JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMNTAL ENGINEERING

ENVIRONMENTAL ENGINEERING CHAIR

REMOVAL OF IRON AND MANGANESE FROM GROUNDWATER BY USING AERATION AND NATURAL SAND FILTRATION TECHNIQUES, METEKLE ZONE, BENISHANGUL GUMUZ REGIONAL STATE, WESTERN ETHIOPIA

BY: TAGAY ADDISU

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF JIMMA INSTITUTE OF TECHNOLOGY, JIMMA UNIVERSITY IN PARTIAL FULFILMENT OF THE REQUIREMENTS OF THE MASTERS OF SCIENCE IN ENVIRONMENTAL ENGINEERING.

OCTOBER, 2021

JIMMA, ETHIOPIA

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OCTOBER, 2021

JIMMA, ETHIOPIA

DECLARATION

I declare that, this thesis entitled "the removal of iron and manganese from groundwater by using aeration and natural sand filtration techniques the case of gilgel beles town water supply, metekle zone, benishangul gumuz regional state, western Ethiopia" is my own original work, and has not been submitted as a requirement for the award of any degree in Jimma University or elsewhere.

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ABSTRACT

Groundwater is the most commonly used drinking water source for gilgel beles town. The concentrations of iron and manganese are commonly present in groundwater at worldwide. At gilgel beles town the concentrations of iron and manganese found in groundwater are beyond the standard, thus, concentrations of iron and manganese in domestic water supply may cause unpleasant taste, affect color and flavor of food and cause staining of different products also encourages bacterial growth in water distribution networks which affect the pipes transfer efficiency but in general they do not cause health problems in aerobic conditions they form sediments: dark brown (manganese) or brown-red (iron). Therefore, the study was to remove iron and manganese from groundwater supply of gilgel beles town by using aeration and natural sand filtration. Aeration and rapid sand filtration were commonly used methods for the removal of iron and manganese from groundwater. Aeration was carried out before filtration by spraying the water in the form of fine droplets into the air, thus creates a large gas-liquid interface for O_2 transfer. This study was used different filtration materials for the removal of iron and manganese, including coarse sand, fine sand and supportive gravel. The pure water was passed through the filter beds easily for all the control units and experimental filter units. The filtrate from all the units were analyzed separately for iron and manganese concentration at a depth of 10, 15, 20, 25 and 30 cm of the filter run according to the standard methods. The initial concentration of iron and manganese sample raw water was 5.79 mg/L and 4.11 mg/L respectively. At the beginning of an experiment that was high concentration of iron and manganese in which was reduced by filtration was 0.09 mg/L for iron and 0.11 mg/L for manganese. The removal efficiency of iron and manganese during the experiment was good for coarse sand varying from 98.44% and 97.31% for iron and manganese respectively. Also, the correlation coefficient, $R^2>0.994$ for iron and $R^2>0.999$ for manganese within filter media was achieved with a treatment at 30 cm of natural sand filter depth. It was also found that there was a regular pattern of increase the removal efficiency of iron and manganese from groundwater with the increase in natural sand filter depth. Therefore, natural sand is more effective in removing iron and manganese from groundwater and it is locally available.

***Keywords:** Aeration; Filtration; Gilgel beles; Groundwater; Iron; Manganese; Natural sand.*

ACKNOWLEDGEMENTS

ACRONYMS

BGRS	Benishangul Gumuz Regional State
BSF	Bio-Sand Filtration
E	Efficiency
EPA	Environmental Protection Agency
EWQS	Ethiopian Water Quality Standard
IOB	Iron Oxidizing Bacteria
JiT	Jimma Institute of Technology
MCL	Maximum Contaminant Level
MF	Membrane Filtration
MoH	Ministry of Health
NTU	Nephelometric Turbidity Unit
POE	Point of Entry
R^2	Correlation of Coefficient
RSF	Rapid Sand Filter
TCU	True Color Unit
WHO	World Health Organization

CHAPTER ONE

INTRODUCTION

1.1　Background of the study

Groundwater is the major source of drinking water in many countries across the world. Groundwater is the most common source of drinking water in Ethiopia boasts a population of about 114 million people and urban areas are more than rural areas have access to safe drinking water sources and to provide all Ethiopians with access to basic sanitation, almost all drinking water is from groundwater. Groundwater is generally considered as the best source for potable water as it is well protected from contamination. Groundwater quality has become an important water resources issue due to rapid increase of population, rapid industrialization, unplanned urbanization and too much use of fertilizers and pesticides in agriculture (Gizachew et al., 2020).

