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ORIGINAL ARTICLE

Removal of Iron and Manganese from Groundwater by Using Aeration and Natural Sand Filtration Techniques

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Abstract

Groundwater is the most common source of drinking water in Gilgel Beles. The concentrations of iron and manganese in Gilgel Beles Town's groundwater are higher than the national average iron and manganese concentrations in the domestic water supply may give an unpleasant taste, alter the color and flavor of food, and stain a variety of objects. It also encourages bacterial growth in water distribution networks, reducing pipe transfer efficiency while posing minimal health risks. As a result, this study was carried out to remove iron and manganese from groundwater utilizing aeration and quick natural sand filtration. The research was conducted using laboratory-scale sand filters with depths of 10, 15, 20, 25, and 30 cm and three graded sand particles. The initial iron and manganese concentrations in the raw water sample were 5.79 and 4.11 mg/L, respectively. The high concentrations of Fe and Mn in groundwater were lowered to 0.09 mg/L for iron and 0.11 mg/L for manganese at the maximum runtime of the experiment due to aeration and filtration. For coarse sand, the removal efficiency of iron and manganese was good during the trial, ranging from 98.44 to 97.31% for iron and manganese, respectively. It was also revealed that as the depth of natural sand filters was increased, the removal efficiency of iron and manganese from groundwater improved. Natural sand is thus more effective in removing iron and manganese from groundwater and is more easily available.

Keywords Aeration · Filtration · Groundwater · Iron · Manganese · Natural sand

1 Introduction

In many countries worldwide, groundwater is the primary supply of drinking water[1] and it is the central to human development[2]. In Ethiopia, which has a population of over 114 million people and more urban areas than rural ones, groundwater is the most prevalent source of drinking water. Almost all drinking water in Ethiopia is derived from groundwater to provide all Ethiopians with safe drinking water and adequate sanitation [3].

Groundwater is extracted via hand-dug wells, hand-pump-driven shallow wells, and submersible pump-powered deep wells or boreholes. [4]. Groundwater has a low temperature (7–10 °C), a low redox potential (lack of oxygen), high carbon dioxide concentration, high mineral content (high alkalinity and hardness), and very little suspended solids [5]. Groundwater chemistry is primarily controlled by interactions between water and rock, recharge and discharge (percolation and pumping), ion exchange, residence time, atmospheric inputs (precipitation-dissolution processes), chemical inputs from human activities, geological structures, and aquifer mineralogy[6].

Groundwater contamination is a serious threat to human health. The effects of groundwater development on human development are multifaceted and include food security, clean drinking water, sanitation, and climate change mitigation [7–10], and for local rivers and groundwater, surface runoff is a major source of contamination [11–13]. Although

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it is a serious issue and difficulty in many nations, ground water is still less polluted and cleaner than surface water [14, 15].

Groundwater is rich in iron and manganese all throughout the planet. Iron and manganese are two of the most abundant elements in the earth's crust. The dissolving of minerals and iron-bearing rock under anaerobic conditions during the rain-fltering process is what causes the presence of dissolved iron in groundwater [16]. Iron and manganese are common in groundwater, but due to a lack of dissolved oxygen, the water is often colored – reddish-brown with iron and black with manganese, and their presence causes a variety of problems, including water coloring and taste, clothing staining, deposits on laundry, and plumbing fixtures [17]. One of the most important difficulties with groundwater is its reddish and blackish color due to excessive amounts of iron (Fe) and manganese (Mn)[18–20] High iron and manganese concentrations may generate a bitter taste and encourage bacterial development in water distribution networks, reducing the efficiency of pipe transmission, but they do not cause health problems in general. Iron and manganese have long been a cause of concern for regulatory organizations in regard to industrial and public water supplies. [21]. To solve this challenge, better technology must be developed to improve the previously deemed standard water quality.

The removal of Fe and Mn ions from water resources by surface adsorption and a cheap adsorbent has been proposed due to environmental and health concerns[22, 23]. To remove iron and manganese from ground water, oxidation, precipitation, and sand filtration are employed to separate the oxidation element.

Aeration and quick sand filtration are the most common methods for removing iron and manganese from groundwater. It is possible to dissolve iron and manganese and return it to the groundwater. Anthropogenic causes that lead to high iron and manganese concentrations in groundwater include industrial effluents, landfill leakages, and acid mine drainage [22, 24]. When iron and manganese are present in water in a soluble form in drinking water supplies, many issues arise[25]. Temperature, pH, turbidity, taste, color, conductivity, and other water parameters are also needed to determine the system that was used to remove iron (Fe) and manganese (Mn). Traditional aeration followed by filtration is the most effective water treatment method for eliminating iron and manganese concentrations. Before iron and manganese can be filtered, they must first be oxidized to the point where they can form insoluble complexes [26]. The most common method for extracting iron and manganese from groundwater is oxidation filtration.

