Groundwater quality often does not meet the standards as a result of geological factors and human activities. This study was conducted at the University of Pembangunan Nasional "Veteran" Yogyakarta (UPNVY), Condongcatur Campus, to evaluate groundwater quality and provide appropriate treatment recommendations. Groundwater samples were taken from three bore wells: Rectorate Building (SR), Nyi Ageng Serang Lecture Hall (SNAS), and Prof. Bambang Soeroto Lecture Hall (SAL). Sampling followed SNI 6989.57:2008, while laboratory tests were performed on physical parameters (turbidity and TDS) and chemical parameters (pH and Fe). The results showed that turbidity, pH, and iron concentration at most sampling did not meet the quality standards. Water turbidity reached 39.89 NTU at the SAL, far above the threshold of <3 NTU. Iron content was recorded at 5.85 mg/L in the SNAS, exceeding the 0.2 mg/L standard. The pH values at all three sites were also below the standard, ranging from 6.1 to 6.4, indicating acidic conditions. Geological analysis indicated that the high Fe content is associated with the weathering of volcanic minerals such as augite, hornblende, and biotite, which are abundant in Merapi Muda deposits. As a follow-up, a proposed water treatment system was designed using a multitray aeration and filtration combination with shell sand media. This method is expected to be effective in reducing iron concentration by up to 99.9%, decrease turbidity by more than 90%, and raise pH to a more neutral level. In the treatment scenario for SAL, Fe concentration decreased from 2.74 mg/L to 0.002 mg/L.

Keywords: *Groundwater, Water quality, Iron content (Fe), Aeration–filtration, Multitray Aeration*

INTRODUCTION

Groundwater is water stored within aquifer layers, layers of rock beneath the earth surface that can capture, store, and transmit water through its pores. The estimated volume of groundwater on Earth reaches 1.69% or about 23,400 km^3 (Darwis, 2018). Although about 70% of the Earth surface is covered by water, only 1% is fit for human consumption, with 99% of that portion coming from groundwater. This makes groundwater the primary source for meeting water needs to this day (Amanambu et al., 2020). Usable water must comply with proper physical, chemical, and biological quality standards. To assess clean water quality, established benchmarks are applied, and in this study, the reference is the Regulation of the Minister of the Republic of Indonesia No. 2 of 2023.

The University of Pembangunan Nasional "Veteran" Yogyakarta, particularly at Condongcatur Campus, is one example of an educational facility that depends on groundwater as its primary source of clean water. However, previous studies revealed that the groundwater in this area does not fully comply with quality standards. The parameters that failed to meet the standards include turbidity, color, and iron (Fe) (Wisaksono et al., 2020). These issues lead to various

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problems, including reduced aesthetic quality, limitation in water usability for sanitation purposes, and potential damage to pipelines or equipment from rust buildup. Therefore, this study aims to further analyze groundwater quality and propose suitable water treatment strategies.

LITERATURE REVIEW

Groundwater, typically stored in aquifer layers within subsurface rock formations, is the main source of water used by humans to meet daily needs. Clean water, as defined by the Regulation of the Minister of Health of the Republic of Indonesia No. 416/Menkes/PER/IX/1990, is water used for daily activities that meets health standards and is safe for drinking once boiled. These standards are further reinforced in the Regulation of the Minister of Health No. 2 of 2023, which implements Government Regulation No. 66 of 2014 on Environmental Health. According to this regulation, clean water must comply with essential and additional parameters covering physical, biological, chemical, and radiological aspects.

The geological conditions and the surrounding environment of the groundwater are key natural factors shaping groundwater quality (Cahyadi et al., 2023). This relationship can be examined through landforms and rock characteristics, as the mineral and chemical composition of rocks directly affects ion and metal content in groundwater. As a result, metals such as iron (Fe) and manganese (Mn) are commonly present in significant concentrations. When exposed to air, groundwater containing Fe and Mn develops a yellowish-brown color, often producing unpleasant odors and leaving yellow stains on basin walls, in addition to posing potential health risks (Al Kholif et al., 2024).

