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The Effectiveness of Tray Aerator in Reducing Ferrum (Fe) Levels in Dug Well Water

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Abstract

Dug well water is still widely used by communities in areas not yet served by piped water networks, but it often contains Ferrum (Fe) levels exceeding the drinking-water quality standard, which can reduce water quality and cause health problems. A preliminary observation found an Ferrum concentration of 2.48 mg/L in dug well water, far exceeding the standard set by Regulation of the Minister of Health of the Republic of Indonesia No. 2 of 2023, namely 0.2 mg/L. One method used to reduce Ferrum levels is aeration using a tray aerator. This study aimed to determine the effectiveness of a tray aerator with hole-diameter variations of 1 mm, 2 mm, and 3 mm in reducing Ferrum (Fe) levels in dug well water. This study used a quasi-experimental design with a pretest-posttest equivalent material group design. The sample consisted of 30 L of dug well water, with 9 replications for each treatment. Data were collected through laboratory examination using the spectrophotometric method and analyzed using the Kruskal-Wallis test. The results showed a decrease in Ferrum (Fe) levels after treatment with the tray aerator at every hole-diameter variation: the 1 mm diameter reduced the concentration to 0.06 mg/L with a reduction effectiveness of 80.20%, the 2 mm diameter reduced it to 0.14 mg/L with an effectiveness of 55.12%, and the 3 mm diameter reduced it to 0.18 mg/L with an effectiveness of 40.92%. The statistical test showed an Asymptotic Significance value of 0.000 ($p < 0.05$), indicating a significant difference between Ferrum concentrations before and after treatment. It is concluded that the tray aerator is effective in reducing Ferrum (Fe) levels in dug well water, with the 1 mm hole diameter giving the best performance.

Keywords Tray aerator · Ferrum (Fe) · Dug well water · Aeration · Water treatment

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Introduction

Clean water is one of the essential means of improving human welfare and health (Poerwati et al. 2018; Poerwati et al. 2021). Groundwater accessed through dug wells is widely relied upon in areas not yet reached by piped water utilities, mainly because dug wells require relatively low construction cost. However, mineral content that exceeds the permitted maximum concentration can pose a risk of poisoning and disease (Koefisien et al. 2022).

Water supply remains a central issue in both urban and rural areas. Safe drinking water must satisfy physical parameters (dissolved solids, turbidity, color, taste, odor, and temperature), chemical parameters (ions, toxic compounds, dissolved oxygen, and chemical oxygen demand), biological parameters (microorganism content), and radioactive parameters. Ferrum (Fe) is an abundant metallic element, ranking second among the most commonly found metals and the most abundant heavy metal in the Earth's crust, comprising more than 85% of it; its concentration in groundwater varies considerably with depth (Gudam et al. 2024).

Ferrum content is an important parameter in determining dug well water quality. Although Ferrum is abundant and beneficial in many respects, it is prone to rusting under envFerrummental exposure to fresh water, seawater, lake water, river water, and groundwater. High Ferrum (Fe) concentrations in well water can be detrimental to public health, industrial machinery, agriculture, and municipal water use (Shintawatia 2025). Elevated Fe levels can turn water yellowish-brown after contact with air, leave an unpleasant odor, and stain clothing. Continuous consumption of water with high Ferrum content may also cause health problems; conversely, Ferrum in the human body supports red blood cell production, but excessive accumulation can lead to diarrhea, anemia, and skin and kidney damage (Ramayanti et al. 2022).

One method used to reduce Ferrum concentrations in well water is gas transfer, in which gas is transferred from one phase to another, typically from the gas phase to the liquid phase. Aeration is a specific form of gas transfer that targets oxygen transfer from air into water; its main function is to increase the dissolved-oxygen concentration so that the Ferrum (Fe) content decreases. Among common gas-transfer techniques, the multiple tray aerator has a simple, inexpensive configuration and requires a relatively small footprint (Koefisien et al. 2022; Adriano 2023; Endah et al. 2025).

According to Hidayah (2024), the effectiveness of Ferrum (Fe) removal is strongly influenced by the contact area between water and air. One important technical factor is the diameter of the holes in the tray aerator. A previous study using hole-diameter variations of 4 mm, 5 mm, and 6 mm found that a 4 mm hole diameter was the most efficient, and recommended that a smaller hole diameter increases the water-air contact area. Building on that recommendation, this study developed smaller hole-diameter variations of 1 mm, 2 mm, and 3 mm, aiming to increase the intensity of water-air contact and extend the water fall time, so that Ferrum (Fe) removal in dug well water becomes more effective (Fadhilah 2024; Fauziah et al. 2023).