Groundwater plays a vital role in the production of clean and adequate drinking water supply all around the world so that, the groundwater is an important source of drinking water (Sharma et al., 2018). Groundwater is abstracted through hand-dug wells; hand-pump operated shallow-wells and submersible pump operated deep well or boreholes (Ojo, 2002). Groundwater is often high in mineral content such as magnesium and calcium salts, iron and manganese depending on the chemical composition of the stratum through which the water flows (Nitzsche et al., 2015).

Groundwater is characterized by a low temperature (7-10°C), a low redox potential (absence of oxygen), a high carbon dioxide concentration, a high mineral content (high alkalinity and hardness) and a very low suspended solid content (Fito et al., 2019). The extensive use of groundwater can be due to its ease of access, better protection from pollution sources, higher water quality as compared to surface water (Obiefuna and Orazulike, 2010), less subject to seasonal and perennial changes, uniformly spreading over large areas and also lower capital cost of production. These benefits have resulted in groundwater use for water supply at large scale. Groundwater contamination can pose serious threat to human health. The most common sources of groundwater pollution include waste disposal practices, storage and handling of materials and waste, saline water intrusion and agricultural activities (Karakish, 2005).

Iron and manganese are commonly present in groundwater at worldwide. Iron and manganese are among the most abundant metals in the earth's crust. Iron and manganese are occurring naturally in groundwater where both elements are present in anoxic environment (Sarewitz et al., 2012).

Iron and manganese are usually present in groundwater as but little dissolved oxygen is often colored - reddish- brown with iron or black if manganese is present and existence of iron and manganese in water causes many problems like water coloring and taste, clothes staining, deposits on laundry and plumbing fixtures. High iron and manganese concentrations may cause a bitter taste and encouraging bacterial growth in water distribution networks which affect the pipes transfer efficiency but in general they do not cause health problems. Iron and manganese have been causing problems for regulatory authorities in connection to industrial and main water supplies for a long time (Mohd Sanusi et al., 2016).

To solve this problem a better technology has to find, make the water quality that used to have a standard quality. The removal of iron and manganese from ground water accomplished by oxidation, precipitation and sand filtration for separation the oxidation metal (Tekerlekopoulou and Vayenas, 2007). Aeration and rapid sand filtration commonly used method for the removal of iron and manganese from groundwater. The iron and manganese content can be dissolved and go back to the groundwater. The anthropogenic sources include industrial effluents, landfill leakages, acid mine drainage, etc. leading to a high iron and manganese concentration in groundwater (Obiri-Nyarko et al., 2015).

Natural sources of heavy metal may include weathering and erosion of bedrocks and ore deposits. Some heavy metals like lead, chromium and mercury may impose acute toxicity even in lower concentrations. Other metals like magnesium, calcium, iron and manganese however are necessary to sustain the vital body function in trace amounts (Biyani et al., 2017). When iron and manganese are present in water as soluble form in drinking water supplies, then come across many objectionable problems related to their presence (Hoque, 2006).

Another thing that is needed to determine the system that was used for the removal iron (Fe) and manganese (Mn) is water characteristics, such as temperature, pH, turbidity, taste, color, conductivity, and soon. The temperature used to initialize a factor for aquatic life associated

with the life cycles, for pH indicate whether the water acidic or alkaline (pH 1.0-14.0), while turbidity, taste and color can know by discoloration and taste in water (Obiefuna and Orazulike, 2010).

Natural sand can be used as a filter material for removal of iron and manganese from groundwater. The conventional aeration followed by filtration is the most effective water treatment method used to remove iron and manganese concentrations. Before iron and manganese can be filtered, they need to be oxidized to a state in which they can form insoluble complexes (Antunes et al., 2016).

