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Microwave Activation Innovation in Nambo Sand: The Latest Solution for Filter Media in Clean Water Treatment

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ABSTRACT

Producing clean water from sources unfit for use, both for drinking and bathing, washing and purifying purposes, requires efforts to treat the water to meet the quality standards set by the Government. One effective method is filtration, with the primary material being filter media. This research focuses on analyzing the mineral content of Nambo sand as a filter media to purify well water using microwave activation and the addition of Potassium Permanganate ($KMnO_4$). The objectives of this research are: (1) Analyze the mineral content, grain morphology and micropores of Nambo sand; (2) Optimizing the characteristics of Nambo sand through microwave activation; (3) Apply Nambo active sand to reduce iron and manganese levels in healthy water. The findings show that: (1) Nambo Sand has high potential as a source of silica sand because of its high Si and SiO_2 content; (2) Microwave activation to a maximum temperature of 400℃ increases the concentration of Si and SiO_2 reduces impurities and increases the number and area of pores on the sand surface, which is effective in reducing the levels of iron (Fe) and manganese (Mn); (3) The addition of 5% $KMnO_4$ to sand activated by microwave at a maximum temperature of 400℃ reduces Fe and Mn levels in healthy water to the lowest level of 0.01 mg/L.

1. INTRODUCTION

All creatures in this world need water for their life. Water from nature is not all clear or clean, so technology is necessary to purify and clean water from impurities. Technology must also ensure drinking water contains the substances required [1, 2]. Clean water is a basic need for humans to carry out their lives because water has many benefits for human life [3, 4]. Therefore, the water used must meet the requirements of good quality and quantity. To obtain such water, enhancement of water treatment technology is crucial to study.

In terms of quality, water must meet physical, chemical, and biological health standards. If one of the parameters does not meet the requirements, then the water is unsuitable. Using water that does not meet quality standards can cause health problems directly and indirectly and cause unpleasant odours [5, 6]. Based on data from the Central Statistics Agency in 2023, around 21.1% of the Indonesian people do not have access to clean water [7]. This contradicts one of the goals of the Millennium Development Goals (MDGs), namely "Ensure Environmental Sustainability", one of the targets of which is to reduce half of the total population living without access to sustainable water and sanitation.

Kendari City, in 2023, the percentage of protected well water users will be 7.16%, unprotected healthy water will be 8.97%, and others will be 67.82%. Around 63.90% of wholesome water in Kendari often contains iron (Fe) and manganese (Mn) in relatively high amounts [7]. This condition shows the importance of water treatment technology in ensuring that the water used by the community meets established health standards to prevent various health and environmental problems.

Groundwater is water in the ground divided into shallow and deep groundwater [8, 9]. Shallow groundwater comes from rainwater bound by tree roots and is not far from the ground surface, above the waterproof layer. On the other hand, deep groundwater is formed from rainwater, which seeps deeper through the process of adsorption and filtration by rocks and minerals in the soil [10, 11]. This process makes deep groundwater more evident than shallow groundwater. This groundwater is generally obtained by making wells [12].

In general, groundwater is classified as clean from a bacteriological perspective. However, chemical levels in groundwater are relatively high and are strongly influenced by the lithospheric formations through which they pass. Because groundwater comes into contact with various materials in the earth, it usually contains dissolved cations, anions, and some inorganic compounds [13, 14]. This suggests that although groundwater may be free from bacteriological contamination, attention must be paid to its chemical content to ensure its suitability and safety.

Groundwater often contains high iron (Fe) and manganese

(Mn) levels. The Fe and Mn content in water causes the colour of the water to change to yellow-brown after a short period of contact with air [15]. Apart from being detrimental to health, this content also causes an unpleasant odour, leaving yellow stains on the tub walls and yellow spots on clothes [16]. This condition shows that the presence of Fe and Mn in groundwater can cause significant aesthetic and health problems for water users.

