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(RESEARCH ARTICLE)

Development of groundwater pollution removal technology

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Abstract

A trial treatment plant model was constructed and the performance of the model was found to be effective as an effective technique for removing iron and other contaminants from groundwater. With an effective size of 0.45 mm, a uniformity factor of 1.5 and a porosity of 0.6, the filter material was able to filter water with a high iron content and other parameters. The backwash speed of the sand filter is 1.44 m/s (86.4 m/h). At this speed, the pressure was sufficient to cause the media to expand and boil, so that the iron sludge, flakes and other dirt remained in the filter. Nine (9) daily inflows and outflows at depths of 60 cm, 70 cm and 80 cm were determined. An iron removal efficiency of 99.1% was achieved at a depth of 60 cm and 90.63% at a depth of 80 cm. Similarly, the model was able to remove physical and organoleptic parameters (color, turbidity, fluorine, manganese, nitrite, Ph, zinc, E-coli and total coliforms). The technology developed in this research can be used as an alternative, simple and cost-effective way to remove iron and other contaminants from groundwater.

Keywords: Groundwater; Iron; Pollutants; Filtration; Sand

1. Introduction

Groundwater is currently one of the most important sources of water supply in rural areas of Nigeria. Most people trust groundwater quality over all sources. However, one of the problems of groundwater among several pollutants is in some cases a high iron content. Most water supplies contain some iron because iron is common in many igneous rocks and is found in small amounts in sedimentary rocks [1]. Iron is usually found in ferric (Fe^3) and precipitated form in surface water, often with suspended solids; Iron found in foods such as offal, dried legumes, York egg, cocoa, shellfish, milk and milk products, ground flour, potatoes [2]. On the other hand, ferrous iron (Fe^2) is found in most groundwater and in the deep zones of some eutrophic water bodies [1].

Iron in drinking water is not dangerous to health. To some extent, iron is an essential nutrient for the human body. Iron in the human body for males is about 49 mg/kg and 38 mg/kg for females Depending on its severity, iron deficiency may or may not have symptoms. Constant fatigue, even during adequate rest, is the most common sign. Other symptoms may include paleness, tired and sore muscles, headache, dizziness and shortness of breath.. The iron content of water is important because small amounts seriously affect the usability of water for domestic and industrial purposes [2]. Iron present above 0.2 or 0.3 ppm is usually highly objectionable [3]. Some industries such as dying, tanning, paper making and finishing cannot even tolerate more than 0.1 mg/L iron [1].

However, another problem of iron in water is aesthetic. Iron also gives the water a metallic acid test; Food cooked in water with a high iron content gets an unpleasant color and clothes get stained during washing. That is why people always abandon the use of high iron drill holes and return to other available options. Therefore, this study is aimed at using appropriate technology to remove iron and other pollutants from groundwater.

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1.1. Study area

The location of this study is National Water Resources Institute, Mando Road in Kaduna North Local Government Area, Kaduna State. The geographical location recorded on global positioning system (GPS) $10^{0}34'57''$N and $7^{0}25'10''$E with total land area of 1.79km, (Figure 1)

