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THE USE OF QUARTZ SAND FILTERS TO IMPROVE IRON (Fe) LEVELS IN WELL WATER QUALITY

Kirana Noor Azillia Prameswara, Herman Santjoko, Haryono, Narto
Health Polytechnic of Ministry Yogyakarta
Jl. Tata Bumi No. 03, Gamping, Sleman, Yogyakarta 55293, Indonesia
E-mail: kirananoorazilliaprameswara@gmail.com

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ABSTRACT

The Use Of Quartz Sand Filters To Improve Iron (Fe) Levels In Well Water Quality. *Water resource useful for humans in daily lives. Water needs to be processed to make water suitable use. Water quality can affect public health and environmental problems, Iron (Fe) levels in water when consumed can cause health problems. The maximum limit Iron (Fe) levels in water is 0,2 mg/L Permenkes No. 2 of 2023. survey conducted Sindumartani well water, Ngemplak, Sleman with an examination result of 3 mg/L. at Organic Iron (Fe) level in PDAM Sleman Unit Nogotirto well water with examination result of 3 mg/L at of the Inorganic Iron (Fe) level. This study uses a quasi-exsperimen with Pre test- Post test with control Group Design to determine the difference in the decrease in Organic Iron (Fe) and Inorganic Iron (Fe) levels after filtration using quartz sand media in well water. The results of this study on water treatment with KMnO4 quartz sand to reduce Inorganic Iron (Fe) levels in water by an average of 2.35 mg/L (88,13%) and Organic Iron (Fe) levels in water by an average of 1.71 mg/L (46,80%). Oxidation process in quartz sand with the highest effective percentage reduction inorganic iron (Fe) levels of 88.13%. Statistical test results show a Sig value of 0.002>0.05 the Independent Sample T-Test, meaning a difference in Organic Iron (Fe) Levels and Inorganic Iron (Fe) Levels before after filtration using quartz sand. Houshing Filter quartz sand media with a volume 700 ml to reduce 88,13% Iron (Fe) Anorgnaik levels well water.*

INTRODUCTION

Water is an essential resource for human life, serving purposes such as drinking, cooking, bathing, washing, and other domestic activities. Therefore, water used for these purposes must meet clean water quality standards to ensure safety for health. According to the World Health Organization (WHO), the estimated daily clean water demand ranges from 60 to 120 liters per person in developed countries and approximately 30 to 60 liters per person in developing countries[1]. Clean water is defined as water that meets physical, chemical, and microbiological health standards and is safe for consumption after proper treatment. One important chemical parameter to monitor is dissolved iron (Fe), as concentrations exceeding the permissible limit may lead to long-term health risks. The Indonesian Ministry of Health Regulation No. 2 of 2023 stipulates that the maximum allowable concentration of dissolved iron in water used for hygiene and sanitation is 0.2 mg/L[2].

Iron (Fe) in water exists mainly in two forms: soluble ferrous ions (Fe^{2+}) and ferric ions (Fe^{3+}), the latter of which tends to precipitate. In natural waters with neutral pH and sufficient dissolved oxygen, Fe^{2+} can be oxidized to Fe^{3+} through the release of electrons, whereas the reverse reduction process involves electron uptake[3]. Excess iron in water can cause toxic effects such as liver cirrhosis and pancreatic damage. It may also result in environmental issues, such as foul odor, reddish-brown stains on clothing, and disruption of water distribution systems[4].

A preliminary survey conducted in Sleman Regency, Yogyakarta Special Region, revealed that the concentration of organic Fe in a household well in Dusun Bokesan, Sindumartani, Ngemplak, reached 1.67 mg/L on May 31, 2023, and increased to 3 mg/L by August 3, 2023. Meanwhile, the concentration of inorganic Fe in a well managed by PDAM Sleman (Nogotirto Unit) was recorded at 2 mg/L on July 22, 2023, rising to 3 mg/L by August 3, 2023. Both values significantly exceed the maximum allowable Fe concentration of 0.2 mg/L according to Regulation No. 2 of 2023. This highlights the urgent need for appropriate water treatment interventions to reduce iron content to safe levels.