Regulation of the Minister of Health of the Republic of Indonesia No. 32 of 2017 concerning Environmental Health Quality Standards and Water Health Requirements for Hygiene Sanitation, Swimming Pools, Solus Per Aqua, and Public Baths, the maximum Fe content allowed is 1.0 mg/L and the maximum Mn content is 0.5 mg/L. These standards set limits to ensure the water used by the public is safe and healthy. Therefore, processing groundwater containing Fe and Mn needs to be carried out to meet these standards and maintain the health and comfort of water users.

Developing industry and residential areas can threaten clean water quality, so simple and modern improvements are needed. To overcome this problem, it is necessary to provide an effective water treatment system. One method of physical water treatment is filtration, which separates solids or colloids from liquids. In this process, various filtration media are used to support the smooth processing of clean water. One filtration media that is quite effective is quartz sand or silica, which has great potential in this process.

Sand is a type of fine aggregate available in large quantities, but its quality needs to be studied further, especially its material content [17, 18]. Research is required to explore the benefits of local sand, which is abundant in nature, apart from its use as a building material. With proper research, local sand can be optimized as an effective filtration media in clean water treatment systems. This will not only help maintain water quality but also help utilize local resources more efficiently.

Silica sand is a mineral that consists of silica crystals (SiO_2) and contains impurity compounds that are carried away during the deposition process [19, 20] and increases the ability of silica sand as a filter media, usually using physical and chemical activation [21, 22]. Physical activation aims to open and enlarge the sand pores, increasing adsorption capacity [23]. The sand is heated at 200°C for 60 minutes in this process. The temperature is not too high to avoid damage to the active sand structure. Thus, sand's more open pore structure allows for more effective absorption.

The chemical activation process is a treatment of sand to enlarge the pores by breaking hydrocarbon bonds or oxidizing the surface molecules of the sand [24]. This chemical activation increases the sand's surface area, directly affecting the adsorption force. With more open pores, silica sand's ability to filter contaminants in water becomes more efficacious [25]. The combination of physical and chemical activation [26] allows silica sand to become an optimal filter media [27], improving water quality through filtration.

Based on the description of the material above, silica sand can be used as a filter media for purifying healthy water. Therefore, this research conducted an in-depth investigation of this material by analyzing the mineral content of Nambo sand as a filter media for well water purification. Nambo sand, a local material from Southeast Sulawesi, is activated physically using a microwave and chemically using Potassium Permanganate to improve its characteristics. The aim is to use this sand as a highly effective filter media in processing clean water.

Several studies have reported the use of sand as a common aggregate used in water filtration [28-30], however, to our knowledge, very few journals reported the utilization of activated sand, let alone go through two stages of the activation process before being used as a filter media. In addition, we introduced microwaves to physically activate the sand which is more efficient than the conventional oven. Moreover, the sand used in this research was local to ours. Based on that, this research aims to determine the effect of microwave activation on increasing the characteristics of Nambo sand and measuring the impact of chemical activation on reducing iron and manganese levels in healthy water. Physical activation with microwaves is expected to enlarge the sand pores, while chemical activation with $KMnO_4$ aims to break hydrocarbon bonds and oxidize sand surface molecules. These findings will provide a better understanding of how a combination of physical and chemical activation can improve the performance of Nambo sand as a filter media, making it effective in reducing contaminants such as iron and manganese levels in healthy water.

We found that Nambo sand contains several chemical compounds with SiO_2 as the main component that increased from 97.88% to 98.71% after physical activation with heating up to 400°C. The physical activation also increased the amount and the pore area in the sand, which increased its ability to reduce the Fe and Mn in the water. The chemical activation using Potassium Permanganate further improves the filter's ability to reduce the contaminants.

2. METHODS

The research implementation stages began with the Nambo sand preparation. This initial step includes analyzing the mineral content of Nambo sand using X-ray fluorescence (XRF), morphological characterization (grain shape and size) using Scanning Electron Microscopy (SEM), and determining the number and size of pores using ImageJ software. This analysis provides a basis for understanding the initial conditions of Nambo sand before further optimization is carried out.