An effective approach to reducing iron in groundwater is the aeration–filtration method. This treatment process not only removes iron but also improves turbidity levels and increases pH. Aeration–filtration has been shown to reduce iron concentrations by up to 99.9%, decrease turbidity by 92.062%, and raise pH by 2.17 units (Kasri et al., 2024). The process typically involves spray aeration, followed by multi-tray aeration, and ends with filtration using shell sand media. Research indicates that this method offers strong potential for producing clean water. However, despite its proven effectiveness in minimizing iron content, it requires careful operation and regular maintenance of the treatment system.

RESEARCH METHOD

Groundwater Sampling

This research was conducted at Universitas Pembangunan Nasional "Veteran" Yogyakarta, at Condongcatur Campus. Groundwater samples were collected from three borehole wells considered representative of the groundwater conditions in the campus area, namely the wells at the Rectorate Building (SR), the Prof. Bambang Soeroto Lecture Building (AL-D) (SAL), and the Nyi Ageng Serang Lecture Building (NAS-D) (SNAS). The groundwater sampling procedure followed the Indonesian National Standard (SNI) 6989.57:2008.

Groundwater Quality Analysis

The groundwater quality analysis in this study was carried out by testing several parameters to determine the actual condition of the groundwater. The parameters tested included physical parameters (turbidity and Total Dissolved Solids/TDS) and chemical parameters (pH and iron/Fe). The tools and methods used for laboratory testing are presented in Table 1.

Determination of Proposed Water Treatment

The management guidelines for groundwater quality were established specifically for the Prof. Bambang Soeroto Lecture Building (AL-D) (SAL). The test results showed that several parameters did not meet the quality standards. Therefore, appropriate management strategies are needed to ensure these parameters comply with the required standards. In this study, management guidelines were formulated based on relevant literature and applied through the design of a clean water treatment system using the aeration–filtration method. The process consists of spray aeration, followed by multiple-tray aeration, and finalized with filtration using shell sand media. A technical analysis was then carried out to assess removal effectiveness and plan the treatment technology design. This stage of determining management guidelines also included calculating projected clean water demand as the basis for determining the appropriate design capacity.

Table 1. Groundwater quality testing equipment

No	Parameter	Testing Equipment	Testing Method
		Physical	
1	Turbidity	Turbidity Meter Lutron TU-2016	SNI 06-6989.2-2004
2	*Total Dissolved Solid* (TDS)	TDS & EC Meter (Hold)	SNI 06-6989.11-2004
		Chemical	
1	pH	pH Meter Hanna Instrument HI98107	SNI 06-6989.4-2004
2	Iron (Fe)	Spektrofotometer UV-VIS Faithful Series 721	SNI 06-6989.13-2004

Source: Author's Analysis, 2025

FINDINGS AND DISCUSSION

Groundwater Quality

The results of laboratory analysis of groundwater quality parameters can be seen in Table 2.

Table 2. Groundwater Quality Test Results

No	Parameter	Quality Standard	Unit	Test Results		
				SR	**SNAS**	**SAL**
			Physical			
1	Turbidity	< 3	NTU	2,68	9,57	39,89
2	*Total Dissolved Solid* (TDS)	< 300	mg/L	292	258	202
			Chemical			
1	pH	6,5 – 8,5	-	6,4	6,3	6,1
2	Iron (Fe)	0,2	mg/L	2,58	5,85	2,74

Source: Laboratory Test, 2025
Quality Standard: Regulation of the Minister of Health of the Republic of Indonesia No. 2 of 2023
Notes:
SR = Rectorate Building Borehole
SNAS = Nyi Ageng Serang Lecture Building Borehole (NAS–D)
SAL = Prof. Bambang Soeroto Lecture Building Borehole (AL–D)

Based on the laboratory test results of several groundwater quality parameters, it is evident that the current condition falls significantly short of the established standards. This shows that the groundwater has not yet met the requirements for clean water suitable for hygiene and sanitation purposes.

Turbidity

Turbidity is an optical phenomenon of a solution determined by the amount of light absorbed and scattered by substances present in the water. Dissolved organic and inorganic particles reduce water clarity (Astuti et al., 2024). Based on the test results, the SR sample had a turbidity value of 2.68 NTU, which is still below the maximum threshold but should be noted because it is approaching the permitted limit. The SNAS sample showed a turbidity value of 9.57 NTU, and the SAL sample was 39.89 NTU, both of which exceeded the maximum threshold. The graph of turbidity test results is shown in Figure 1. It is shown that the groundwater quality at the SNAS and SAL sampling points does not meet clean water standards due to the high levels of dissolved organic and inorganic particles. High turbidity values also lower the aesthetic quality of water, as it appears cloudy and unsuitable for use.