Groundwater accessed through dug wells is commonly classified as shallow groundwater, generally found at depths of less than 40 m and characterized by an unconfined aquifer that is strongly influenced by surrounding envFerrummental conditions, in contrast to deeper, confined groundwater that is naturally filtered through rock and mineral layers and is therefore comparatively clearer (Bestari 2021). Clean-water quality itself is governed by physical, chemical, biological, and radioactive parameters, with Ferrum (Fe) regulated as one of the chemical parameters under Regulation of the Minister of Health of the Republic of Indonesia No. 2 of 2023, which sets a maximum permissible Fe concentration of 0.2 mg/L for clean water intended for hygiene and sanitation purposes (Pontororing et al. 2023). Beyond hole diameter, the efficiency of an aeration system is also shaped by physicochemical conditions such as pH, water temperature, and flow rate, all of which influence the rate of Fe2+ oxidation and the extent of dissolved-oxygen transfer during treatment (Prasidya et al. 2022). Studies describing Fe in well water and treatment approaches provide related context for this issue (Khoiriah and Mutholib 2021; Salisna et al. 2021; Sappewali et al. 2024).

The study is used by local residents to meet their daily clean-water needs. A preliminary survey indicated that the water was slightly turbid, with a metallic odor developing after contact with air, causing residents to be reluctant to use it; yellow-brown staining was also observed on storage tank walls and on laundered clothing. Laboratory analysis at the Trenggalek Regional Health Laboratory confirmed an Ferrum (Fe) concentration of 2.48 mg/L, well above the clean-water quality standard of 0.2 mg/L set by Regulation of the Minister of Health of the Republic of Indonesia No. 2 of 2023. Based on this condition and the recommendation of previous researchers, this study was conducted to assess the effectiveness of a tray aerator with hole-diameter variations of 1 mm, 2 mm, and 3 mm in reducing Ferrum (Fe) levels in dug well water in Trenggalek Regency.

Materials and methods

Study design and site

This study used a quasi-experimental design, in which the treatment (aeration using a tray aerator with hole-diameter variations of 1 mm, 2 mm, and 3 mm) was applied directly to the research object to determine its effectiveness in reducing Ferrum (Fe) levels in dug well water. The specific design applied was the equivalent material group, pretest-posttest design, in which the Ferrum (Fe) concentration of the water sample was measured before and after the aeration treatment.

Dug well water samples were collected from a well located in RT 20 RW 08, Suruh Village, Suruh District, Trenggalek Regency, East Java, Indonesia. The tray aerator experiment was conducted at the workshop of the Sanitation Study Program, Magetan Campus, and laboratory analyses were carried out at the chemistry laboratory of the same study program.

The aeration treatment and sample preparation were carried out at the workshop of the Sanitation Study Program (Diploma Three), Magetan Campus, while the laboratory analyses were performed at the chemistry laboratory of the Sanitation Study Program, Magetan Campus, and at the Trenggalek Regional Health Laboratory.

Tray aerator apparatus

The tray aerator used in this study consisted of stacked collection trays through which water was pumped upward and distributed via a distribution pipe, then allowed to fall downward through holes drilled in the base of each tray before being collected in a final holding tank for sampling. Three tray-aerator units were constructed with hole diameters of 1 mm, 2 mm, and 3 mm, respectively. Each tray had 6 holes spaced 5 cm apart, a drop distance of 20 cm from the distribution pipe to the tray, a tray height of 13 cm, a tray length of 36 cm, a tray width of 25 cm, and a 20 cm spacing between successive trays. Water flow rate was monitored using a flow meter, water temperature was measured with a thermometer, and pH was measured using litmus paper. The apparatus and the three tray-hole configurations are shown in Figs. 1–5.

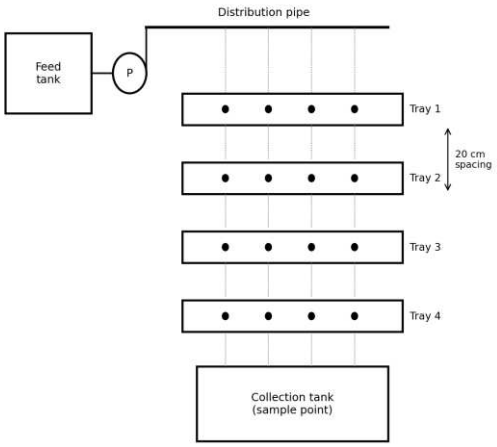

Fig. 1 Schematic configuration of the multiple tray aerator: water is pumped from the feed tank through a distribution pipe onto a stack of perforated trays, falls through the holes in successive stages, and is collected in a final tank for sampling