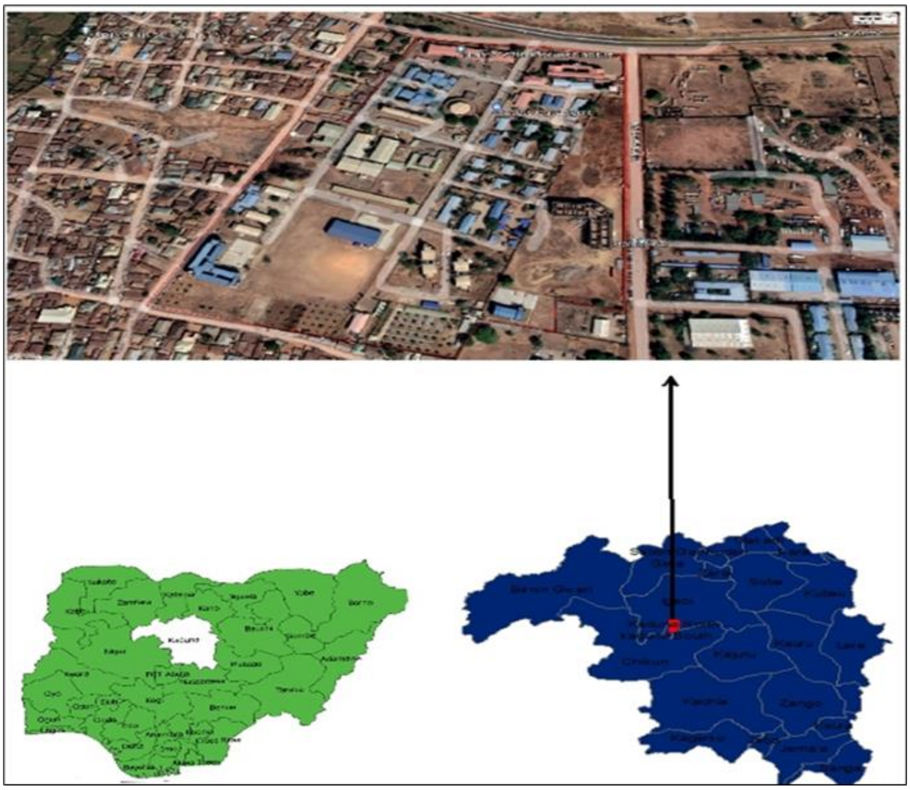

Figure 1 Location Map of study area

2. Material and methods

2.1. Filter Media

2.1.1. Sand samples site and collection.

Sand sample was collected along river Kaduna specifically at Unguwar Kukumaki about 30 km from Kaduna metropolis.

2.2. Determining the physical properties of the filter material

Various materials and equipment were used to determine the physical properties of the device Sand filter sample. These are: **I.** Standard British strainer set with an opening size of; 2.36 mm, 1.7 mm, 1.18 mm, 0.6 mm, 0.425 mm, 0.212 mm, 0.0150 mm and 0.075 mm for sieve analysis. **II.** Mechanical electric shaker. **III.** Beam balance. **IV.** Special heavy bottles. **V**. Measuring cylinders.**VI**. Decanter glasses. **VII**. Concentrated Hydrochloric Acid (HCL).

2.2.1. Determining the physical properties of the filter material

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II. Mechanical electric shaker.
III. Beam balance.
IV. Special heavy bottles.
V. Measuring cylinders.

VI. Decanter glasses.
VII. Concentrated Hydrochloric Acid (HCL).

2.3. Methods of determining physical properties of the sand

2.3.1. Effective size and uniformity coefficient.

The sample collected from Kaduna River and the dry 100 g portion of the sample imported from France were examined to determine effective size (ES) and uniformity coefficient (UC). The samples were sieved through a standard British sieve with the following apertures: 4.75 mm, 2.36 mm, 1.18 mm, 0.600 mm, 0.425 mm, 0.300 mm, 0.212 mm, 0.075 mm and cup. The sieves were arranged in the above order from top to bottom. A test sieve was used to shake and sieve the sand sample for 10 minutes. The percentage **of** weight passing each sieve was determined using an electronic balance and the results were plotted on logarithmic paper relative to the sieve size. The sieve size that allowed a 10% by weight sand sample (d_{10}) to pass through the test area is interpolated to give the effective sample size (ES). In the same way, a sieve size was obtained that allowed to pass a 60 mass percent sand sample (d_{60}). The uniformity coefficient U_C is a measure of the size range of the medium. The U_C was calculated using Equation 1.

$$\text{UC} = \frac{d_{60}}{d_{10}} \quad 1$$

2.3.2. Specific gravity

The weight of the empty specific gravity bottle was measured with an electronic scale and recorded as W1. Three quarters of the bottle was filled with the sand sample and the weight was recorded as W2. Water was added to the sand sample up to the rim of the bottle when the sand was completely submerged and the value was noted as W3. Finally, the bottle was filled with water only and recorded as W4. The specific gravity is calculated using Equation 2.

$$\mathbf{S.G} = \frac{W_{2-W_1}}{(W_{4-W_1})-(W_{3-W_2})} \quad \mathbf{2}$$

2.3.3. Porosity

The method used to determine porosity is the Wisconsin Model Academic Standards (WMAS). method A 100 ml beaker was filled with the sand sample up to the 75 ml mark. A 100 ml cylinder was filled with water to the 100 ml mark. Water was poured from the measuring cylinder into the beaker containing the sand sample until it reached the level where the sand was placed (75 mL mark). The amount of water needed to saturate the sand (fill the pores) was recorded directly from the cylinder. The sand void volume was recorded as Vv. The total volume was recorded as V. Porosity (%). Porosity is calculated using Equation 3.