Aeration is a low-cost method of oxidation used in the groundwater treatment process. It is a reasonably simple procedure that does not require the use of chemicals. Aeration and filtration are typically sufficient to lower iron and manganese levels to acceptable levels, and it can also be used as a depth filtration using specific media such as sand particles [27]. Therefor this study was conducted on the removal of iron and manganese from drinking groundwater using aeration and natural sand filtration.

2 Materials and Methods

2.1 Description of Study Area

Gilgel Beles town is located in Benishangul-Gumuz Regional State, Metekel Zone, Western part of Ethiopia, 546 km from Addis Ababa at the town is Latitude 11°9'16.28"N and longitude of 36°20'49.56"E, average annual temperature, 27.6 °C, Average annual rainfall 1222 mm. The location of the study area was presented in Fig. 1.

2.2 Materials

Photometer (palintest 7100), Stiller, Test-tube (10 mL), glass (PT 595), Sieve (0.5, 1.18, 9.50 mm size), Conductivity meter (palintest 7100), Plastic bucket, Plastic bottle, Sprayer, Sand and gravel, Scoop, Oven dry (105–115°C). Palintest Iron MR No 1 Tablets, Palintest Iron MR No 2 Tablets, Palintest Manganese No 1 Tablets, Palintest Manganese No 2 tablets, Nitrate powder and tablet 1 and 2, Distilled water.

2.3 Methods

Aeration and sand filtration were the most important technologies used to make the iron and manganese removal technology successful and simple to operate. Dissolved iron and manganese are first converted to undissolved compounds, which can then be removed using a single-stage or two-stage separation process.

2.3.1 Oxidation with Aeration

Aeration was required before precipitation, settling, or filtration. Soluble ferrous iron (Fe^{2+}) was oxidized to a ferric iron (Fe^{3+}), which readily forms the insoluble iron hydroxide complex $\mathrm{Fe}\,(\mathrm{OH})_3$. Manganous (Mn^{2+}) was oxidized to manganic (Mn^{4+}), which forms insoluble manganese dioxide MnO_2. The insoluble heavy metals can be precipitated was removed by filtration [21]. Previous research suggested that the MnOx particles aided in the chemically auto-catalytic oxidation of Mn^{2+} to MnO_2 and hence led to significant manganese elimination [28–30].