Fig. 2 Tray with 1 mm hole diameter



Fig. 3 Tray with 2 mm hole diameter



Fig. 4 Tray with 3 mm hole diameter



Fig. 5 Aeration process using the tray aerator

Sample size and replication

A total of 30 L of dug well water was used as the sample, with each individual sample requiring 600 mL. Because the study involved three treatments (1 mm, 2 mm, and 3 mm hole diameters), the number of replications was determined using the Federer (1963) formula:

$$(t - 1)(r - 1) \geq 15$$

where t is the number of treatments and r is the number of replications. With t = 3, solving the inequality gives $r \geq 8.5$, so 9 replications were used for each treatment.

Sampling procedure and data collection

Samples were collected using the grab sample technique, in which water was taken at a single point in time from one dug well, following the chemical clean-water sampling procedure of SNI 7828:2012. Clean 600 mL plastic sample bottles were used, rinsed 2–3 times with the sample water prior to collection, then filled completely and sealed before being labeled with the sampler's name, date, time, location, sample type, type of examination, and temperature, and sent to the laboratory for analysis. Primary data consisted of laboratory examination results and preliminary observations, while secondary data were obtained from relevant books and previous journal articles on tray-aerator effectiveness in reducing Ferrum (Fe) levels in water. Ferrum (Fe) concentration was measured using the spectrophotometric method.

Data analysis

Data were processed through editing, coding, recapitulation, and tabulation before analysis (Mahardika 2024). The reduction in Ferrum (Fe) concentration was calculated as the difference between the Ferrum concentration before and after treatment, while the percentage reduction was calculated using the following formula:

$$\% \text{ Reduction} = [(\text{Fe before treatment} - \text{Fe after treatment}) / \text{Fe before treatment}] \times 100\%$$

Data were analyzed descriptively (mean, minimum, and maximum values, and percentage reduction of Fe for each treatment) and inferentially. Prior to hypothesis testing, normality and homogeneity tests were performed. Because the data did not satisfy the assumptions of normality and homogeneity of variance ($p < 0.05$), the non-parametric Kruskal-Wallis test was used to determine whether a significant difference in Ferrum (Fe) concentration existed among the treatment groups ($\alpha = 0.05$), followed by a pairwise comparison test with Bonferroni correction to identify which treatment pairs differed significantly.

Results and discussion

Study area characteristics

The study in a hilly and mountainous area at an elevation of approximately 300–500 m above sea level. Most residents rely on shallow groundwater obtained through dug wells reaching an average depth of about 10 m, drawn from an area with relatively hard, rocky (padas) subsoil containing Ferrum-bearing minerals in parts of its geological layers. Under the generally low-oxygen conditions of the local groundwater, Ferrum predominantly occurs as soluble, colorless ferrous ion (Fe^{2+}); once pumped to the surface and exposed to air, Fe^{2+} is oxidized to ferric ion (Fe^{3+}), forming a yellowish-brown precipitate. This explains the turbidity, metallic odor, and brownish staining reported by residents on storage tanks, taps, and household utensils in contact with the well water for extended periods.

During the aeration treatments, the water temperature remained constant at 28 °C, the pH was 6, and the flow rate was 0.1 L/s across all treatments, so that these confounding variables were controlled and did not differ among treatment groups. Under these conditions, differences in Ferrum (Fe) removal among treatments can be attributed to the hole-diameter variation of the tray aerator rather than to differences in temperature, pH, or flow rate. This is consistent with Zahroh et al. (2024), who reported that a higher flow rate accelerates water flow and shortens the water-air contact time, reducing the efficiency of oxygen transfer during aeration.

Ferrum (Fe) concentration before treatment

Table 1 Ferrum (Fe) concentration in dug well water before treatment

Sample no.	Fe concentration (mg/L)
1	0.38
2	0.35
3	0.12
4	0.34
5	0.34
6	0.22
7	0.35
8	0.28
9	0.35
Mean	**0.30**

As shown in Table 1, laboratory examination of nine samples of dug well water prior to treatment showed an average Ferrum (Fe) concentration of 0.30 mg/L, which exceeds the clean-water quality standard, indicating that the well water required treatment before use.