Next, optimization of the characteristics of Nambo sand was carried out through physical activation using a microwave with temperature variations ranging from 250°C to 400°C in the 50°C range. After the activation process, Nambo sand was characterized again to determine changes in mineral content using XRF, grain morphology using SEM, and the number and size of pores using ImageJ software. A comparison of sand characteristics before and after activation using a microwave was carried out to evaluate the effect of activation on sand quality.

The final stage of this research is using activated Nambo sand as a filter media to reduce iron (Fe^{2+}) and manganese (Mn^{2+}) levels in healthy water. Nambo sand, physically activated at various temperatures, is chemically reactivated with 5% Potassium Permanganate ($KMnO_4$). The filter media produced from this process are used to test their effectiveness in reducing Fe^{2+} and Mn^{2+} levels in healthy water, aiming to improve water quality to make it safer and cleaner for use.

3. RESULTS AND DISCUSSION

3.1 Effect of activation temperature on the mineral content of Nambo sand

Characterization using XRF is carried out to determine the elemental composition of a material [31]. In this research, Nambo sand samples were analyzed before and after being activated using a microwave at varying temperatures of 250°C, 300°C, 350°C and 400°C. The results of this analysis can be seen in Table 1.

Table 1. Compound content of characterization results XRF of Nambo sand samples

Composition (%) of Nambo Sand Samples					
Compound	**Before Activation**	**Activation Temperature**			
		250ºC	**300ºC**	**350ºC**	**400ºC**
SiO_2	97.88	98.47	98.58	97.56	98.71
Fe_2O_3	0.99	0.49	0.495	0.477	0.378
TiO_2	0.599	0.489	0.496	0.470	0.24
K_2O	0.388	0.38	0.63	0.328	0.33
P_2O_5	-	-		0.31	0.28
ZrO_2	0.0646	0.0596	0.028	0.316	0.0133
Cr_2O_3	0.0451	0.0279	-	-	-
Nb_2O_5	0.0135	0.0135	0.0132	0.0161	0.0165
MoO_3	0.0093	0.0092	0.0103	0.0117	0.0125
SnO_2	-	-	-	-	0.0052

The elements in Nambo sand combine with oxygen to form various compounds [32]. The compound content, resulting from XRF characterization of the Nambo sand samples before and after activation at each temperature, is depicted in Figure 1(a) and Figure 1(b).

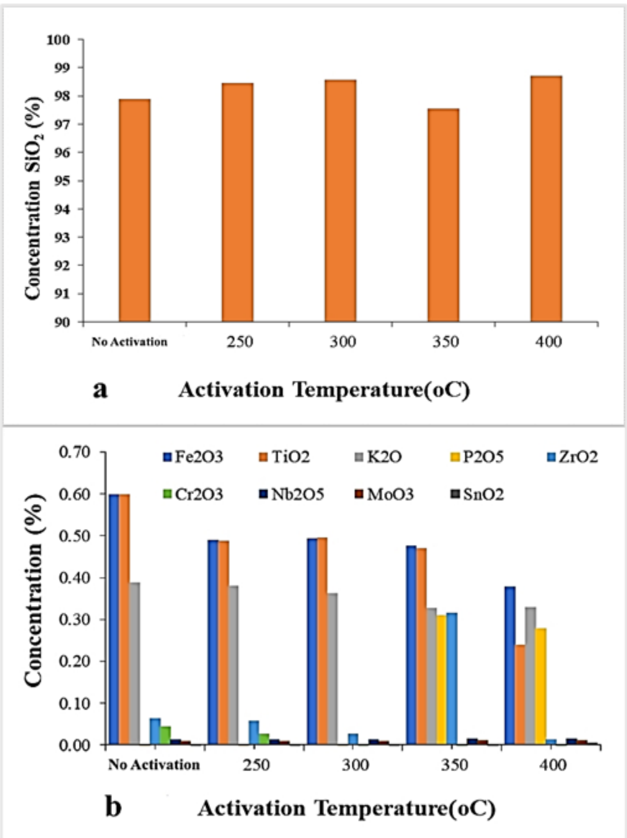


Figure 1. Relationship between activation temperature and the content of Nambo sand compounds, (a) SiO_2 compounds, (b) secondary compounds