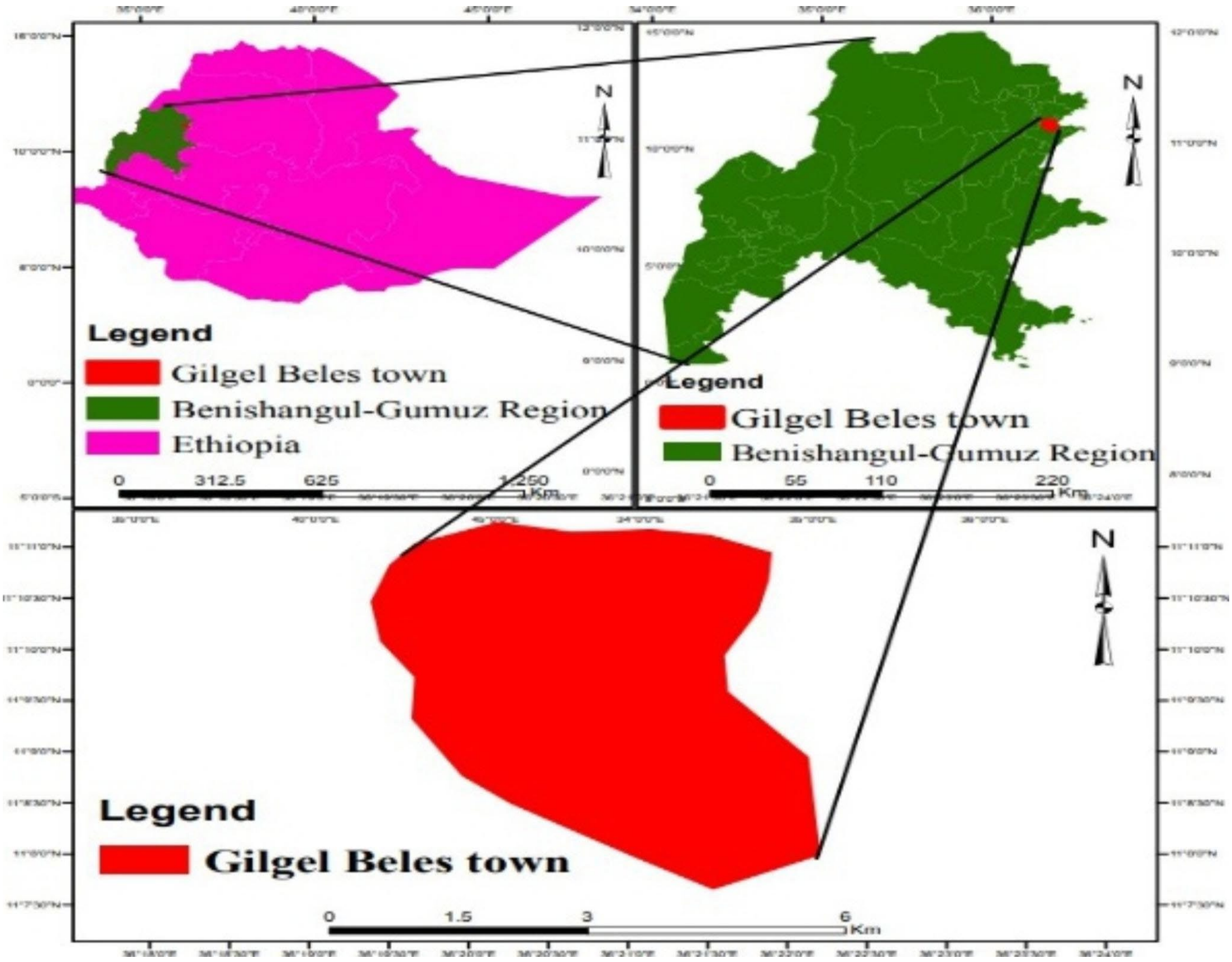

Fig. 1 Map of BGRS metekle zone gilgel beles town

The following equations represent the oxidation of iron and manganese by oxygen, respectively.

$$Fe^{+2} \rightarrow Fe^{+3} + e^{-} \quad (1)$$

$$Fe^{+3} + 3OH^{-} \rightarrow Fe(OH)_3 \quad (2)$$

$$Fe^{+2} + 3H_2O \rightarrow Fe(OH)_3 + 3H^{+} + e^{-} \quad (3)$$

$$Mn^{+2}+ \rightarrow Mn^{+4} \quad (4)$$

$$Mn^{2+} + 2H_2O \rightarrow MnO_2 + 4H^{+} + 2e^{-} \quad (5)$$

2.3.2 Preparation of Filter Media or Filter Bed

Iron and manganese particles that remained suspended in the water after oxidation were caught by filters. Because these deposits have a catalytic effect on the oxidation process, when the grains of the filter medium got covered in iron or manganese oxides, the procedure was often more successful. Filter material such as supporting gravel, coarse and fine sand is used in both the adsorption and filter basins. Selecting sand and gravel, washing the sand and gravel, drying the sand and gravel, converting the sand particles to each particle size, and filtering the sand using sieve analysis were all phases in the creation of natural sand filter media (0.5, 1.18, 9.50 mm size). When new washed and sieved sand was given to the filter unit, coarse and fine sand got too thin, the filter was more efficient and cleaner with time.

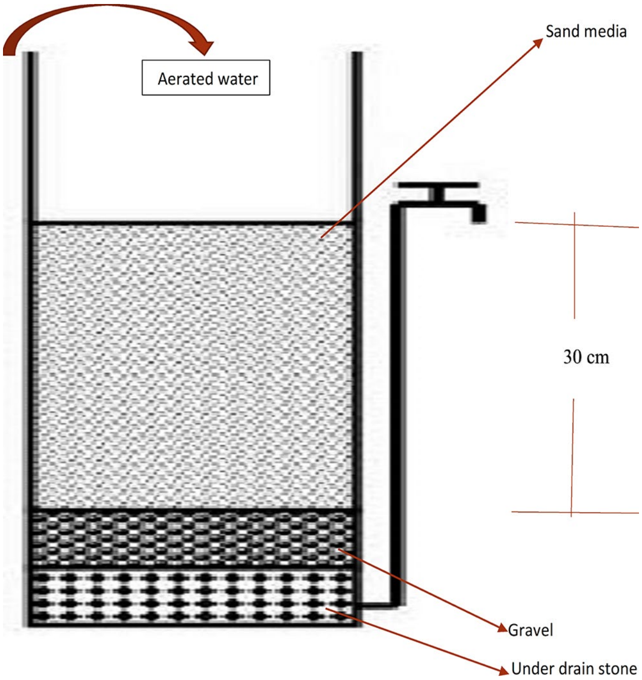

Fig. 2 Sketch of simple slow filtration processes by using natural sand materials

2.3.3 Sampling Data Collection Procedure

The raw water samples were collected in plastic bottles from issued areas of deep groundwater samples with high iron and manganese contents, and the bottle was rinsed or washed by water to be sampled before the water was collected [31]. As a result, groundwater samples of 2 and 25 L were obtained. As a result, prior to filtering, aeration was done, and 25 L of aerated groundwater samples were collected. After aeration, all water quality measures were evaluated to see how they changed.