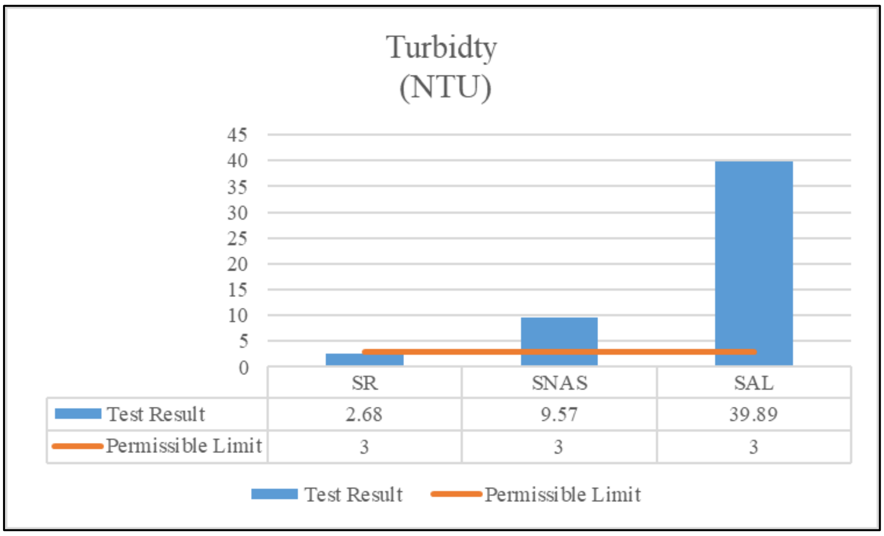


Figure 1. Groundwater Quality Test Results – Turbidity Parameter
Source: Author's Analysis, 2025

Total Dissolved Solid (TDS)

Total Dissolved Solids (TDS) represent the total amount of dissolved solids, including organic ions, compounds, and colloids, present in water (Zamora et al., 2016). Based on the test results, the TDS value in the SR sample was 292 mg/L, which is still below the maximum threshold but should be noted as it is approaching the permitted limit. The SNAS sample showed a TDS value of 258 mg/L, and the SAL sample 202 mg/L, both of which exceeded the maximum threshold. The graph of TDS test results is shown in Figure 2. The concentration of dissolved solids at all sampling points is relatively safe and still in accordance with the applicable standards.

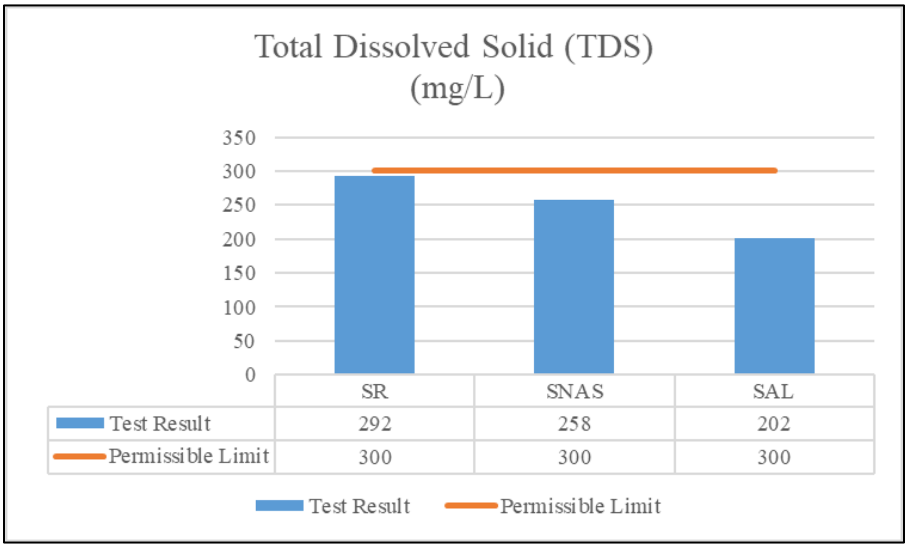
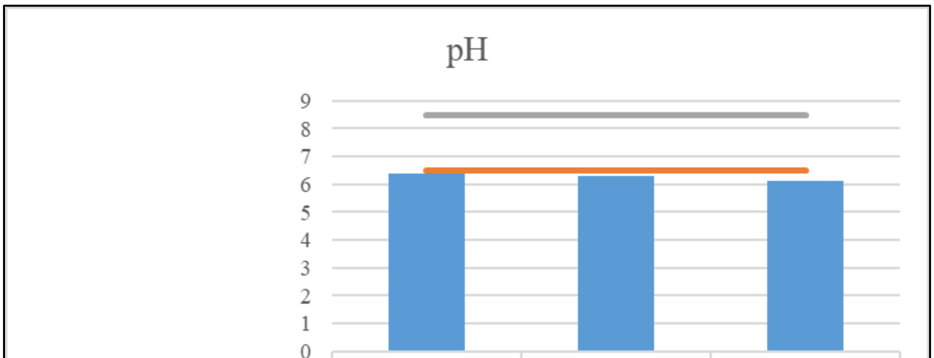