$$\mathbf{n} = \frac{V_v}{V} \mathbf{x\,100} \quad \mathbf{3}$$

2.3.4. Acid solubility

The method recommended by [4] was adopted to determine the acid solubility of the sand samples. Sand samples of 100 g were taken and washed with distilled water to remove dust and fine materials. The sample was then dried in an oven and weighed on a laboratory electronic scale. The weighed sample was then immersed in 40% (v/v) hydrochloric acid (HCL) at room temperature for 24 h. The sample was then thoroughly washed with distilled water, dried in an oven, and finally reweighed to determine weight. The solubility was then calculated using Equation 4.

$$\text{Solubility (\%)} = \frac{\textit{Loss in weight}}{\textit{original weight}} \text{x } 100 \quad 4$$

2.3.5. Water quality evaluation and process selection

The first step in developing a new iron removal plant or upgrading an existing plant is to fully assess raw water quality and develop treatment and finished water quality objectives. Raw water quality parameters such as iron and manganese levels, chlorine, TOC levels, pH, H2S levels, NH4 content, hardness and dissolved oxygen levels can all affect water treatability and the treatment process selected. Treatment goals must be set that take into account ready water. Prepared water must meet all current and pending regulations. Other criteria to consider are capital costs, ease of use, backflow capabilities, operating costs, regulatory approval of the

2.3.6. Iron

The photometer is calibrated with the sampling water sample. The test is simply done by adding an iron tablet (alkaline thioglycolate) to a 10 ml water sample. The contents are allowed to stand for 1 minute for full color development. The resulting color is directly proportional to the iron content and is measured with a 7100 wagtech photometer.

2.3.7. Evaluation of the borehole at NWRI Kaduna

Water quality assessment: Samples were taken to assess the quality and level of pollutants. The sample was collected from a borehole where iron disposal is planned to be built. Sampling of the well began by pumping water from the well for over an hour (flushing). After washing, the water sample was collected from the pump spillway using glass and plastic containers. Below is the results of the water quality parameters analyzed according to the standards methods of examination of water and wastewater {4}.

T able 1 Concentration of parameters before treatment

S/No.	**Parameters**	**Unit**	**Sample of water from NWRI borehole**	**Maximum Permitted Level**	**Remarks**
1	Clour	TCU	Reddish brown	15	Astatically unacceptable
2	Odour			Objectionable	Pungent smell of iron
3	Test			Objectionable	Metallic test of iron
4	Temperature	^oC		Ambient	
5	Tubidity	NTU	46.8	5	Above limit
6	Conductivity	µS/cm	151.7	1000	
7	Calcium	mg/L	10		
8	Fluoride (F^-)	mg/L	0.81	1.5	Ok
9	Iron (Fe^{+2})	mg/L	2.5	0.3	833.33% above limit.
10	Magnesium (Mg^{+2})	mg/L	9	20	Ok
11	Manganese (Mn^{+2})	mg/L	0.026	0.2	Ok
12	Nitrate (NO_3)	mg/L	2.90	50	Ok
13	pH	-	6.7	6.5-8.5	Ok
14	Sodium (Na)	mg/L		200	
15	Sulphate (SO_4)	mg/L	0.00	100	Ok
16	Total Alkalinity	mg/L	43		
17	Total Dissolved Solids	mg/L	75.7	500	Ok
18	Total Hardness	mg/L	45	150	Ok
19	Zinc (Zn)	mg/L	3.48	3	Above limit
20	Escherichia coli	cfu/100ml	0	0	Ok
21	Total coliform	cfu/100ml	40	10	Above limit

Pilot filtration testing apparatus

The pilot plant constructed for testing the quality of the filtrate and the designing of the filter depth (thickness of sand) comprises the following components:

- An aeration tank with spray aerator for proper oxidation of iron two (Fe^2) to iron three (Fe^3).
- A tank for containing charcoal to remove odour
- A filtration column constructed using 650 mm diameter transparent pipe containing:
    - Gravel of 0-3.3 mm size and 15 cm thick,
    - Sand of 1.18 mm diameter size and 30 cm thick,
    - Sand of 600 microns diameter and 25 cm thick.

Manometers manifolds were fixed at various heights so that filtered water is collected at various heights (depths) per unit time. Figure 2: Schematic section of treatment plant. Figure 3 below shows the photograph of the constructed pilot model plant.