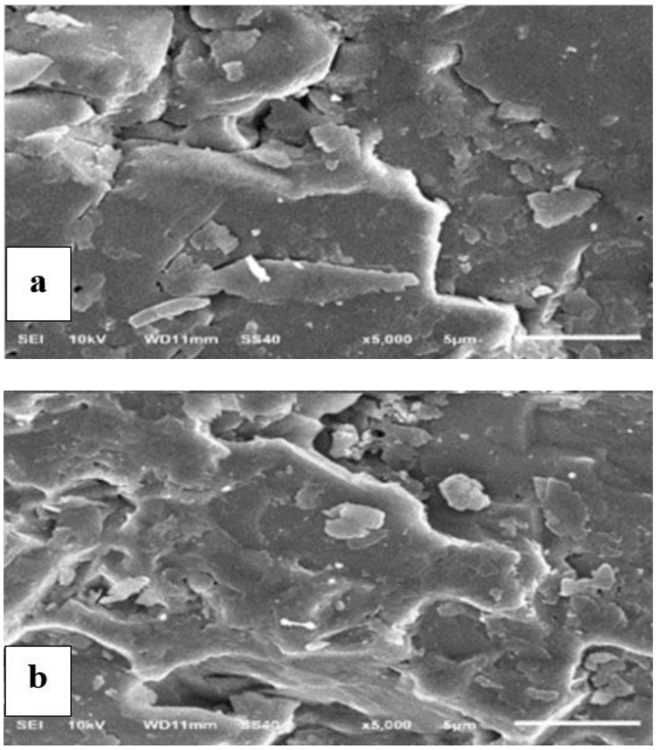
Analysis shows that Nambo sand contains several chemical compounds, such as SiO_2, Fe_2O_3, TiO_2, K_2O, P_2O_5, ZrO_2, Cr_2O_3, Nb_2O_5, MoO_3, and SnO_2. Before activation, the highest concentration was found in SiO_2, reaching 97.88%, which increased with increasing activation temperature. After activation to a temperature of 400°C, the concentration increased to 98.71%, indicating an increase in the purity of SiO_2. The activation process at a higher temperature effectively reduces the water content and contaminant compounds in Nambo sand, allowing the arrangement of the Si and O atoms to be better so that the SiO_2 composition becomes purer.

Increasing the activation temperature can remove volatile compounds, leaving pores or spaces in the sand material. Then, SiO_2 compounds can fill these spaces, increasing the SiO_2 concentration in the Nambo sand sample. This process shows that microwave activation at higher temperatures optimizes SiO_2 purity and reduces contaminants in Nambo sand. The results of high-temperature activation increase the potential of Nambo sand as an efficient filter media in processing clean water.

Increasing the activation temperature can reduce Nambo sand contaminant compounds, as evidenced by the XRF test results of Nambo sand samples before and after activation (Figure 1). Silica sand generally contains contaminant compounds such as Fe_2O_3 and K_2O. In this research, the most dominant impurity compound is Fe_2O_3. The Fe_2O_3 concentration of Nambo sand decreased from 0.599% to 0.378% before and after activation at a maximum temperature of 400ºC. This is because increasing the activation temperature causes impurity compounds in silica sand to tend to be released from the surface of the sand, as well as causing some impurity compounds to become more volatile, which allows impurity compounds to separate from the silica sand.

3.2 Effect of activation temperature on the number and extent of Nambo sand pores

The SEM test results are shown in Figure 2, which shows the distribution of pores formed in Nambo sand before and after activation. The morphology of Nambo sand from SEM results was then analyzed using ImageJ software, shown in Table 2.