Figure 2. Groundwater Quality Test Results – Total Dissolved Solids (TDS) Parameter

Source: Author's Analysis, 2025

pH

The acidity level (pH) of water is the result of measuring hydrogen ion (H^+) concentration in water. Water with a high concentration of H^+ ions tends to be acidic, while water with a low concentration of H^+ ions tends to be alkaline(Hendrajat, 2018 in Aning Saputri et al., 2020). Based on the test results, the pH value of the SR sample was 6.4, the SNAS sample 6.3, and the SAL sample 6.1. All of these values are below the specified threshold range. The graph of pH test results can be seen in Figure 3. The water at all three sampling points is slightly acidic, meaning it does not meet clean water quality standards. Acidic water may cause corrosion in distribution pipes and metal equipment, reducing physical quality and lifespan. Conversely, water that is too alkaline may cause a bitter taste, leave deposits on surfaces, and reduce the effectiveness of soap and detergents.



	SR	SNAS	SAL
Result Test	6.4	6.3	6.1
Min Permissible Limit	6.5	6.5	6.5
Max Permissible Limit	8.5	8.5	8.5

Figure 3. Groundwater Quality Test Results – pH Parameter
Source: Author's Analysis, 2025

Iron (Fe)

Iron (Fe) is a naturally occurring element that is widely distributed across the Earth, present in various geological layers and water sources. In water, it is typically found in dissolved form, and its concentration is greatly influenced by soil structure (Arrizal et al., 2021). Test results showed Fe levels of 2.58 mg/L in the SR sample, 5.85 mg/L in the SNAS sample, and 2.74 mg/L in the SAL sample. All of these measurements exceeded the permissible limit. The Fe parameter test results are illustrated in Figure 4. The figure indicates that groundwater from all three sampling locations fails to meet clean water quality standards due to elevated iron concentrations. Excessive Fe levels can alter the water's color, taste, and odor, while also leaving residue on equipment.

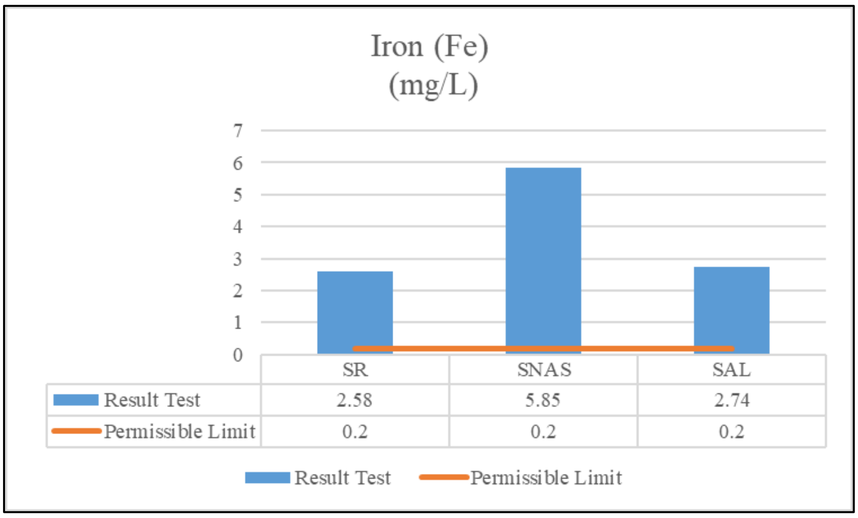


Figure 4. Groundwater Quality Test Results – Iron (Fe) Parameter
Source: Author's Analysis, 2025