The most commonly applied method to remove iron and manganese from groundwater is the oxidation-filtration processes. A low-cost method of oxidation used in water treatment process for groundwater would be aeration, which is a relatively simple process and does not require the use of chemicals. It is often sufficient with aeration and filtration to lower the levels of iron and manganese to acceptable levels and also be used like depth filtration with special media like sand particles (Ahmad, 2012). Therefore, this study was conducted the removal of iron and manganese from drinking groundwater by using aeration and natural sand filtration.

1.2   Statement of the problem

Iron and manganese are two chemically similar elements in causing problems that can be a nuisance to a drinking water supply. Iron is more common than manganese, but they often occur together. Although iron and manganese in a household water supply are not hazardous to health, they can cause different types of problems. The high concentration of iron and manganese can give water an unpleasant taste, odor and color. The flavor of food and water can be affected due to the presence of iron and manganese, because they can react with tannins in coffee, tea and alcoholic beverages producing black sludge. Another unpleasant side-effect of the presence of iron and manganese bacteria is that they often create hydrogen sulfide as a by-product - giving water an unpleasant "rotten egg" odor.

Iron can cause reddish- brown staining of laundry, utensils, dishes and glassware. Soaps and detergents do not remove these stains. The excessive concentrations of manganese were result in metallic taste or bad tasting and smelling wat in water. Manganese causes brownish-black

stains on the same materials. staining of different products like clothes, paper and plastics, water use plumbing fixtures, pumps and valves.

Iron and manganese deposits build up in pipelines, pressure tanks, water heaters and water softening equipment. These deposits restrict the flow of water and reduce water pressure and amount of available water and also increase in cost of water using appliances. Buildup can be expensive when it results in repairing of water softener or plumbing. More energy is required to pump water through clogged pipes and to heat water if heating rods are coated with mineral deposits. This raises energy and water costs. Water contaminated with iron and manganese often contains iron or manganese bacteria. These bacteria feed on the minerals in the water.

Iron and manganese can be effectively removed from water using a number of treatment processes depending on both the form and concentration of the metals. Since iron and manganese are aesthetic problems that affect all potential uses of the water, they must be removed from all water entering the home using Point-of-Entry (POE) treatment devices.

1.3 Objectives of the study

1.3.1 General objective

The general objective of this study is to remove iron and manganese from groundwater supply of gilgel beles town by using aeration and natural sand filtration.

1.3.2 Specific objectives

The specific objectives of the study are: -

1. To investigate the effect of pH, color, turbidity, conductivity, temperature, chloride, nitrate and sulfate on the removal of iron and manganese using natural sands.
2. To investigate factors that influence aeration and natural sand filtration processes on removing iron and manganese from groundwater in the filter media.
3. To determine the iron and manganese removal efficiency of natural sands.

1.4 Research questions

1. What is the effect to measure the removal of iron and manganese concentrations of each parameter from groundwater using natural sands?
2. What are the factors that influence aeration and natural sand filtration processes on removing iron and manganese from groundwater in the filter media?
3. What is the removal efficiency of iron and manganese using natural sands?

1.5 Significance of the study

The World Health Organization stipulates that the maximum acceptable level of iron in drinking water must be less than 0.3 mg/L and for manganese <0.1 mg/L respectively. The Ethiopian Standard has established secondary standards of 0.3 mg/L for iron and less than 0.5 mg/L for manganese. So, if concentrations are higher than the standards, then water must be treated before use. If water is not treated then there can be different problems for water consumers and also for that municipality that delivers drinking water to consumers (Khadse et al., 2015).

Aeration and filtration can be an effective, low-cost method to remove iron and manganese. Aeration reduces the carbon dioxide content of water and thus decreasing the solubilization tendencies of water, which causes iron and manganese in water are not considered as health hazards but mainly as esthetical technical and economic problems. Aeration and filtration may

be advantageous because it does not add chemicals to the water. Aeration units also require a filter for removal of the oxidized iron and manganese which must be backwashed.

Aeration and filtration techniques to remove iron and manganese are in use now, but the search for better, cheaper and safer technique never stops. Oxidation runs on suitable beds, where filtration and adsorption take place simultaneously. The most often used bed are sand beds, which are often enriched in other materials.