Aeration of groundwater aids the precipitation of ferrous and manganese. Following that, a one-liter treated water sample was obtained in each filter media to assess the concentration of each parameter, and aerated water samples were added to the filter media after rinsing or cleaning the filter media with deionized water many times with the sample water. Finally, groundwater iron and manganese precipitate concentrations were reduced. The quality of raw water (Fe and Mn concentrations) and processed water (at outlets with separate filtering columns) was assessed throughout the study.

The amount of water entering the filter columns and the amount of water exiting the columns at the same time were measured using water characteristics. The concentrations of Fe and Mn, as well as other elements, were measured in each ml sequentially before and after the treatment, and then the concentrations of the aqueous phase were measured using the Palin test (photometer 7100), which includes all major water quality parameters and is made in England, making water quality testing simple and easy by following the method [32].

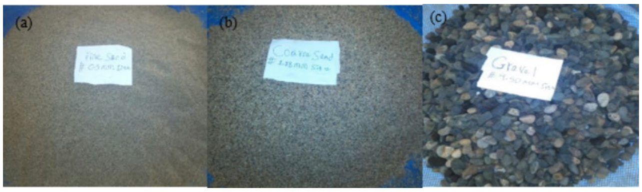

Fig. 3 Sand materials: - fine sand(a); coarse sand (b) and gravel (c) after sieve analysis in the laboratory

2.3.4 Experimental Setup

The filter bed design included depths of 10, 15, 20, 25, and 30 centimeters. The down flow filter is made up of a layer of supporting gravel with a grain size of 10 cm at the bottom, and coarse sand with a size of 1-1.18 mm inserted before fine sand with a size of 0.3–0.5 mm on the top, with a thickness of 4.75–9.50 mm. 1.18 mm effective size with uniformity coefficients ranging from 1.2 to 1.8, and 0.5 mm effective size with uniformity coefficients ranging from 1.30 to 1.75, The basin also has a treated water exit and an overflow outlet 5 cm below the filter bed. To avoid erosion of the filter's top layer during water filtering, a layer of flat stone was raised above the sand. Finally, pour the aerated water to the desired level, wait 1–5 h for contact time, and then filter the supernatant water if necessary. Arrangement of filter material was indicated in Fig. 2.

The overall efficiency of the system is removing both iron and manganese in groundwater. The following shows the calculations used to obtain the efficiency of natural sand filtration [33]. The different types of sand material used in this experiment was shown in Fig. 3.

$$\%E_{Fe} = \frac{(befor\ treatment - after\ treatment)}{befor\ treatment} \times 100 \tag{6}$$

$$\%E_{Mn} = \frac{(befor\ treatment - after\ treatment)}{befor\ treatment} \times 100 \tag{7}$$

2.3.5 Data Quality Control Assurance

The quality of the data was assured through reanalysis of samples using standard operating procedures. The samples were duplicated and the average values were reported to ensure reproducibility. Each sample of water was initially

Table 1 Physico-chemical analysis of the treated and raw water samples collected from deep wells in Gilgel Beles town water supply

No	Parameter	Unit	Raw water	Treated water	WHO Guideline	Ethiopian Standard
1	pH	-	8.5	6.85	6.5–8.5	6.5–8.5
2	Color	TCU	15.5	0.0	15	15
3	Turbidity	NTU	5.4	0.0	5	5
4	Conductivity	µs/cm	387	359	NA	NA
5	Temperature	oC	28.5	25	12–25	12–25
6	Iron	mg/L	5.79	0.09	<0.3	<0.3
7	Manganese	mg/L	4.1	0.11	<0.1	<0.5
8	Chloride	mg/L	0.46	0.12	250	250
9	Nitrate	mg/L	0.81	0.26	50	50
10	Sulfate	mg/L	0.63	0.14	250	250

characterized in accordance with Standards. The iron and manganese levels in the treated groundwater complied with Ethiopian and World Health Organization (WHO) drinking water requirements. The concentrations of $\mathrm{Fe}^{2+}$and Mn^{2+} were measured using a Palintest (photometer 7100). (palintest 7100). Data was compared with authors to ensure the accuracy of the results.

3 Results and Discussion

To improve the quality of deep drinking water with high iron and manganese content, the use of iron and manganese filtering systems must be considered; thus, selecting the most appropriate design depends on the cost of materials and ease of construction [33]. As Table 1 indicated that the raw water was heavily polluted with iron and manganese, and that the treated groundwater sample was within WHO Guidelines and Ethiopian Standards for drinking water quality permissible limits.