Proposed Water Treatment Method

The case study for estimating the effectivity of the proposed method is taken at SAL groundwater. The building is assumed to accommodate 640 people, consisting of 600 students and 40 lecturers and staff. According to Noerbambang & Morimura (2005) in the daily water requirement per person in a building is 50 liters/person/day. Therefore, the total clean water requirement for the AL-D building is 32,000 liters/day, equivalent to 0.00037 m^3/second.

The groundwater quality parameters that do not meet the standard are turbidity (39.89 NTU), pH (6.1), and iron (Fe) content (2.74 mg/L). Meanwhile, the parameter that meets the standard is Total Dissolved Solids (TDS) with a value of 202 mg/L. The detailed test results are presented in Table 3 below.

Table 3. Groundwater Quality Testing Equipment in Prof. Bambang Soeroto Lecture Building (AL-D)

No	Parameter	Quality Standard	Test Results	Unit	Notes
			Physical		
1	Turbidity	< 3	39,89	NTU	Does not meet qualification
2	*Total Dissolved Solid* (TDS)	< 300	202	mg/L	Meets qualification
			Chemical		
1	pH	6,5 – 8,5	6,1	-	Does not meet qualification
2	Iron (Fe)	0,2	2,74	mg/L	Does not meet qualification

Source: Author, 2025

Groundwater quality parameters that do not meet the quality standards must be treated before being used as a source of clean water. According to Kasri et al. (2024), one effective treatment method is the combination of aeration and filtration. Aeration is the process of transferring oxygen into water with the aim of oxidizing iron (Fe) so that it transforms into a solid form (Manurung & Ivansyah, 2017). Meanwhile, filtration is the process of separating solid particles from fluids by passing the fluid through a filter medium (Manurung & Ivansyah, 2017). The combination of aeration–filtration has been proven effective in reducing iron content, increasing pH, and decreasing water turbidity. In this study, the aeration methods used were spray aeration and multiple tray aeration, while filtration was carried out using seashell sand as the filter medium.

The filtration method utilizes seashell sand as the filter medium. According to Kasri et al. (2024), seashell sand contains $CaCO_3$, which reacts with water to form calcium hydroxide, a basic compound. The reaction of $CaCO_3$ solution in water can be described as follows:

$$CaCO_{3\,(s)} + H_2O_{(l)} \rightarrow Ca(OH)_{2\,(aq)} + H_2O_{(l)} + CO_{2\,(g)} \ldots (1)$$

$Ca(OH)_{2(aq)}$ undergoes a dissolution process, as shown in the following reaction:

$$Ca(OH)_{2(aq)} \leftrightharpoons Ca(OH)_{2(s)} \ldots (2)$$

In addition to dissolution, complete dissociation also occurs through the reaction below:

$$Ca(OH)_{2(aq)} \rightarrow Ca^{2+}{}_{(aq)} + 2OH^{-}{}_{(aq)} \ldots (3)$$

The combined dissolution and dissociation process can be summarized as follows:

$$Ca(OH)_{2(s)} \rightarrow Ca^{2+}{}_{(aq)} + 2OH^{-}{}_{(aq)} \ldots (4)$$

The formation of ionic solutions from $CaCO_3$ in water results in the following reaction:

$$CO_{2\,(g)} + H_2O_{(l)} \leftrightharpoons H_2CO_{3\,(aq)} \leftrightharpoons HCO_3^{-}{}_{(aq)} + H^{+}{}_{(aq)} \ldots (5)$$

$$Ca^{2+}{}_{(aq)} + 2HCO_3^{-}{}_{(aq)} \leftrightharpoons CaCO_{3\,(s)} + CO_{2(g)} + H_2O_{(l)} \ldots (6)$$

The dissolution of $CaCO_3$ produces $Ca(OH)_2$, which imparts alkaline properties that help raise the water's pH. This is essential because hydroxide ions from $Ca(OH)_2$ can neutralize excessively acidic water. When seashell sand is used as the filtration medium, ensuring uniform grain size is crucial. Consistent grain size controls the dissolution rate, minimizing the amount of seashell sand that dissolves into the water. This allows effective pH adjustment without introducing excessive minerals that could affect water quality.