The works over searching for environmentally friendly, local availability, more effective materials as bed media for iron and manganese removal are still in progress. One of such materials are natural sands. It is reduced customer compliant due to taste, rust, and staining clothing and other house hold materials. This study was improved safe water free from iron and manganese pollutant.

Finally, the finding of this study uses as reference for future researcher for further investigation of the similar issues.

1.6   Scope of the study

This study was focused on removal of iron and manganese from groundwater using low cost, abundant and locally available raw materials using aeration and natural sand filtration concentrated at gilgel beles town water supply.

CHAPTER TWO

REVIEW OF LITERATURE

2.1. Nature and occurrence of iron and manganese

Iron and manganese are common elements in the earth's crust. As water percolates through soil and rock it can dissolve these minerals and carry them into groundwater. Also, iron pipes can corrode and leach iron into a household water supply. Iron and manganese are common metallic elements that occurs together naturally especially in deeper wells with little or no oxygen present. Natural sources of iron and manganese may include weathering of iron and manganese bearing minerals like amphibole, iron sulfide and iron rich clay minerals. In areas where groundwater flows through an organic rich soil, iron and manganese will also dissolve in the groundwater (Homoncik et al., 2010).

Iron and manganese in water also promote the growth of bacteria including iron bacteria. These organisms obtain energy for growth from the chemical reaction that occurs when iron and manganese mix with dissolved oxygen. These bacteria form thick slime growths on the walls of the piping system and on well screens. These shines tend to be our rust-colored from iron and black-colored from manganese. Variations in flow can cause these slime growths to separate from pipe walls, resulting in dirty water in the system. Iron and manganese can also have anthropogenic sources including industrial effluents, landfill leakages and acid mine drainage. Well casing, pump parts, piping and storage tank can also contribute iron and manganese to groundwater (Karakish, 2005).

In natural conditions, water percolates through the organic soil where dissolved oxygen is consumed by the decomposition of organic matter and microbes in the soil. The decomposition process reduces the pH due to the microbial action. In combination with the lack of oxygen, the iron and manganese atoms are also reduced from Fe^{3+} and Mn^{4+} to Fe^{2+} and Mn^{2+} (Nitzsche et al., 2015). The most dominant form of dissolved iron is the soluble Fe^{2+} under the pH range of 5 to 8. When groundwater is pumped up to the surface it gets into contact with air (O_2) which enters the solutions and starts the oxidation process that releases carbon dioxide (CO_2) from the groundwater to the atmosphere. When this happens, the pH values are

increased and hence the Fe^{2+} and Mn^{2+} are changed into the insoluble Fe^{3+} and Mn^{4+} minerals (Barloková and Ilavský, 2010).

$$CH_2O + 2MnO_2 + 3H^+ \rightarrow 2Mn^{2+} + HCO_3 + 2H_2O \text{ -- (1)}$$

$$CH_2O + 4Fe(OH)_3 + 7H^+ \rightarrow 4Fe^{2+} + HCO_3 + 10H_2O \text{ -- (2)}$$
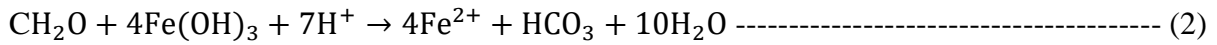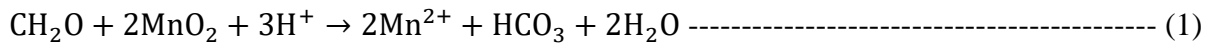
Iron is 5% of the rocks in the earth's crust are formed by iron oxides or other iron compounds which can be in either ferrous (Fe^{2+}) or ferric (Fe^{3+}) forms. The form and solubility of iron in natural water are strongly dependent upon the pH and the oxidation-reduction potential of the water. Iron may also be present in drinking-water systems as a result of the use of iron coagulants or the corrosion of steel and cast-iron pipes during water distribution (Kwakye-Awuah et al., 2019).

Manganese is found in the divalent (Mn^{2+}) and the quadrivalent (Mn^{4+}) forms. Manganese is much less abundant in the earth's crust than iron. Manganese is the fifth most common metal in the earth crust. Apart from the fact that solutions of manganese compounds are more stable and therefore more difficult to treat than ferrous solutions, the removal procedures are similar for both metals (Shahin et al., 2019).