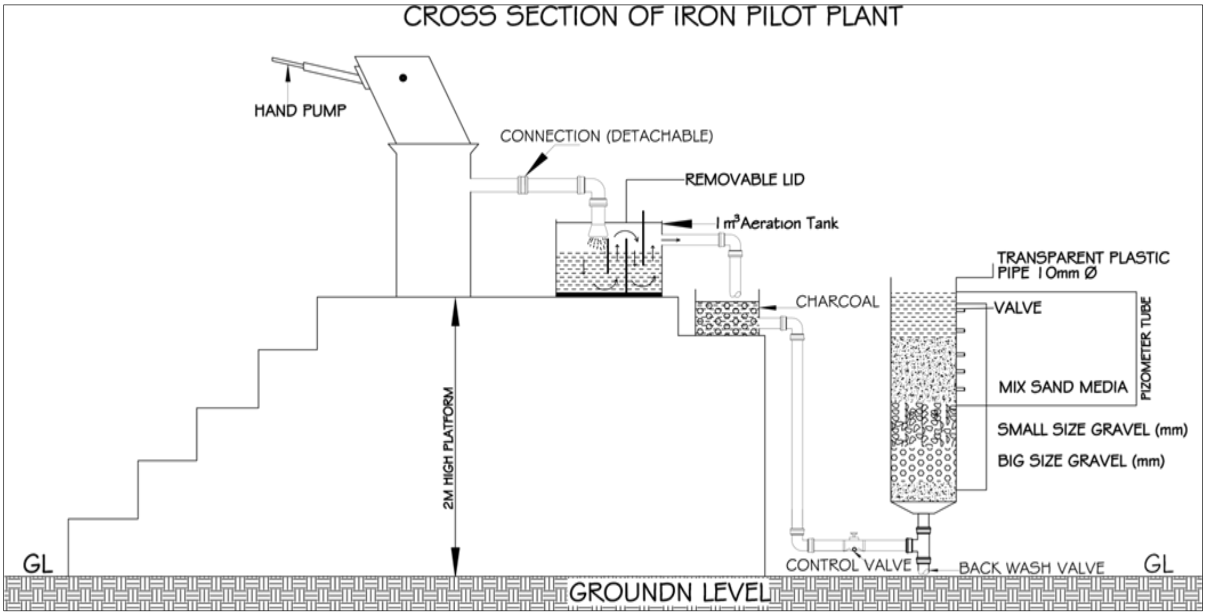

Figure 2 Schematic section of the treatment plant

Figure 3 Photo of the constructed iron removal pilot model plant

3. Results and discussions

3.1. Kaduna river sand

From the sieve analysis result, it was discovered that 9.07% of the sample was retained on sieve size 1.18mm, and 24.11% was retained on sieve size 600micron. This mean that 33.18% portion of the sample was discovered to be useful as filter media in the iron removal process.

3.2. Depth determination

[5] reported that "the majority of rapid sand filters in use today contain sand with an effective size of 0.35 - 0.50mm, although some have sand with E_S as high as 0.70mm[6] presented a porosity range of 0.35 - 0.50. However,[2] guidelines gave the effective size (E_S) range from 0.45 – 1.00mm, uniformity coefficient (U_C) 1.20 – 1.70, and porosity of 0.42 – 0.47. From the sieve analysis result, it was discovered that the sand filter media has E_S value of 0.45mm, U_C is 1.50 and porosity is 0.46. All the above results fall within the acceptable standard ranges. [7] Reported that, a uniformity graded soil will have its coefficient of uniformity of less than 2.0. This means that both the filter media are uniformly graded since they have the value of 1.50.

For depth selection, [8] was used alongside with the effective size of each filter media. The depth of the sand should range from 500 – 700mm. [6] suggested that the specific gravity of filter media should not be less than 2.5, and acid solubility of less than 5% (loss by weight). The result obtained from test on the filter media showed that both the specific gravity and acid solubility are within the acceptable limit. The filter media has the specific gravity is 2.6 and acid solubility (loss by weight) is 0.23%. The gravel which is the under drain has specific gravity of 2.7 and porosity of 0.60.

3.3. Backwash rate design

With a specific gravity of 2.6, which is within the prescribed standard, the filter material has enough weight to withstand the high pressure during the backwash process, which can cause material loss. The backwash rate is calculated using the above specific gravity and D90. The results revealed that the backwash velocity of the sand filter medium is 1.44 m/s (86.4 m/h). The standard of backwash speed is 37-49 m/h. At this rate, there is enough pressure to cause the medium to expand and boil to remove iron sludge, flakes and other dirt trapped in the filter. Based on the above result, the material can withstand reasonable backwashing without fear of material loss.