Iron in groundwater originates from two major sources. Organic iron typically comes from the incomplete decomposition of living organisms in wetland or peat environments. Peatlands are formed from decayed plant material under highly moist, anaerobic conditions and often contain high levels of Fe and Mn, giving the water a reddish-brown hue[5]. In contrast, inorganic iron usually results from the chemical weathering of rocks or soil rich in minerals such as Ni, Fe, and Mg, with water acting as the dissolving and oxidizing medium[6].

One potential method to reduce Fe levels in well water is through an oxidation-filtration process using quartz sand media activated with potassium permanganate ($KMnO_4$). This activated media is placed inside a 10-inch housing filter for filtration. The present study aims to compare the effectiveness of quartz sand filtration in reducing both organic and inorganic Fe in well water. The findings are expected to provide a simple, community-level solution for treating iron-contaminated water in areas with similar environmental characteristics.

MATERIALS AND RESEARCH METHODS

This research is a quasi-experimental study employing a pre-test post-test with control group design to examine differences in the reduction of organic and inorganic iron (Fe) concentrations after filtration using activated quartz sand media. The experiment included six repetitions for each water sample without replacing the filter media. The number of repetitions was determined using the Federer formula $(t-1)(n-1) \geq 15$, where t is the number of groups and n is the number of subjects per group. With $t = 4$, the required minimum value for n is ≥ 6.

Quartz sand was activated by soaking it in a $KMnO_4$ solution for 24 hours, using a ratio of 1 liter of clean water, 1 kg of quartz sand, and 3.1606 grams of $KMnO_4$ (0.1 N / 0.02 M). The activated media was then packed into a 10-inch filter housing containing 700 mL of quartz sand in a cartridge. During filtration, water flow was maintained at 500 mL/min with a contact time of 2.20 minutes. Iron concentrations in the water samples were measured using the HANNA HI 721 Iron Checker.

The study was conducted in two different locations. The organic Fe sample was taken from a household well owned by Mr. Yosa at the quail farm in Desa Wisata Bokesan, Sindumartani Village, Ngemplak Subdistrict, Sleman Regency. The inorganic Fe sample was obtained from the PDAM Sleman Nogotirto Unit well, located in Donokitri Hamlet, Trihanggo Village, Gamping Subdistrict, Sleman Regency.

Data were statistically analyzed. Normality was tested using the Shapiro-Wilk test. Since the organic Fe data were normally distributed, a Paired T-test was used to analyze differences before and after treatment. The inorganic Fe data were not normally distributed and were therefore analyzed using the Wilcoxon test. To compare reductions in organic vs. inorganic Fe between groups, an Independent Sample T-test was applied. These analyses were conducted to determine the statistical significance of activated quartz sand in reducing iron concentrations in well water.

RESEARCH RESULTS AND DISCUSSION

This study assessed the effectiveness of $KMnO_4$-activated quartz sand in reducing organic and inorganic iron (Fe) levels in well water. Samples were collected from two locations: a private well in Dusun Bokesan, Sindumartani with high organic Fe content, and a PDAM well in the Nogotirto Unit containing predominantly inorganic Fe. Each sample type was tested six times to observe changes in iron concentrations before and after filtration using a housing filter containing 700 mL of activated quartz sand.

The average organic Fe concentration before treatment was 3.64 mg/L, which decreased to 2.40 mg/L after filtration. This corresponds to a mean reduction of 1.71 mg/L, or a removal efficiency of 46.80%.

Table 1. Frequency Distribution of Organic Iron (Fe) Concentration Before and After Filtration Using Quartz Sand Media in Well Water at Bokesan Village

Repetition	***Pre* (mg/L)**	***Post-Control Results* (mg/L)**	***Post-Treatment Results* (mg/L)**	**Control Group Reduction (mg/L)**	**Treatment-Induced Reduction (mg/L)**	**Post-Treatment Effectiveness (mg/L)**	**Reduction Effectiveness (mg/L)**	**%**
1	3,41	3,37	2,96	0,04	0,45	2,92	0,49	14,36
2	3,58	2,85	1,66	0,73	1,92	0,93	2,65	74,02
3	3,69	2,19	2,05	1,5	1,64	0,55	3,14	85,09
4	3,65	3,41	2,42	0,24	1,23	2,18	1,47	40,27
5	3,62	3,61	2,57	0,01	1,05	2,56	1,06	29,28
6	3,92	3,61	2,75	0,31	1,17	2,44	1,48	37,75
$\sum$	21,87	19,04	14,41	2,83	7,46	11,58	10,29	280,77
$\bar{\chi}$	3,64	3,17	2,40	0,47	1,24	1,93	1,71	46,80