Iron and manganese occur in dissolved forms as single treatment is mostly related to undesirable concentrations of (Fe, Mn) or in undissolved higher forms mainly as $Fe(OH)_3$ or $Mn(OH)_4$, respectively. They can also be present in colloid form (bound to humic substances). The form of their occurrence depends on oxygen concentration, solubility of Fe and Mn compounds in water, pH value, redox potential, hydrolysis, the presence of complex-forming inorganic and organic substances, water temperature, and water composition e.g. CO_2 content (Biyani et al., 2017).

2.2.   Iron and manganese in groundwater

Groundwater with a low redox potential often contains soluble iron and manganese ions. As this water does not contain much oxygen, some micro-organisms reliant on oxygen for survival can only exist in this environment by reducing ferric compounds into the ferrous form. In the same way manganese is reduced from the quadrivalent to the divalent form (Jeż-Walkowiak et al., 2015).

Iron and manganese can form complexes with organic matter (humic substances). In this case, iron is normally present in its ferric form and bound in the molecular structure of the humic compounds. Further they write that occurrence of manganese and iron in groundwater which will eventually become drinking water is a serious environmental issue and that the removal of the two substances is essential (Kamel, 2012).

2.3. Factors affecting the removal of iron and manganese

The removal of dissolved iron and manganese from groundwater is generally accomplished by the oxidation and filtration. The removal process is affected by the different chemical and physical characteristics of water including pH, temperature, total organic carbon (TOC) and concentration of dissolved oxygen (Elsheikh et al., 2020).

In general, the removal of iron and manganese greatly influenced by some parameters, such as pH, temperature, turbidity, color and electrical conductivity (EC). The oxidation rates are faster at high pH values and slow at low pH values. The oxidation by aeration demands a pH greater than 5.8 for iron and more than 4.1 for manganese. Carbonic acid lowers the pH value of water and hence slows down the oxidation rate (Jeż-Walkowiak et al., 2015).

Increased temperature also enhances the oxidation reactions while lower temperature slows down the oxidation process. In general, the rate of reaction is double for every 10-degree Celsius temperature increase. In the presence of higher concentrations of total organic carbon, the oxidation of iron and manganese is reduced due to less available oxygen. In totality, the time factor also plays a crucial role. The precipitation of manganese takes a longer time than precipitation of iron. Normally, precipitation of iron can take place within minutes but the precipitation of manganese can take more than hours (Elsheikh et al., 2020).

2.4. Physicochemical quality of iron and manganese from water

The term physicochemical quality is used in reference to the characteristics of water which may affect its acceptability due to aesthetic considerations such as color and taste; produce toxicity reactions, unexpected physiological responses of laxative effect, and objectionable effects during normal use such as curdy precipitates (Shah, 2017).

pH

pH is one of the most important parameters of water quality. It is defined as the negative logarithm of the hydrogen ion concentration. It is a dimensionless number indicating the strength of an acidic or a basic solution. Acidic water contains extra hydrogen ions (H^+) and basic water contains extra hydroxyl (OH^-) ions. The pH of the test waters is significant during the removal of iron and manganese. It is apparent that oxidation of iron and manganese depends on holdup time and pH. Thus, removal of iron and manganese using aeration and sand filtrations a practical proposition. The pH of the water influences how much time is needed for the reaction to be completed. After oxidation of the iron and manganese, the water must be filtered to remove the precipitated iron and manganese (Alley, 2007).

In addition, small changes in water quality may affect the pH of the water and the oxidation rate may slow to a point where the plant capacity for iron and manganese removal is reduced. Fe^{2+} and Mn^{2+} oxidation rate as well as hydrolysis of emerging oxides of higher iron and manganese oxidation forms in groundwater depends on the pH value. Various graphic dependencies of these relationships with respect to oxidation time are listed in literature. The pH value should be equal or greater than 7 in removal of iron from groundwater. Adjusting the pH to alkaline levels also reduces the corrosivity of the water to pipes and plumbing (Vries et al., 2017).

 pH ranges from 0 to 14, with 7 being neutral. pH of less than 7 indicates acidity, whereas a pH of greater than 7 indicates a base solution. Pure water is neutral, with a pH close to 7.0 at 25°C. Normal rainfall has a pH of approximately 5.6 (slightly acidic) owing to atmospheric carbon dioxide gas. Safe ranges of pH for drinking water are from 6.5 to 8.5 for domestic use and living organisms need. Therefore, water with a pH below 6 or above 9.5 can be corrosive to metal plumbing pipes and fixtures. There are two methods available for the determination of pH: electrometric and colorimetric methods (Fito et al., 2019).