According to Kasri et al. (2024), the aeration–filtration process begins with spray aeration, where small holes at the base produce fine water droplets. This step introduces oxygen into the water to oxidize dissolved ions such as Fe^{2+}. The water then moves to the multiple-tray aeration stage, which includes gravel at the base to improve aeration efficiency. The presence of gravel allows water to break into finer droplets, further optimizing oxygen transfer. Finally, the water passes through a filtration unit containing seashell sand, palm fiber, and gravel. The flowchart of this aeration–filtration process is shown in Figure 5.

The study by Kasri et al. (2024) showed that both aeration and aeration–filtration methods can improve water quality, albeit with different results. The aeration process alone reduced iron (Fe) content by 91.20% due to the oxidation of Fe^{2+} into Fe^{3+}, which then precipitated. However, turbidity increased by 241.655% because dissolved iron transformed into precipitate particles. For the pH parameter, an increase of 1.31 was observed, triggered by the release of CO_2 gas into the atmosphere, making the water more alkaline.

Meanwhile, the aeration–filtration combination proved more effective, as it reduced turbidity, lowered iron content, and increased pH simultaneously. This process decreased turbidity by 92.062% because the precipitate was trapped by the sand media, making the water clearer. Iron content dropped by up to 99.9% with the aid of shell sand, which enhanced the precipitation process. The pH value also rose by 2.17 due to the alkaline nature of $CaCO_3$ in the shell sand. The results of Kasri et al. (2024) are shown in Table 4.

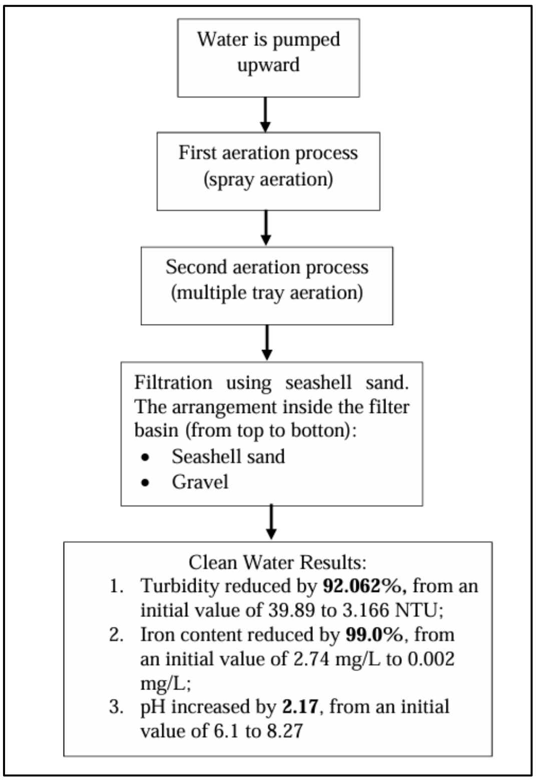


Figure 5. Aeration–Filtration Process Flow Diagram
Source: Author's Analysis, 2025

Table 4. Research Results

No	Parameter	Unit	Quality Standard	Raw Water	After Aeration	Decreased Efficiency (%)	After Aeration + Filtration	Decreased Efficiency (%)
1	Turbidity	NTU	< 3	147,4	503,6	-241,655	11,70	92,062
2	Iron (Fe)	mg/L	6,5-8,5	2,83	0,249	91,20	0,001	99,9
3	pH	-	0,2	5,63	6,76	-	7,8	-

Source: Kasri et al. (2024)

Groundwater treatment calculations at the SAL were carried out based on the efficiency of the aeration–filtration method reported by Kasri et al. (2024). The estimates indicate that this method is quite effective in reducing high iron content in groundwater. The results showed turbidity decreased from 39.89 NTU to 3.166 NTU. Iron content dropped from 2.74 mg/L to 0.002 mg/L. Nevertheless, the turbidity parameter still did not meet the applicable water quality standard. As an improvement effort, one suggestion is to add a thicker fiber layer in the filtration unit to better retain precipitates. The estimated results of groundwater treatment using this method are presented in Table 5.