Table 1 demonstrates a variation in the reduction of organic iron (Fe) concentration across the six repetitions. The greatest decrease was observed in the third replication, amounting to 1.64 mg/L, while the smallest reduction occurred in the first replication, at 0.45 mg/L. This fluctuating reduction percentage suggests that the filtration process was relatively effective, although it was still influenced by factors such as the specific characteristics of the water, the probable presence of high organic matter content, and limited contact time[7-9].

To confirm the appropriateness of applying parametric statistical tests, a normality test was performed using the Shapiro–Wilk method. The results indicated a significance value of 0.727 for the pre-treatment data and 0.237 for the post-treatment data. Since both values exceed the 0.05 threshold, the data were considered to follow a normal distribution.

Table 2. Shapiro–Wilk Normality Test Results for Organic Iron (Fe) Concentration

	Shapiro-Wilk (Sig)	Note
Before Treatment	0,727	The data are normally distributed
After Treatment (Effective)	0,237	The data are normally distributed

Since the assumption of normality was met, statistical analysis was continued using the paired t-test to examine the difference in organic iron (Fe) concentrations before and after treatment. The test results showed a significance value of 0.008.

Table 3. Paired T-Test of Organic Iron (Fe) Concentration

	Paired T-Test Sig (2-tailed)	Note
Pre-Test – Post-Test (Effective Group)	0,008	$p < 0.05$, the null hypothesis (H_0) is rejected and the alternative hypothesis (H_a) is accepted.

The p-value < 0.05 indicates that there is a statistically significant difference between the concentrations of organic Fe before and after filtration. This significant reduction supports the hypothesis that the activated quartz sand medium is effective in reducing the concentration of organic Fe in well water. However, its efficiency has not yet reached the ideal threshold to meet clean water quality standards, which require Fe levels not to exceed 0.2 mg/L, as stipulated in Regulation of the Minister of Health of the Republic of Indonesia No. 2 of 2023[2].

The reduction of organic Fe in this study occurred through an oxidation mechanism. Fe^{2+} ions originating from organic compounds were oxidized to Fe^{3+}, which then precipitated in the form of $Fe(OH)_3$. The activation of quartz sand using $KMnO_4$ produces a MnO_2 layer, which acts as a strong oxidizing agent. The main chemical reaction involved is as follows:

$$4\ Fe^{2+} + O_2 + 10\ H_2O \rightarrow 4\ Fe(OH)_3 + 8\ H^+$$

However, in water containing high levels of organic matter, a portion of the available oxygen in the system is consumed by microbial decomposition processes. This may explain why the reduction efficiency for organic Fe was lower compared to that of inorganic Fe.

For inorganic Fe concentrations, testing was conducted on well water from the PDAM Nogotirto Unit. Before treatment, the average concentration was 2.67 mg/L, which decreased to 0.56 mg/L after filtration. This corresponds to a reduction of 2.35 mg/L or an efficiency rate of 88.13%, significantly higher than the reduction observed in organic Fe levels.

Table 4. Frequency Distribution of Inorganic Iron (Fe) Concentrations Before and After Filtration of Well Water Using Quartz Sand Media at PDAM Sleman Nogotirto Unit

Repetition	***Pre* (mg/L)**	***Post-Control Results* (mg/L)**	***Post-Treatment Results* (mg/L)**	**Control Group Reduction (mg/L)**	**Treatment-Induced Reduction (mg/L)**	**Post-Treatment Effectiveness (mg/L)**	**Reduction Effectiveness (mg/L)**	**%**
1	2,84	2,48	0,71	0,36	2,13	0,35	2,49	87,67
2	2,54	2,42	0,34	0,12	2,2	0,22	2,32	91,33
3	2,58	2,39	0,74	0,19	1,84	0,55	2,03	78,68
4	2,53	2,39	0,52	0,14	2,01	0,38	2,15	84,98
5	2,96	2,48	0,74	0,48	2,22	0,26	2,7	91,21
6	2,56	2,35	0,34	0,21	2,22	0,13	2,43	94,92
$\sum$	16,01	14,51	3,39	1,5	12,62	1,89	14,12	528,79
$\bar{x}$	2,67	2,42	0,56	0,25	2,11	0,31	2,35	88,13