3.4. The filters performance on iron

The pilot plant constructed for the purpose of this study was used to filter raw water with high iron concentration. and other pollutants. Results of the daily analysis of the treatment plant performance is as follows.

3.4.1. First day

During the first 10 minutes of treatment at a depth of 30 cm, the iron concentration decreased from 0.21 mg/L to 0.14, which is 33.33% removal; At 50 cm depth, it decreased from 0.21 mg/L to 0.01 mg/L, which is 95.24% removal, and at 60 cm depth, it decreased from 0.21 mg/L to 0.11 mg/L, which is 47.62%. After 30 minutes, the removal was 33.33% at 30 cm depth, 66.67% at 40 cm depth, 100% complete iron removal at 60 cm depth, 71.43% at 70 cm depth, and 95.24% at depth. 33.33 at a depth of 80 cm and 90 cm. After 120 minutes, 100% was removed at 50 cm depth, 62% at 60 cm depth, 76.20% at 70 cm depth, 81% at 80 cm depth and 100% at 90 cm depth. After 140 minutes, 100% were removed from a depth of 60 cm and 67% from a depth of 70 cm.

3.4.2. Second day

The iron concentration was 1.0 mg/L and after 20 min of treatment it was reduced to 0.02 mg/L, which means 98% removal at 50 cm depth, 100% removal at 60 cm depth and 98% removal at 70 cm depth and 97% removal at 80 cm depth. After 90 minutes, 94% was removed at a depth of 50 cm, 96% at a depth of 60 cm, 99% at a depth of 70 cm, and 96% at a depth of 70 cm. After 120 minutes of treatment, 99% was removed at a depth of 50 cm, 97% at a depth of 60 cm, 96% at a depth of 70 cm, and 94% at a depth of 80 cm. After 165 minutes of treatment, 99% was removed at 50 cm, 98% at 60 cm, 95% at 70 cm and 98% at 80 cm. After 240 minutes of treatment, 98% of the iron was removed at 50 cm, 93% at 60 cm, 100% at 70 cm and 99% at 80 cm.

3.4.3. Third day

After 120 minutes of treatment, 100% of 0.11 mg/l was removed from depths of 50, 60 and 70 cm, respectively. After 240 minutes of treatment, 82% was removed at 40 cm, 64% at 50 cm, 90% at 60 cm, 90% at 70 cm and 90% at 80 cm.

3.4.4. The fourth day

After 10 minutes of treatment, iron content decreased from 0.16 mg/L to 0.04 mg/L, representing 75% removal at 50 cm depth, 100% total removal at 60 cm depth, 75% removal at 70 cm depth and 13% at 80 cm depth. After 50 minutes treatment, total removal was 100% at 50 cm depth, 87.5% removal at 60 cm depth and 94% removal at 70 cm depth and 56.25% removal at 80 cm depth. After 95 minutes of treatment, 81.25% was removed at a depth of 50 cm, 75% was removed at a depth of 60 cm, total removal was 100% at a depth of 70 cm, and 75% was removed at a depth of 80 cm. After 220 minutes of treatment, 81.25% was removed from the 50 cm depth, 100% from the 60 cm depth, 75% from the 70 cm depth, and 87.5% from the 80 cm depth.

3.4.5. The fifth day

Only a depth of 60 cm was used. After 30 minutes of treatment, the iron content was reduced from 0.17 mg/L to 0.1 mg/L, which is 41.18%, 64.71% removed after 60 minutes, 88.2% removed after 120 minutes, and 64.71% after 180 minutes, 76.40% after 40.40% and 40.40% after 40.2%.

3.4.6. The sixth day

Only a depth of 60 cm was used. After 30 minutes of treatment, 0.14 mg/L of iron was reduced to 0.04 mg/L, which is 71.43%, 85.71% was removed after 60 minutes, 64.29% was removed after 120 minutes, 85.71% was removed after 180 minutes, and 90% was removed after 862 minutes. After 120 minutes of treatment, 57.14% of the filtrate was removed from the charcoal.

3.4.7. The seventh day

Only a depth of 60 cm was used. After 60 minutes of treatment, 0.14 mg/L of iron was reduced to 0.00 mg/L, which is 100%. Viscosity was 92.86% at 120, 180 and 240 minutes and 85.71% at 300 minutes.