Table 5. Estimated Groundwater Treatment Results for SAL Groundwater

No	Parameter	Unit	Quality Standard	Raw Water	After Aeration	After Aeration + Filtration
1	Turbidity	NTU	< 3	39,89	136,286	3,166
2	Iron (Fe)	mg/L	0,2	2,74	0,241	0,002
3	pH	-	6,5-8,5	6,1	7,4	8,27

Source: Author's Analysis, 2025

The design dimensions of the aeration–filtration technology can be determined based on design criteria, which help ensure appropriate sizing and requirements of the units. The reference design criteria used here are for aeration and filtration. The design criteria for both units are presented in the following table:

Table 6. Aeration–Filtration Design Criteria

Aeration (*Multiple Tray Aerasi*)				**Filtration (Rapid Sand Filter)**			
Design Criteria		**Sources**	**Proposed Design**	**Design Criteria**		**Sources**	**Proposed Design**
CO_2 Removal	>90%	(Qasim, 2000)	99%	Numbers of Filter Tanks	$N = 12\ Q^{0,5}$	SNI 6774 :2008	2
Air Requirement	7,5 m^3/m^3 air	(Qasim, 2000)	7,5 m^3/m^3 air	Filtration Rate	6-11 m/hour	SNI 6774 :2008	8 m/hour
Distance Between Trays	30-75 cm	(Qasim, 2000)	40 cm	Thickness of Sand Media	300-700 mm	SNI 6774 :2008	700 mm
	20-75 cm	(American Water Works Association (AWWA), 1990)		Thickness of Single Media	600-700 mm	SNI 6774 :2008	700 mm
Q	50-73 m^3/day	(American Water Works Association (AWWA), 1990)	50 m^3/day	Effective Size, ES	0,3-0,7 mm	SNI 6774 :2008	0,3 mm
Area	50-160 m^2/m^3 second	(Qasim, 2000)	50 m^2/m^3 second	Depth of Supporting Layer	80-100 mm	SNI 6774 :2008	100 mm
				Grain Size of Supporting Media	2-5 mm	SNI 6774 :2008	2 mm

Source: Compilation analysis, 2025

Based on the design criteria, the dimensions of each water treatment unit have been determined. The spray aeration system is designed with five pipes spaced 0.2 meters apart, using perforated-¾-inch PVC pipes. The multiple tray aeration unit is planned with a basin length of 1.15 meters and width of 1.15 meters. The system consists of four tray levels with vertical spacing of 0.4 meters, resulting in a total structure height of approximately 3.8 meters.

For the filtration unit, the designed discharge is set at 0.025 m^3/s, corresponding to the water demand in Building AL-D, a conventional rapid sand filter (gravity type) is applied. The design includes two filter basins, each measuring 3.4 × 1.7 meters, operating at filtration rate of 8 m/h. the filter media consists of seashell sand with a thickness of 70 cm and grain size of 0.3 mm, supported by a 10 cm of gravel layer with a grain size of 2 mm.

CONCLUSIONS

Groundwater with high iron content results from the interaction between water and iron-bearing rocks; therefore, it requires treatment before use. The aeration–filtration method is an effective approach, capable of reducing iron concentrations by up to 99.9% and turbidity by 92.06%**.** The proposed design consists of spray aeration system and multiple tray aeration units. The spray aeration system employs five ¾-inch PVC pipes spaced 0.2 meters apart, while the multiple tray aeration unit measures 1.15 × 1.15 meters, has a total height of 3.8 meters, and includes four tray levels. The filtration unit measures 3.4 × 1.7 meters and uses seashell sand as the filter medium. However, this method requires a large installation area, making it less suitable for Building AL-D, which has limited space. As an alternative, membrane technology can be applied, as it is more space-efficient and effectively removes iron**,** although it involves higher operational and maintenance costs.

LIMITATION & FURTHER RESEARCH

This study is limited to theoretical calculations based on Indonesian Standards (SNI) and findings from previous studies without laboratory or pilot-scale validation. Therefore, the actual efficiency of iron (Fe) removal using the designed multitray aeration system has not yet been verified. Further research should focus on experimental evaluation to determine oxidation efficiency in Iron removal, optimize design parameters such as number of trays and spacing, and compare the system's performance with other aeration methods to assess its practical applicability and cost-effectiveness in real groundwater treatment operations.

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