Color

The presence of Fe and Mn in high concentrations is undesired in drinking water as these metals are well known contributors to color and turbidity. Iron causes staining of clothes and dishes in washing machines. Besides, high concentrations of iron favor bacterial growth in water transmission and distribution systems. It was found that iron and manganese were partially removed during conventional treatment and appeared in treated water which developed yellowish to brown red color. Normally the color is depending on the suspended particles of the water (Vries et al., 2017).

Inorganic contaminants, such as metals, are also common causes of color. Other contaminants that may be related to change in water color include iron, manganese aluminum, copper and total dissolved solids. Materials decayed from organic matter, namely, vegetation and inorganic matter such as soil, stones, and rocks impart color to water, which is objectionable for esthetic reasons, not for health reasons. Color is measured by comparing the water sample with standard color solutions or colored glass disks. True color is measured after filtering the water sample to remove all suspended material. Color is graded on scale of 0 (clear) to 70 color units. Pure water is color less, which is equivalent to 0 color units (Obiefuna and Orazulike, 2010).

Turbidity

Iron and manganese ions can cause staining of laundry clothes and plumbing fixtures, and lead to the accumulation of sediment in the water delivery system. The presence of high iron and manganese concentration from groundwater also causes bad odor, taste and color, and increases the turbidity of the water. They can also raise the color and turbidity of the groundwater. The iron and manganese reduction causes the cutback of color and turbidity measurements. The turbidity also may produce the coloring effect. Aeration and filtration processes increases the removal efficiency of color and turbidity (Malkov and Sadar, 2010).

Turbidity in drinking water is esthetically unacceptable, which makes the water look unappetizing. The impact of turbidity can be summarized in the following points:

It can increase the cost of water treatment for various uses, The particulates can provide hiding places for harmful microorganisms and there by shield them from the disinfection process, Suspended materials can clog or damage fish gills, decreasing its resistance to diseases, reducing its growth rates, affecting egg and larval maturing, and affecting the efficiency of fish catching method, Suspended particles provide adsorption media for heavy metals such as mercury, chromium, lead, cadmium, and many hazardous organic pollutants such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and many pesticides, The amount of available food is reduced because higher turbidity raises water temperatures in light of the fact that suspended particles absorb more sun heat. Turbidity often is associated with surface water sources. Treatment includes mixing with a substance such as alum that causes filtration of the suspended materials, which then can be removed by sand filter filtration. Consequently, the concentration of the dissolved oxygen (DO) can be decreased since warm water carries less dissolved oxygen than cold water (Alley, 2007).

Turbidity more than 5 NTU can be visible to the average person while turbidity in muddy water, it exceeds 100 NTU. Groundwater normally has very low turbidity because of the natural filtration that occurs as the water penetrates through the soil (Obiefuna and Orazulike, 2010).

Electrical conductivity (EC)

When the presence of high concentration of iron and manganese ion in the groundwater the conductivity of electric current also increase. The electrical conductivity (EC) of water is a measure of the ability of a solution to carry or conduct an electrical current. Since the electrical current is carried by ions in solution, the conductivity increases as the concentration of ions increases. TDS can be used to estimate the ionic strength of water in the applications of groundwater recharging by treated wastewater. The normal method of measurement is electrometric method (Li et al., 2016).