Table 4 shows that in all replications, a sharp decrease in Fe levels was observed, with the highest reduction recorded at 2.70 mg/L and the lowest at 2.03 mg/L. This high level of efficiency indicates that the activated quartz sand performed optimally in water conditions with relatively low organic matter content.

Normality testing revealed that the pre-treatment inorganic Fe concentration data were not normally distributed (significance value = 0.034), while the post-treatment data followed a normal distribution (significance value = 0.924). Since one of the datasets did not meet the assumption of normality, the Wilcoxon signed-rank test, a non-parametric method, was employed for further statistical analysis.

Table 5. Normality Test Results for Inorganic Iron (Fe) Concentration

	Shapiro-Wilk (Sig)	Note
Pre	0,034	Not normally distributed
Effective Post-test	0,924	Normally distributed

Table 5 shows that the normality test results for the pre-treatment data produced a significance value of 0.034, which is less than 0.05, indicating that the data are not normally distributed. Meanwhile, the post-treatment data yielded a significance value of 0.924, greater than 0.05, indicating that the data are normally distributed. Since one of the data sets does not follow a normal distribution, the appropriate statistical analysis is the Wilcoxon Signed-Rank Test, a non-parametric alternative to the paired t-test.

Table 6. Wilcoxon Signed-Rank Test Results for Inorganic Iron (Fe) Concentration

	Wilcoxon Test Asymp, Sig (2-tailed)
Effective Post - Pre	0,028

The results of the Wilcoxon test showed a significance value of 0.028. This value is below 0.05, indicating a significant difference between the concentrations of inorganic Fe before and after filtration. The effectiveness of this reduction is most likely due to the absence of complex organic substances in the water, which could otherwise inhibit the oxidation reaction.

Chemically, the presence of inorganic Fe in groundwater generally originates from the weathering of minerals in ultramafic rocks. The activation of quartz sand with $KMnO_4$ allows the formation of a SiO_2 surface coated with MnO_2, according to the following reaction:

$$SiO_2 + 2\ KMnO_4 + H_2O \rightarrow SiO_2 + 2\ KOH + 2\ MnO_2 + 3/2\ O_2$$

This MnO_2 coating acts as a strong oxidizing agent that converts Fe^{2+} to Fe^{3+}, which subsequently precipitates as iron hydroxide compounds. This reaction works particularly well in clear deep well water with minimal interference from organic matter.

A comparison of the effectiveness of the media on organic versus inorganic Fe showed a significant result. Based on the Independent Sample T-Test, a significance value of 0.002 was obtained.

Table 7. Independent Sample T-Test

	Independent Sample T-Test (Sig) Levene's Test for Equality of Variances
Effective Post-test (Equal variances assumed)	0,002

This value indicates that there is a significant difference in the reduction effectiveness between the two types of iron compounds. With an efficiency of 88.13% for inorganic Fe and 46.80% for organic Fe, it is evident that filtration using activated quartz sand is more optimally applied to water sources dominated by inorganic Fe content[9-13].

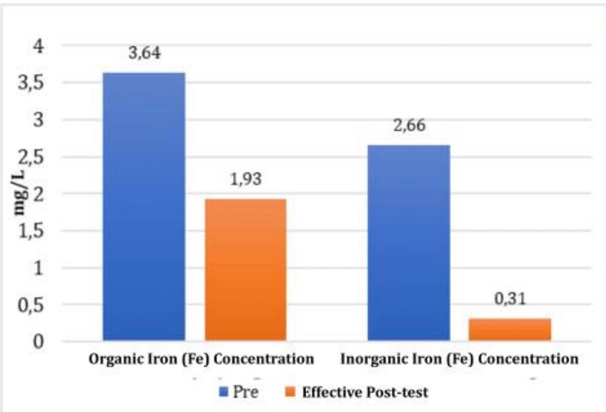

Figure 1. Reduction in Organic and Inorganic Iron (Fe) Concentrations in Well Water After Filtration Using Quartz Sand Media