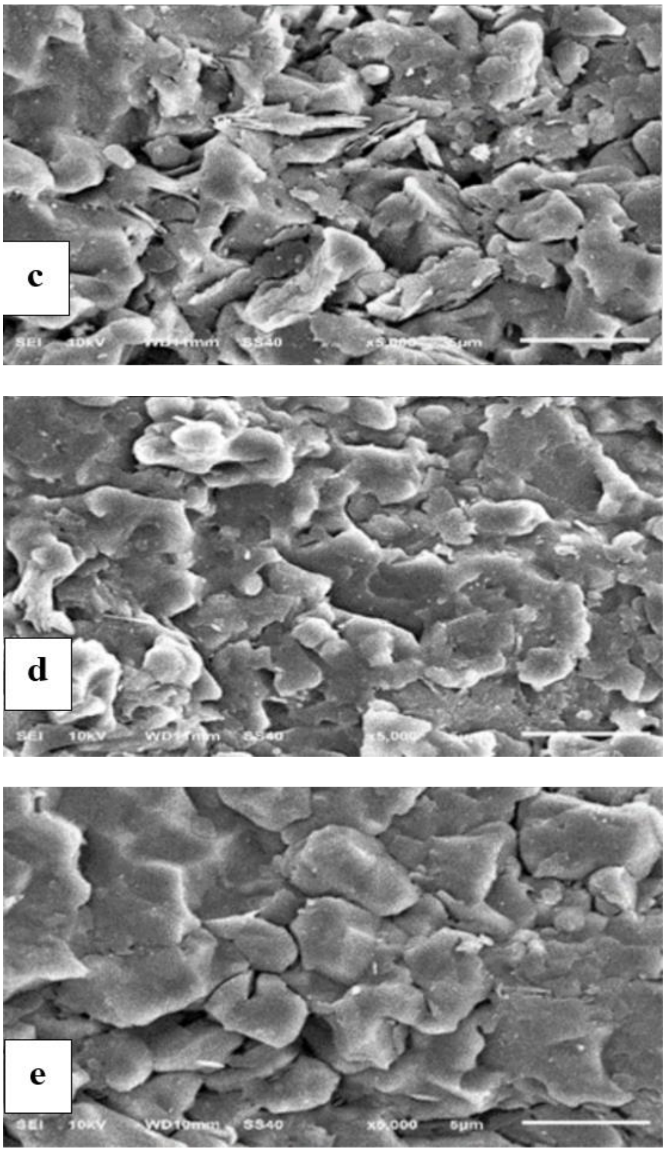


Figure 2. Morphology of Nambo sand with a magnification of 5,000 times before activation (a) and after activation at temperatures of 250°C (b), 300°C (c), 350°C (d), and 400°C (e)

Table 2 shows that the activation temperature increases the number and area of pores. This increase in the number of pores is caused by increasing the activation temperature, which can reduce the water content and contaminant compounds contained in Nambo sand and leave pores or cavities in the sand material. The increase in pore area is caused by more pores forming in the sand material. The increase in pore area is caused by the loss of residues or contaminant compounds that fill gaps in the pores. The more pores formed, the greater the pore surface area [33].

Table 2. Number, radius, and area of Nambo sand pores before and after activation

Activation Temperature (°C)	Amount Pore	Pore Radius (µm)	Pore Area (µm^2)
No Activation	153	1.197	18.009
250	246	1.295	21.091
300	293	1.405	24.823
350	542	1.565	30.770
400	576	1.606	32.395

3.3 Application of nambo sand to reduce iron (Fe) and manganese (Mn) levels in well water

3.3.1 Results of measurement of Fe and Mn levels in dug well water samples

The results of measuring the Fe and Mn levels of dug well water samples before being processed using the filtration method can be seen in Table 3.

Table 3. Results of measuring Fe and Mn levels in dug well water samples

Element Name	Level (mg/L)	Standard Rate (mg/L)
Iron (Fe)	0.39	1.0
Manganese (Mn)	0.79	0.5

Before filtration, the dug well water sample had Fe and Mn levels of 0.39 mg/L and 0.79 mg/L, respectively. The Fe and Mn levels have exceeded the quality standards set based on the Republic of Indonesia Minister of Health Regulation No. 32 of 2017 concerning the General Standard for Environmental Health and Water Health Requirements for Hygiene Sanitation, Swimming Pools, Solus Per Aqua and Public Baths.