3.1 Physico-chemical Parameter Removal Efficiency of Different Depths of Coarse Sand

The initial concentration of iron and manganese in the raw water samples was 5.79 mg/L and 4.11 mg/L, respectively. At the beginning of an experiment, the high concentration of Fe and Mn in groundwater decreased by aeration on filtration, it was reduced to 0.09 mg/L for iron and 0.11 mg/L for manganese. Figure 4 (a) and (b) indicated that the concentration of iron and manganese reduced due to increasing the size of coarse sand. The best filter media was coarse sand, which produced the highest percentage and outstanding results for iron and manganese removal. The filter media was accomplished with a treatment for 0 to 30 cm of natural sand filter depth.

The result in Fig. 4 (c) showed that the removal of pH concentration using natural sand by 0 to 30 cm filter the depth in the coarse sand. The pH serves as an index to denote the extent of pollution by acidic or basic waste. The pH values were found between 6.85 and 85. The pH shows a slightly alkaline nature of all samples [34]. Pure water is neutral, with a pH close to 7.0 at 25 °C. Safe ranges of pH for drinking water are from 6.5 to 8.5 for domestic use and living organisms need [34]. As shown in Fig. 4 (c), the concentration of pH reduced as the depth of coarse sand was increased. The optimum value of pH was obtained at 20 cm depth of coarse sand.

Figure 4 (d) depicts that the removal of color with different depth of coarse sand. As the figures we explain that the reduction of color was increased as the depth of coarse sand was increased. The true color was measured after filtering the water sample to remove all suspended material. Pure water is colorless, which is equivalent to a 0 color unit obtained at 24.5 cm depth of coarse sand[34]. Turbidity is the cloudiness of water caused by a variety of particles and is another key parameter in drinking water analysis[35]. Turbidity in water and wastewater is caused by the presence of suspended particles, fine organic matter, bacteria, various types of sludge, and colloidal particles [36, 37].The turbidity also may produce the coloring effect [27]. Therefore, the color and turbidity were reduced due to the aeration and filtration process that increased the removal efficiency of turbidity. Groundwater normally has very low turbidity because of the natural filtration that occurs as the water penetrates passes through the soil.

Figure 4 (e) indicated that the reduction of turbidity at different depth of coarse sand [34]. Null turbidity was obtained at 25 cm depth of coarse sand. High water temperature enhances the growth of microorganisms and may increase taste, odor, color and corrosion problems [38]. Figure 4 (f) has shown that the temperature of sample water was reduced as the depth of coarse sand was increased. The optimum value of temperature was obtained at 30 cm of coarse sand. The initial concentrations of chloride, nitrate & sulfate were very low in groundwater.

The result presented in Fig. 4 (g), (h), and (i) shows that the reduction of chloride, nitrate, and sulfate concentrations with the depth of coarse sand increases. The conductivity of a material depends on several factors including temperature