Ferrum (Fe) concentration after treatment with 1 mm hole diameter

Table 2 Ferrum (Fe) concentration in dug well water after treatment using a 1 mm tray-hole diameter

Sample no.	Fe concentration (mg/L)
1	0.06
2	0.04
3	0.08
4	0.05
5	0.04
6	0.07
7	0.07
8	0.07
9	0.06
Mean	**0.06**

Table 2 presents the Fe concentrations after treatment with the 1 mm tray-hole diameter. After treatment with the 1 mm hole diameter, the average Ferrum (Fe) concentration decreased to 0.06 mg/L, a reduction of 0.24 mg/L (80.20%) compared with the pretreatment value of 0.30 mg/L, well below the 0.2 mg/L quality standard. The smaller hole diameter caused water to exit as finer droplets, increasing the water-air contact surface area and extending the contact time as the droplets fell between trays, which promoted more complete oxidation of Fe^{2+} to Fe^{3+}. All nine replicates showed relatively uniform Fe concentrations (0.037–0.077 mg/L), indicating that the aeration process was stable and consistent across repetitions. These findings are consistent with Namira and Hidayah (2025), who reported that smaller tray hole diameters produce finer water droplets, increase the contact area with oxygen, and achieve an Ferrum removal efficiency of more than 75%.

Ferrum (Fe) concentration after treatment with 2 mm hole diameter

Table 3 Ferrum (Fe) concentration in dug well water after treatment using a 2 mm tray-hole diameter

Sample no.	Fe concentration (mg/L)
1	0.11
2	0.14
3	0.15
4	0.17
5	0.14
6	0.15
7	0.12
8	0.09
9	0.17
Mean	**0.14**

As shown in Table 3, treatment with the 2 mm hole diameter reduced the average Ferrum (Fe) concentration to 0.14 mg/L, a reduction of 0.16 mg/L (55.12%), which still met the quality standard but was less effective than the 1 mm treatment. This was likely because the larger hole diameter produced a less finely divided water flow, reducing the water-air contact surface area and slowing the oxidation of Fe2+ to Fe3+, so that a larger fraction of Ferrum remained in dissolved form. Rosidah et al. (2025) similarly reported that aeration efficiency depends strongly on the system's ability to increase dissolved-oxygen levels, and that tray designs producing finer water spray achieve higher Ferrum-removal efficiency than those producing a relatively coarse, continuous stream. Zahroh et al. (2024) likewise noted that larger tray hole diameters reduce droplet formation and thus reduce oxygen transfer.

Ferrum (Fe) concentration after treatment with 3 mm hole diameter

Table 4 Ferrum (Fe) concentration in dug well water after treatment using a 3 mm tray-hole diameter

Sample no.	Fe concentration (mg/L)
1	0.20
2	0.15
3	0.23
4	0.17
5	0.15
6	0.19
7	0.18
8	0.17
9	0.19
Mean	**0.18**

Table 4 presents the Fe concentrations after treatment with the 3 mm tray-hole diameter. The 3 mm hole diameter reduced the average Ferrum (Fe) concentration to 0.18 mg/L, a reduction of 0.12 mg/L (40.92%), the lowest reduction percentage among the three treatments, although the resulting concentration still met the 0.2 mg/L quality standard. The lower effectiveness of this treatment is likely attributable to a faster, larger water flow that shortened the water-air contact time and produced less spray, limiting oxygen transfer into the water. According to Abdillah et al. (2026), aeration performance depends on oxygen-transfer efficiency, which in turn is determined by flow characteristics, contact surface area, and turbulence; lower oxygen transfer slows the oxidation of dissolved Ferrum and reduces removal efficiency. This is consistent with Rosidah et al. (2025), who described aeration as a mass-transfer process in which a shorter contact time and smaller contact area reduce the formation of insoluble ferric hydroxide (Fe(OH)3).

Effectiveness of Ferrum (Fe) reduction across hole-diameter variations

Table 5 Summary of Ferrum (Fe) reduction in dug well water before and after aeration treatment

No.	Tray hole diameter	Fe before (mg/L)	Fe after (mg/L)	Mean reduction (mg/L)	Reduction (%)
1	1 mm	0.30	0.06	0.24	80.20
2	2 mm	0.30	0.14	0.16	55.12
3	**3 mm**	**0.30**	**0.18**	**0.12**	**40.92**

The comparative reductions are summarized in Table 5. The recapitulation shows that all three hole-diameter treatments reduced Ferrum (Fe) concentrations, with reduction percentages of 80.20%, 55.12%, and 40.92% for the 1 mm, 2 mm, and 3 mm hole diameters, respectively — a clear trend in which a smaller tray hole diameter produces a greater reduction in Ferrum (Fe). According to Abdillah et al. (2026), Ferrum-removal efficiency through aeration is governed by the system's capacity to increase dissolved oxygen, which depends on flow characteristics, contact surface area, and turbulence generated during aeration. Smaller holes distribute the water into finer droplets, increasing the water-air contact area and promoting more effective oxygen diffusion and Ferrum oxidation, whereas larger holes produce a more coalesced flow with more limited air contact. Notably, all three treatments produced final Ferrum concentrations below the 0.2 mg/L quality standard, confirming that the tray aerator is a simple yet effective method for improving the quality of Ferrum-rich dug well water.