3.3.2 Effect of nambo sand activation temperature on reducing Fe and Mn levels in well water

The appearance of healthy water and water filtered using Nambo sand, which was not and which was activated using a microwave with temperature variations of 250°C, 300°C, 350°C and 400°C is shown in Figure 3.

Figure 3. Initial samples of well water (a), water filtrated using sand without activation (b), water filtration results using microwave-activated sand with temperatures 250°C (c), 300°C (d), 350°C (e), and 400°C (f)

Table 4. Results of measuring Fe and Mn levels in dug well water from Nambo sand filtration with and without microwave temperature activation

Temperature (°C)	Level (mg/L)		Processing Effectiveness (%)	
	Fe	Mn	Fe	Mn
-	0.38	0.45	3.29	42.89
250	0.17	0.42	57.88	47.08
300	0.13	0.35	67.06	55.16
350	0.13	0.23	68.26	70.22
400	0.12	0.16	70.04	79.68

Analysis of iron (Fe) and manganese (Mn) levels was carried out using an AAS tool, which was carried out by comparing data on Fe and Mn levels in healthy water before the filtration process with water resulting from the filtration process using both sand without activation and activated by the influence of microwave temperature. The results are displayed in Table 4.

From Table 4, the iron and manganese levels in filtrated well water decrease as the activation temperature increases. This is because the high activation temperature causes impurity particles to come out/evaporate, forming larger pores. As a result, the absorption of the metal elements iron and manganese in dug healthy water will be better because it will be increasingly tricky for iron (Fe) and manganese to pass through the gaps between particles and be absorbed into the pores. Apart from that, this increase in temperature also causes an increasing number of pores to form due to the increase in heat energy received. The number of pores formed will increase the pore surface area of the sand. This large sand pore surface area increases the adsorption speed. The greater the number of pores produced, the greater the pore surface area [33]. The decrease in iron and manganese levels in water can be seen from the colour of the filtered healthy water, which is more apparent and has no metallic smell, as seen in Figure 3.

From Table 4 it can also be seen the effectiveness of filtration processing using sand that is not, and that is activated using a microwave with temperature variations of 250°C, 300°C, 350°C and 400°C, with the same sand thickness of 30 cm. An activation temperature of 400°C has a reasonably high effectiveness in reducing Fe and Mn levels, namely 70.04% and 79.68%, respectively, which can reduce Fe levels up to 0.12 mg/L and reduce Mn levels up to 0.16 mg/L in water. The Fe and Mn levels obtained in this study were below the Fe and Mn levels specified in Minister of Health Regulation No. 32 of 2017.

3.3.3 Effect of nambo sand activation temperature and $KMnO_4$ solution on iron and manganese reduction in well water

Water filtered using Nambo sand, which was activated using a microwave with temperature variations of 250°C, 300°C, 350°C and 400°C was then soaked in a 5% $KMnO_4$ solution to be chemically activated, the results of which are shown in Figure 4. Analysis of dug well water The results of filtration using sand without and with microwave activation, temperature variations and adding 5% $KMnO_4$ to reduce Fe levels can be seen in Table 5 and Figure 5(a). Iron content in filtered healthy water decreases with increasing activation temperature. The addition of $KMnO_4$ causes the formation of a layer of MnO_2 that sticks to the sand surface. Because the sand is first activated by temperature, the MnO_2 layer easily sticks to the pores on the sand surface. The MnO_2 layer attached to the sand is an oxidizer, which causes the Fe^{2+} ions to dissolve in the healthy water and undergo an oxidation reaction. The reaction is as follows:

$$2Fe^{2+} + 2MnO_2 + 5H_2O \rightarrow 2Fe(OH)^3 + Mn_2O_3 + 4H^+ \quad (1)$$

Eq. (1) shows that the Fe^{2+} ion undergoes an oxidation reaction to change from Fe^{2+} to Fe^{3+} in the $Fe(OH)_3$ compound. Potassium permanganate in water will experience ionization of K^+ cations and MnO_4- anions. In the permanganate ion, the oxidation number of Mn is +7, so Mn can act as a potent oxidizing agent. MnO_4- with an oxidation number of +7 will oxidize iron with an oxidation number of +2 to +3. The change in oxidation number from +2 to +3, which is in suspended form, will be more easily filtered by porous filter media.