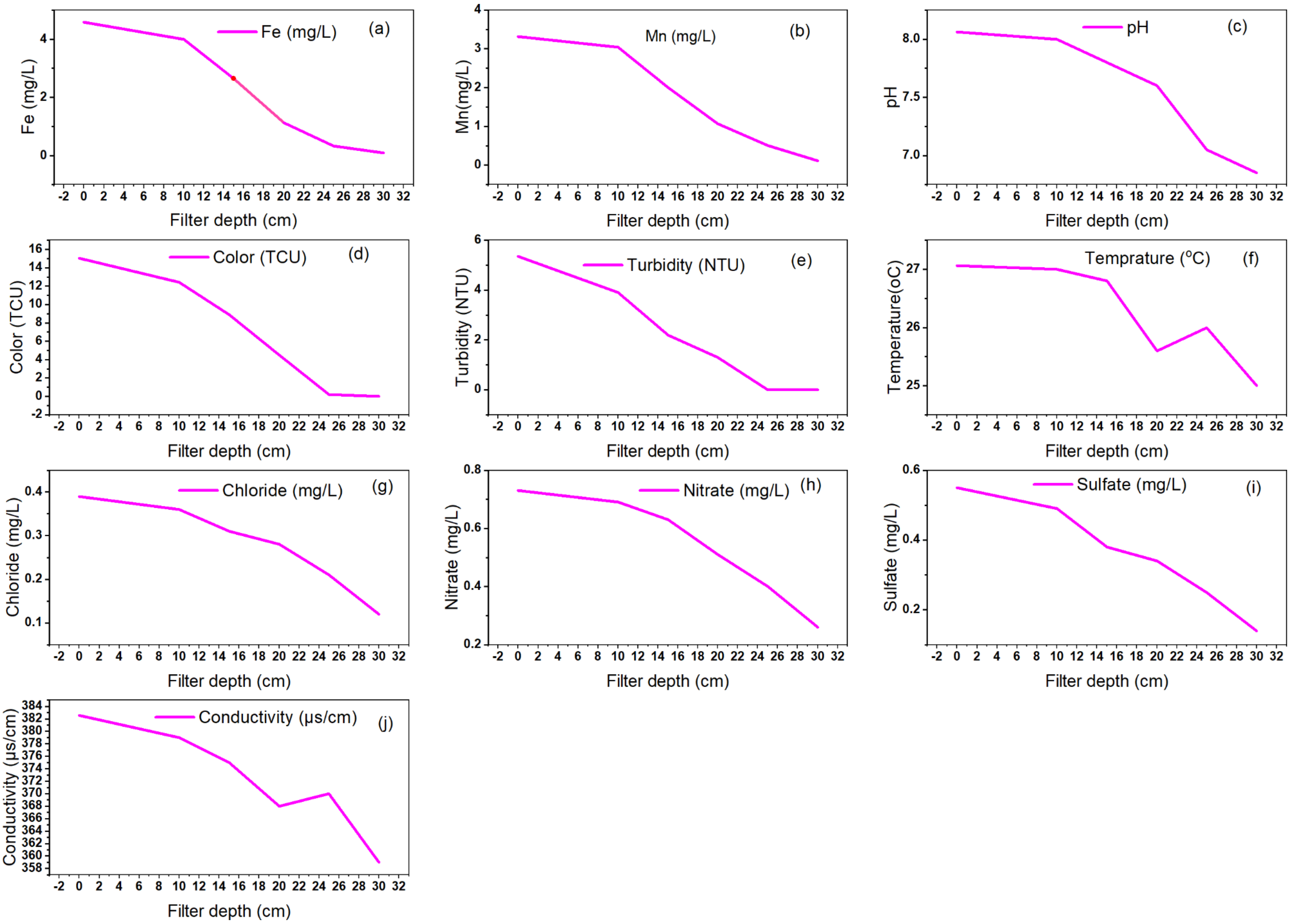

Fig. 4 Concentration of Fe (a); Mn (b); pH (c); Color (d); Turbidity (e); Temperature (°C); Chloride (g); Nitrate (h); Sulfate (i) and Conductivity (j) with filter depth

and the presence of impurities. As observed from Fig. 4 (j), the conductivity of the sampled water reduced as the coarse sand size was increased. Generally, as observed from Fig. 4, the concentrations of each parameter were reduced as the depth of coarse sand increases, this was because of the contact between the water and the surface of the media was increased.

3.2 Effect of Filter Run (Time) in Filter Media

The result in Fig. 5 has shown that the effect of time on the removal of Fe and Mn using aeration and sand filtration. It was shown that increasing the time of filtration and increasing the removal efficiency of iron and manganese. The removal efficiency of iron and manganese in coarse sand was achieved with a treatment time of 5 h. For each digestion time of the potable water, the time and filter depth were important operating for each parameter to consider under the present study.

Figure 5 shows that the maximum iron and manganese removal percentages during the experiment were good for coarse sand, which ranges from 98.44% for iron to 97.31% for manganese. Iron had a higher removal efficiency than manganese, as seen in Fig. 5. This indicated that there is no iron leaching in mixed-media filters as a result of iron consumption within the filter being greater than manganese consumption, which is to be expected given that the redox potential required for oxidation of this metal is significantly lower than that required for iron oxidation [39].

During the first 6 min of constant shaking, the elimination of Fe and Mn rose dramatically, reaching 80%. This indicates that a significant amount of Fe, and Mn were adsorbed during the first step of the adsorption process. The increase in driving force in the solution, which might increase the number of accessible active sites on the surface of coarse sand [18], resulted in a rapid increase in Fe and Mn removal in the first 6 min. Figure 5 demonstrates that Fe and Mn adsorption was greater than 90% when the contact duration reached 10 min, indicating that equilibrium had been attained at 10 min.