3.4.8. Eighth day

Only a depth of 60 cm was used. After 60 minutes of treatment, 0.14 mg/L of iron was reduced to 0.00 mg/L, which is 100%. 92.86% were discharged after 180 minutes, 78.57% after 240 minutes and 71.43% after 300 minutes and 92.86% after 360 minutes. At the end of the process, the filter performance of the plant is presented in Figure 2.

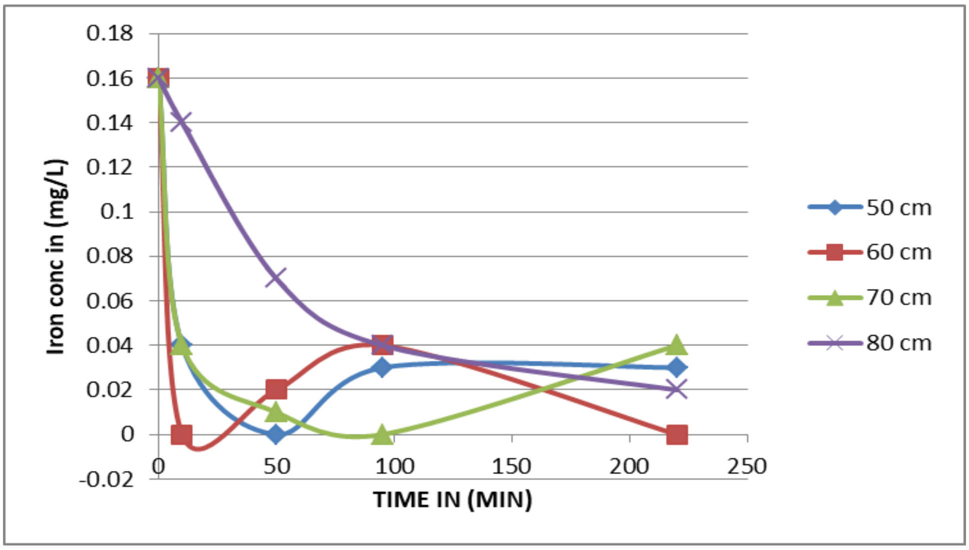

Figure 4 Filter performance on iron at different depths'

Table 2 Performance of the treatment plant on physical/organoleptic, inorganic constituent and microbiological parameters analyzed

S/No.	Parameters	Unit	Sample of water from NWRI borehole	Sample of treated water at 60 cm depth	NSDWQ Maximum Permitted Level	WHO Maximum Permitted Level	Remarks
1	Clour	TCU	Reddish brown	5	15	15	Removed
2	Odour			0	Objectionable	Inoffensive	Removed
3	Taste				Objectionable	Inoffensive	Removed
4	Temperature	^{o}C		29.5	Ambient	Ambient	Ok
5	Turbidity	NTU	46.8	2.8	5	5	94% was Removed
6	Conductivity	μS/cm	151.7	174.4	1000	1000	Ok
8	Fluoride (F^-)	mg/L	0.81	0.25	1.5	1.5	Ok
9	Iron (Fe^{+2})	mg/L	2.5	0.00	0.3	0.3	100% Removed
10	Manganese (Mn^{+2})	mg/L	0.026	0.00	0.2	0.1	100% Removed
11	Nitrate (NO_3	mg/L	2.90	0.76	50	11.3	72% was removed
12	pH	-	6.7	8.09	6.5-8.5	6.5-8.5	Ok
13	Sulphate (SO_4)	mg/L	0.00	0.00	100	250	Ok
14	Total Dissolved Solids	mg/L	75.7	85.4	500	1000	Ok
15	Total Hardness	mg/L	45	68	150		Ok
16	Zinc (Zn)	mg/L	3.48	0.07	3	3	98% was Removed
17	Escherichia coli	cfu/100ml	0	0	0	0	Ok
18	Total coliform	cfu/100ml	40	6	10	10	85% was Removed

4. Conclusion

The research focused on removing iron from water. The iron factory pilot was built with transparent materials so that the manufacturing process could be seen. These units are holding tank, aerator, flocculation tank, and carbon tank and filtration column. Raw water from the plant was run through a high-iron well and the results were compared with drinking water standards established by NSDWQ and WHO..

Based on the above result, the material can withstand reasonable backwashing without fear of material loss. The iron content of the well water, which was 2.5 mg/l, completely removed 100% of the raw water withdrawn from a depth of

60 cm during several moments of treatment. Result of this research, an alternative, simple and cost effective way to remove iron and other pollutants from water, especially groundwater.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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