Table 5 and Figure 5(b) show that the activation temperature and addition of 5% $KMnO_4$ reduce manganese (Mn) levels in the filtrated water. $KMnO_4$ will form a layer of MnO_2, an oxidizer that causes the Mn^{2+} metal to dissolve in water and undergo the following oxidation reaction.

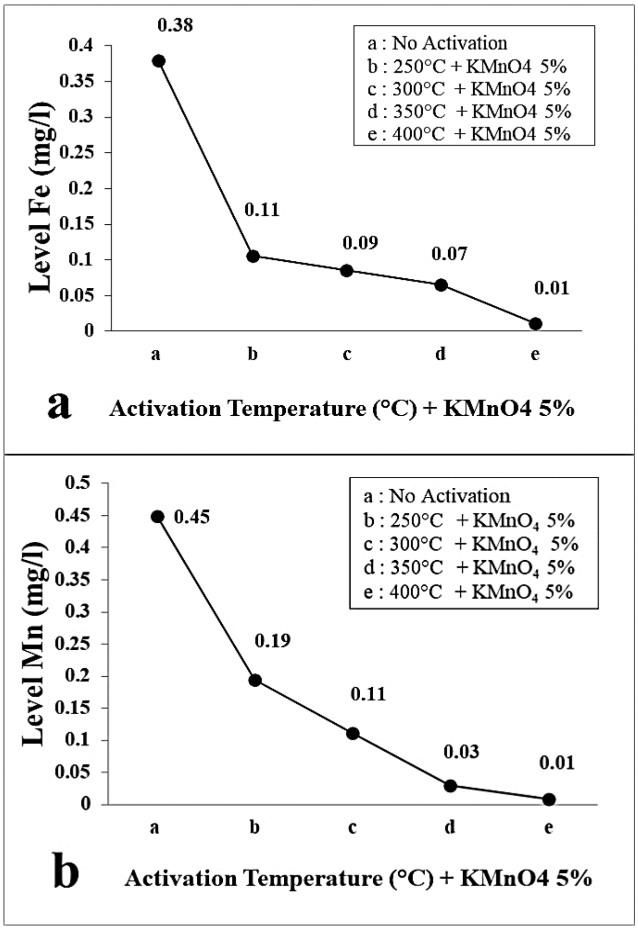


Figure 4. Effect of activation temperature and addition of 5% $KMnO_4$ on decreasing Fe levels (a) and Mn (b) in filtered water

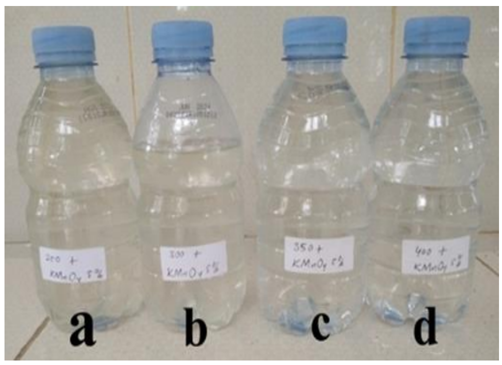


Figure 5. Water resulting from the filtration process using Nambo active sand with the addition of 5% $KMnO_4$ for microwave activation temperatures of 250°C (a), 300°C (b), 350°C (c), and 400°C (d)

$$3Mn^{2+} + MnO_2 + 4H_2O \rightarrow 2Mn_2O_3 + 8H^+ \quad (2)$$

Eq. (2) shows that Mn^{2+} undergoes an oxidation reaction to change from Mn to Mn^{3+}. The change in oxidation number from 0 to +3, suspended, will then be filtered by the porous sand filter media.