Temperature

Temperature is important because of its influence on water chemistry. The rate of chemical reactions generally increases at higher temperature. Water, particularly groundwater, with higher temperatures can dissolve more iron and manganese from the groundwater. Therefore, it will have a higher electrical conductivity. Temperature exerts a major influence on biological activity and growth (Li et al., 2016). The effect of temperature, and especially changes in temperature, on living organisms can be critical and the subject is a very wide and complex one. The importance of temperature in water quality is derived mainly from its relationship with other water quality parameters. Most of these relationships have a bearing on the aesthetic aspects of water quality; some are indirectly related to health. The sweetness of drinking water is to some extent dependent on temperature. Palatability, viscosity, solubility, odors, and chemical reactions are influenced by temperature. Thereby, the sedimentation and chlorination processes and biological oxygen demand (BOD) are temperature dependent. It also affects the biosorption process of the dissolved heavy metals in water. Most people find water at temperatures of 10–15°C most palatable (Li et al., 2016).

Chloride

Chloride occurs naturally in groundwater, streams, and lakes, but the presence of relatively high chloride concentration in freshwater (about 250 mg/L or more) may indicate wastewater pollution. An increase in the normal chloride content of water may indicate possible pollution from human sewage, animal manure or industrial wastes. Chlorides may enter surface water from several sources including chloride-containing rock, agricultural runoff, and wastewater. Chloride ions Cl^- in drinking water do not cause any harmful effects on public health, but high concentrations can cause an unpleasant salty taste for most people. Chlorides are not usually harmful to people; however, the sodium part of table salt has been connected to kidney and heart diseases. Small amounts of chlorides are essential for ordinary cell functions in animal and plant life (Dandwate, 2012).

Nitrate

Nitrogen in the nitrate form is a basic nutrient to the growth of plants and can be a growth-limiting nutrient factor (Fito et al., 2019).

A high concentration of nitrate in surface water can stimulate the rapid growth of the algae which degrades the water quality. Nitrates can enter the groundwater from chemical fertilizers used in the agricultural areas. Excessive nitrate concentration (more than 10 mg/L) in drinking water causes an immediate and severe health threat to infants. The nitrate ions react with blood hemoglobin, thereby reducing the blood's ability to hold oxygen which leads to a disease called blue baby or methemoglobinemia (Fito et al., 2019).

Sulfate

Sulfate ions (SO^{2-}) occur in natural water and in wastewater. The high concentration of sulfate in natural water is usually caused by leaching of natural deposits of sodium sulfate (Glauber's salt) or magnesium sulfate (Epson salt). High sulfate content also affects the taste of water and forms a hard scale in boilers and heat exchangers. If high concentrations are consumed in drinking water, there may be objectionable tastes or unwanted laxative effects, but there is no significant danger to public health (Obiefuna and Orazulike, 2010).

2.5.   Effect of iron and manganese on water quality

Adverse effects of higher Fe and Mn concentrations in drinking water can be summarized as follows: Iron (II) and manganese (II) ions are oxidized to higher forms in a water distribution system and this results in the formation of hydroxide suspensions causing undesirable turbidity and color of water. The presence of iron and manganese bacteria in water supply system causes change in water quality (smell) and bacterial growth in pipes, In the case of the occurrence of iron (II) and manganese (II) ions at the consumer's point, iron and manganese are oxidized and precipitated under suitable conditions e.g., in washing machines, boilers (Syazwan et al., 2020).

Following the above-mentioned facts, higher concentrations of iron and manganese in water cause technological problems, failure of water supply systems operation, water quality deterioration and, in water with slightly higher concentrations of oxygen, they form

undesirable incrustations that result in the reduction of pipe flow cross-section (Moghny et al., 2017).

2.6. Effects of iron and manganese concentrations in drinking water

2.6.1. Effects on health, cloth and plumbing fixtures

Water containing iron and manganese has no harmful effects on humans, whereas high zinc and copper concentrations are toxic. The water quality limits for the concentrations of iron and manganese in drinking water are not based on health considerations but on aesthetic aspects. Water containing more than 0.3 mg/L iron can have a reddish-brown color and generate deposits on plumbing fixtures. High iron concentrations in drinking water may cause a bitter taste. Manganese causes brownish-black stains on the same materials. staining of different products like clothes, paper and plastics. Manganese concentrations over 0.1 mg/L in water are responsible for stained laundry and bathroom fixtures. The presence of manganese often forms a coating in pipes, which may slough off as a black precipitate (Homoncik et al., 2010).