Statistical analysis

Table 6 Independent-samples Kruskal-Wallis test summary

Parameter	Value
Total N	36
Test statistic	31.286
Degrees of freedom	3
Asymptotic significance (2-sided test)	**0.000**

The Kruskal–Wallis test results are presented in Table 6. The Kruskal-Wallis test produced a test statistic of 31.286 with 3 degrees of freedom and an asymptotic significance (p-value) of 0.000 ($p < 0.05$), so that H0 was rejected and H1 accepted: a significant difference in Ferrum (Fe) concentration exists among the control (pretreatment), 1 mm, 2 mm, and 3 mm treatment groups. This confirms that hole-diameter variation of the tray aerator affects the reduction of Ferrum (Fe) concentration in dug well water.

Table 7 Pairwise comparisons (Bonferroni correction)

Comparison	Test statistic	Std. error	Std. test statistic	Sig.	Adj. sig.
1 mm – 2 mm	-9.556	4.965	-1.925	.054	.326
1 mm – 3 mm	-18.000	4.965	-3.625	.000	.002
1 mm – Control	26.444	4.965	5.326	.000	.000
2 mm – 3 mm	-8.444	4.965	-1.701	.089	.534
2 mm – Control	16.889	4.965	3.402	.001	.004
3 mm – Control	**8.444**	**4.965**	**1.701**	**.089**	**.534**

The Bonferroni-adjusted pairwise comparisons are presented in Table 7. Post hoc pairwise comparisons showed significant differences between the 1 mm and 3 mm treatments (adjusted $p = 0.002$), between the 1 mm treatment and the control (adjusted $p = 0.000$), and between the 2 mm treatment and the control (adjusted $p = 0.004$). In contrast, no significant differences were found between the 1 mm and 2 mm treatments (adjusted $p = 0.326$), between the 2 mm and 3 mm treatments (adjusted $p = 0.534$), or between the 3 mm treatment and the control (adjusted $p = 0.534$). Although the 1 mm and 2 mm treatments were not statistically distinguishable, the 1 mm treatment produced the lowest mean Ferrum concentration, indicating the greatest practical reduction effectiveness. Overall, these results are consistent with Namira and Hidayah (2025), who also reported a significant effect of tray-aerator hole-diameter variation on Fe reduction ($p < 0.05$), with smaller hole diameters yielding more optimal Ferrum removal.

Conclusions

This study demonstrates that the hole-diameter variation of a tray aerator significantly affects the reduction of Ferrum (Fe) concentration in dug well water. The average Ferrum (Fe) concentration before treatment was 0.30 mg/L. After treatment, the average concentration decreased to 0.06 mg/L (1 mm hole diameter), 0.14 mg/L (2 mm), and 0.18 mg/L (3 mm), corresponding to reduction effectiveness of 80.20%, 55.12%, and 40.92%, respectively. The Kruskal-Wallis test confirmed a significant difference in Ferrum (Fe) concentration among the treatment groups ($p = 0.000$, $p < 0.05$), and the 1 mm hole diameter produced the most effective Ferrum (Fe) reduction, meeting the clean-water quality standard set by Regulation of the Minister of Health of the Republic of Indonesia No. 2 of 2023. These findings indicate that the tray aerator, particularly with a smaller hole diameter, is a simple, low-cost, and effective technology that communities and local authorities can adopt to treat dug well water with high Ferrum content.

For practical adoption, households relying on Ferrum-rich dug well water are encouraged to use a tray aerator with a 1 mm hole diameter as a simple and inexpensive first-line treatment. Future studies could further examine the influence of tray number, drop height, and flow rate on removal efficiency, since a 1 mm hole diameter requires sufficient inlet water pressure to perform optimally; increasing the number of trays and the drop height is expected to further extend the water-air contact time and improve treatment performance. Local health authorities and educational institutions may also use these findings to promote simple aeration-based water-treatment technologies among communities that depend on dug wells for their daily water supply.

Code availability Not applicable.

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Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Clinical trial number Not applicable.

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