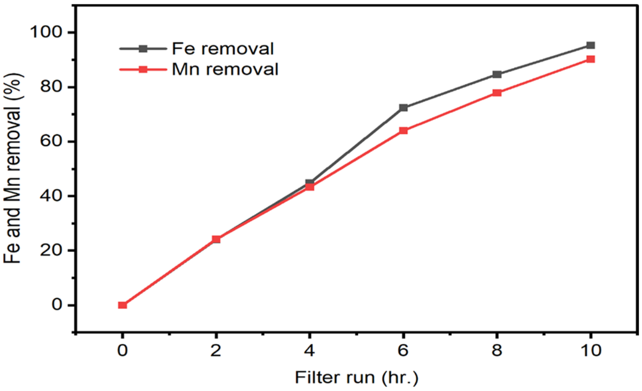

Fig. 5 Effect of filter run on removal of Fe and Mn by coarse sand process

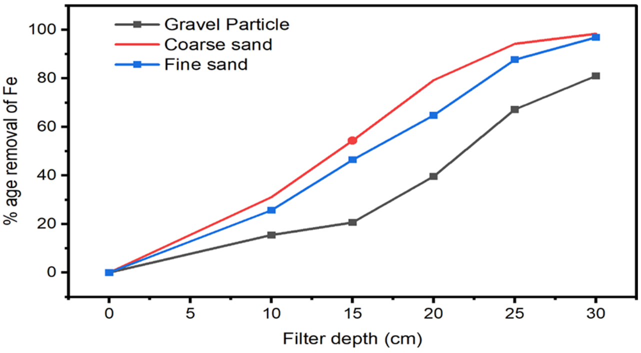

Fig. 6 Iron removal efficiency in different sizes of filter material

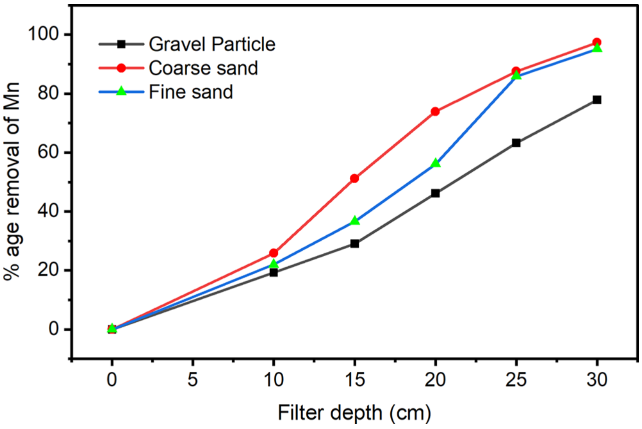

Fig. 7 Manganese removal efficiency in different sizes of filter material

3.3 Effect of Natural Sand Filter Size

For the removal of iron and manganese, several filtration materials were used, including coarse sand, fine sand, and supporting gravel particles. The effect of filter depth on Fe and Mn removal was substantially higher, resulting in longer contact time within the filter material. As a result, increasing the filter depth improves the removal efficiency of iron and manganese from groundwater.

The results were presented in Figs. 6 and 7 showing that the removal efficiency of iron includes 98.44% for coarse sand, 96.89% for fine sand, and 81.03% for gravel particles for sand. The removal efficiency of manganese includes 97.31% for coarse, 95.12% for fine, and 77.9% for gravel sand, respectively. The filter media was achieved with a treatment at 30 cm of sand filter depth. Fe and Mn were almost removed by natural sand filter materials so better to removal. The effect of different types of sand on the removal of iron from ground water is also shown in Fig. 7. According to [40], when the effluent iron concentrations of the three types of sand were compared, it was clear that coarse sand was the best type of filter media, as it resulted in the highest percentage of iron removal for the same sand depth.

3.4 Data Quality Checking Results

While it is imperative for every researcher to gather data that is highly accurate, comprehensive, representative, and comparable, it is well recognized that a water quality dataset frequently includes missing values, outliers, and suppressed values. Every data analysis study should begin with a routine check for incorrect and unusual data items. However, even though the development of computers and other software has made it simple to analyze vast amounts of data, a lack of fundamental statistical knowledge could lead to the use of an incorrect technique. In the end, this can result in costly decisions for both the environment and people. These make it necessary to have a fundamental understanding of the data characteristics and statistical techniques that are frequently used in the water quality industry.

The experiment was repeated several times to ensure the accuracy of the data and the representativeness of the findings. Three trials were conducted for this investigation, and the average value was taken for additional examination. As Fig. 8 indicated that, each parameter was evaluated three times and the average value was determined. According to Fig. 8, the results from these three experiments for each parameter were closely connected.

The WHO Guidelines for Drinking-Water Quality, Second Edition, served as a major foundation for the national standards (the latest guidelines at the time). Different types of water have varying qualities, and a certain quality is necessary for a particular function. The primary uses of groundwater are for drinking and domestic use. It is closely correlated with the consumer's health. As a result, regional and international standards should be used to preserve quality. WHO (World Health Organization) and Ethiopia have guidelines for many parameters to determine whether the water are suitable for drinking [41].

As shown in Fig. 9, the treated groundwater sample met the WHO guidelines and local standards for acceptable