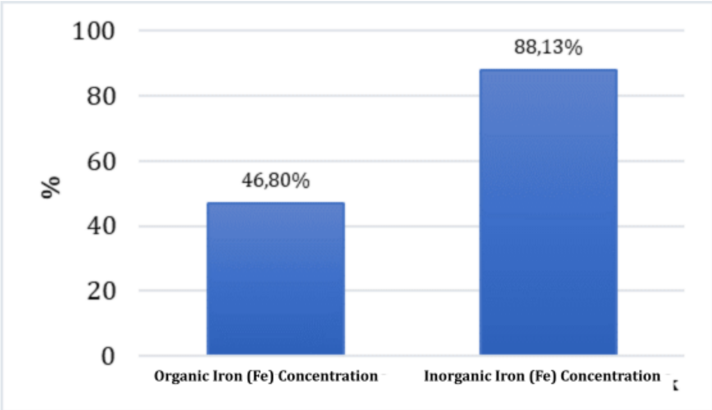

Figure 2. Percentage Difference in Organic and Inorganic Iron (Fe) Concentrations in Well Water After Filtration Using Quartz Sand Media

These findings support existing literature. Yusniartanti[3]. demonstrated that $KMnO_4$ is effective in oxidizing Fe^{2+} ions in groundwater, while Said[14], Explained that oxidant-coated media such as activated sand have the potential to serve as a household-scale technology for heavy metal water treatment. These results are also consistent with the study by Wulandari et al[4]. which reported iron oxidation efficiencies of over 80% through the combination of aeration and chemical oxidants[15-19].

Although the results of this study are promising, several limitations should be noted. The experiment was conducted using only a single type of media and a single-stage filtration system, without incorporating pre-filtration or multi-stage treatment. In addition, supporting parameters such as dissolved oxygen levels and organic compound content were not quantitatively measured. To improve the treatment of water with high organic Fe content, sedimentation and preliminary filtration steps are recommended prior to the main filtration process[20-25].

Overall, this study demonstrates that quartz sand media activated with $KMnO_4$ is highly effective in reducing inorganic Fe concentrations, but shows only moderate effectiveness against organic Fe. The significant reduction in iron concentrations was achieved through oxidation reactions within the activated sand media. These results highlight the potential for applying a simple water treatment technology based on chemical oxidation principles, particularly in areas with high iron content, such as regions with deep rock wells.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results and data analysis, it can be concluded that filtration using quartz sand media activated with $KMnO_4$ is capable of significantly reducing both organic and inorganic iron (Fe) concentrations in well water. In water samples dominated by organic Fe from Bokesan Hamlet, Sindumartani, the average reduction in Fe concentration after filtration was 1.71 mg/L, equivalent to an efficiency of 46.80%. Meanwhile, in samples dominated by inorganic Fe from the Nogotirto PDAM Unit, the reduction was substantially higher at 2.35 mg/L, with an efficiency of 88.13%.

Statistical analysis indicated that the reduction in Fe concentrations in both sample types was statistically significant, with a p-value < 0.05 from the paired t-test for organic Fe and the Wilcoxon test for inorganic Fe. Furthermore, the Independent Sample T-Test revealed a significant difference in the reduction effectiveness between the two iron species, showing that quartz sand media was more effective for inorganic Fe.

These findings suggest that quartz sand activated with $KMnO_4$ has considerable potential as a simple household water treatment medium, especially in areas with high inorganic iron concentrations in deep well sources. However, for regions with wetland or peat soils rich in organic matter, the effectiveness of this medium remains limited. Therefore, it is recommended that sedimentation and preliminary filtration stages be incorporated for water with high organic Fe content before the main filtration process.

Further development of multi-stage filtration units, evaluation of long-term performance until media saturation, and measurement of supporting parameters such as dissolved oxygen and organic compound content are suggested as directions for future research to optimize this technology. This simple and low-cost approach is expected to contribute to the provision of health-compliant clean water for communities in various regions of Indonesia.

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