From Eqs. (1) and (2) above, it can also be explained that iron (Fe) and manganese (Mn) in dug healthy water are dissolved particles. These particles cannot be separated by filtering and also cannot settle. Therefore, the presence of MnO_2 attached to the surface of the sand will change the iron (Fe) in the water into a suspended solid so that it can be deposited and removed by filtering. As a result, the Fe and Mn levels of water were filtrated using sand that was activated using temperature variations, and the addition of 5% $KMnO_4$ at each activation temperature decreased significantly, as shown in Table 5. The Fe and Mn levels of filtrated water decreased very far below the Fe and Mn levels specified in Minister of Health Regulation No. 32 of 2017.

Table 5. Fe and Mn levels in dug well water after filtration with Nambo sand activation and 5% $KMnO_4$ addition

Temperature (°C)	Level (mg/L)		Processing Effectiveness (%)	
	Fe	Mn	Fe	Fe
-	0.38	0.45	32.29	42.89
250°C + $KMnO_4$ 5%	0.11	0.20	73.00	75.23
300°C + $KMnO_4$ 5%	0.09	0.11	78.06	85.88
350°C + $KMnO_4$ 5%	0.07	0.03	83.38	96.19
400°C + $KMnO_4$ 5%	0.01	0.01	97.02	98.84

The effectiveness of filtration processing using sand without and with activation using a microwave with temperature variations of 250°C, 300°C, 350°C and 400°C and the addition of 5% $KMnO_4$ with the same sand thickness of 30 cm can be seen in Table 5. Activation temperature of 400°C and adding 5% $KMnO_4$ is the most optimal reduction of up to 0.01 mg/L, effectively reducing high Fe and Mn levels, namely 97.02% and 9884%, respectively. This is due to the harmony between the high activation temperature causing the formation of pores and increasing the number of pores, so the coating/attachment of 5% $KMnO_4$ to the surface pores of the sand is getting better, thereby increasing the effectiveness of reducing Fe and Mn levels in the filtered water.

Let's compare the results shown in Tables 4 and 5. It can be seen that water filtrated using sand activated using a microwave and 5% $KMnO_4$ can reduce Fe and Mn levels better than sand that is only activated using a microwave. This is because adding 5% $KMnO_4$ is an oxidizing agent that can oxidize Fe and Mn metals [34, 35], reducing high levels of Fe and Mn in healthy water.

From the data presented above, we assure that physically and chemically activated Nambo sand can be used as a media filter to remove Fe and Mn from groundwater. However, it still needs a pilot scale to determine its efficiency, if any more pre-treatment is needed, and its operating condition and efficiency. Furthermore, the process of removing Fe and Mn from groundwater will demineralize the water, hence it will need pH adjustment, hardness, and alkalinity to avoid corrosion if the water is distributed. Water survey's continuing service must be done regularly.

4. CONCLUSIONS

We succeeded produced activated sand as a healthy water filter material obtained from Nambo sand having excellent potential for reducing iron and manganese content in water. The activation of Nambo sand using a microwave with temperature variations has an effect on increasing SiO2 compounds, the number and area of pores, and decreasing iron and manganese levels when applied as filter media. Further chemical activation using 5% $KMnO_4$ on Nambo sand, which has been activated using a microwave with temperature variations (250°C-400°C) with a range of 50°C can reduce iron and manganese levels further to reach the lowest levels of 0.01 mg/L at a temperature of 400°C with processing effectiveness reaching 98.84%. This research is a continuation from the previous research using different sand which are Lasada sand and Moramo Sand, where we found that different sources of sand will give different characteristics. Knowledge of the different characteristics of sand regarding its ability to reduce Fe and Mn content in water will certainly enrich sources of natural materials that can be used as filter media. However, some supporting data such as surface area and pore measurement of the material are still needed for further study.

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