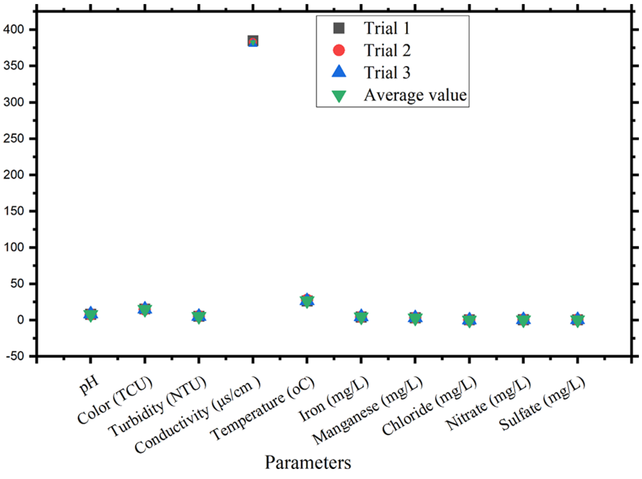

Fig. 8 Different experimental result at selected physico-chemical parameters

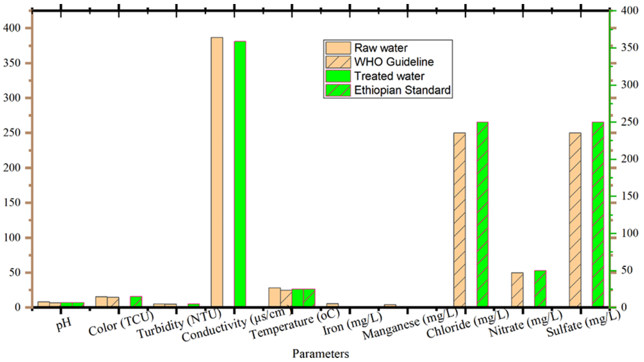

Fig. 9 Comparison of raw water and treated water quality with local and WHO standards

drinking water quality, despite the raw water's heavy iron and manganese contamination. The other all parameter in the study area was found with in WHO and local standards. After treatment the value of Fe and Mn was 0.09 mg/L and 0.1 mg/L respectively. This value was with in WHO (0.3 mg/L and 0.1 mg/L) and Local (0.3 mg/L and 0.5 mg/L) standards for Fe and Mn respectively. According to this study, the majority of the important physical and chemical characteristics of ground water are suitable for drinking and domestic purposes and generally fulfill local and WHO standards with little variation.

Comparing the outcome with those of earlier studies with comparable goals was one technique to ensure that the discovery was accurate. As can be seen from Table 2, various researchers have investigated the removal of iron and manganese using various methods. According to the results, the procedure used was successful in removing iron and manganese, just like in the current study.

Table 2 Comparison of Fe and Mn removal with previous studies

Authors	Methods	Types of water	Medium used	Result of removal
[42]	Iron leaching	In aqueous oxalic acid	Ultrasound-assisted oxalic acid	75.4% maximum Fe removal
[43]	Filtration (dynamic flow columns)	Groundwater at landfill sites (synthetic groundwater)	Calcium carbonate-based materials: limestone and crushed concrete	Effective Fe removal is more than 99.4% (< 0.3 mg/L of effluent concentration
[44]	Filtration	Drinking water	Limestone, Iron coated sand and sand	Maximum removal of Fe (99.8%) was obtained with coated sand
[20]	Membrane Filtration	Ground water	Powdered activated carbon and membrane bioreactor PAR-MBR	Produced effective effluent from 15 mg/L and 1.2 mg/L to < 0.2 mg/L and 0.1 mg/L of Fe and Mn respectively.
[45]	Biosorption	Groundwater	Rosa centifolia waste biomass as biosorbent	Effective removal of 82.78% of Mn
[46]	Aeration-filtration	Artificial raw water	3.68 and 5.21 mm anthracite	Effective removal of 81% of Mn
[47]	Biosorption	Groundwater	Saccharomyces cerevisiae yeast strain as biomass	83% of Mn removal
[16]	Adsorption	Groundwater	Iron-oxidized bacteria with limestone	Effective removal Fe and Mn 81.72% and 83.63% respectively
Current study	Aeration-filtration	Groundwater	10 cm Gravel, 1-1.81 mm coarse sand, and fine sand 0.3–0.5 mm	Maximum removal of Fe (98.44%) and Mn (97.31%) was obtained with coarse sand

4 Conclusion

For the sake of the consumer's health, drinkability must be ensured throughout the water distribution network and maintained at all times. Raw water transportation and the water environment throughout the distribution network, as well as the water combination of several networks, all have a significant impact on the quality of water in a distribution network. According to the findings of this study, aeration and natural sand filtration processes are more effective in removing iron and manganese from groundwater. Almost all variables have been lowered. As a result, increasing the depth of the groundwater filter will boost the iron and manganese removal efficiency. The residual concentrations of each measure are within WHO and Ethiopian recommendations. For both metals, changing the contact time affected the removal efficiency. As a result, it was suggested that the contact time be extended to maximize the removal efficiency, and that the bed height be increased to optimize Fe and Mn removal column efficiency. According to the data, coarse sand was more successful for removing iron than manganese. Of the three-sand media tested, coarse sand was the most effective at removing both iron and manganese. As compared to different media by different researchers, aeration and natural sand filtration are effective for reducing Fe and Mn. It is simple to set up and inexpensive to operate, so it is possible to use even at the household level.

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Data Availability This manuscript contains all of the data. The data is accessible upon request from the corresponding author.

Declarations

Declaration of Competing Interests The authors declare no conflict of interest.

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