2.6.2. Iron and manganese bacteria

Iron and manganese also enhance undesirable bacterial growth in water distribution systems. Most iron and manganese bacteria get their energy from the oxidation of ferrous iron into ferric iron and manganous in to manganic manganese. Iron and manganese are obtained either from the pipe itself or from the water inside the pipe. This process is responsible for deposits in pipes and slimy coatings on plumbing fixtures. The deposits cause a reduction in the carrying capacity of water pipes and the slime is especially bothersome in water being used for public water supply and industrial processes (e.g., food processing, cooling, paper and textile manufacture). The presence of these organisms also causes bad odor, taste and color, and increases the turbidity of the water. The same process of oxidation is caused by bacteria that utilize iron and manganese (Diaz-Alarcón et al., 2019).

2.7. Natural sand raw materials

Natural sand is a common filters material. Natural sand filters are used as a step in the water treatment process of water purification. Natural sand raw materials can be used as adsorption material for removal of iron and manganese from groundwater. Natural Sand filtration normally follows sedimentation or flotation as the final 'polishing' step in conventional water

treatment. Conventional sand filtration is also termed rapid sand filtration to distinguish it from slow sand filtration as discussed below. Sand filtration is a simple process in which the water is allowed to filter through a layer of sand in a specially constructed container. Sand filtration is the oldest and the most reliable process for removing suspended particles as well as ions, micro-pollutants, organic matter, and microorganisms, including pathogens. The main mechanism of the filtration process can be described as the removal of suspended particles from water by passing it through a porous medium in the filtration process the small remaining floc particles are removed by the sand grains and are retained in the bed of sand, while clean water flows out from the bottom of the sand bed. A sand bed filter is a kind of depth filter. Broadly, there are two types of filters for separating particulate solids from fluids: Surface filters, where particulates are captured on a permeable surface, Depth filters, where particulates are captured within a porous body of material (Jeż-Walkowiak et al., 2015).

The composition of sand varies, depending on the local rock sources and conditions, but the most common constituent of sand in inland continental settings and non-tropical coastal settings is silica (silicon dioxide, or SiO2), usually in the form of quartz.

There are a number of filter types and they can be divided into two main types pressure and gravity filters. Pressure filters consist of a vessel which is enclosed and contains the filter medium through which the water is forced under pressure. This type of filtration is used often in industries where a high degree of automation is needed, which is not valid in this case and therefore they will not be further described or treated in this report (Syazwan et al., 2020).

The gravity filters consist of a basin with an open top which is partly filled with the filter medium. The basin is drained at the bottom and the raw water is admitted to the space above the sand and flows downward through the sand and filtered by cause of gravity. The purification takes place during the waters downward passage through the sand by mechanical, biological and chemical processes taking place in the sand (Moghny et al., 2017).

The gravity filters are in turn divided into slow sand filters and rapid sand filters and they are further described in the following sections.

2.7.1. Slow sand filtration

Water passes slowly downwards through a bed of fine sand at a steady rate. The water should not be too turbid, otherwise the filter will get clogged. Pathogens are naturally removed in the top layer where a biological film builds up. A potential problem is that some households do not use this technology effectively and the water can remain contaminated. Slow sand filtration is also called biological filtration because of the biological processes that take place in the sand during the waters passage through it. The purification takes place accordingly: The water is fed through a raw water inlet into a water reservoir which rests above the filter bed. The water will remain here for 3 to 12 hours on its downward passage, depending on the velocity of the filtration. During this time the heavier particles in the water will descend to the bottom of the basin which is also the surface of the filter bed. Smaller and lighter particle will coalesce into bigger particles that will more easily be caught up further in the filtration process. The slow sand filter process about $0.2 - 0.5 \ m^3/m^2$h. The grain size of the sand lies between 0.15-0.35 mm in diameter (ANUAR, 2015).

2.7.2. Rapid sand filtration

The sand used is coarser than in slow sand filtration and the flow rate is higher. The method is used to remove suspended solids and is effective after the water has been cleared with coagulation/flocculation. There is no build-up of biological film, hence the water will still need to be disinfected. It is easier to remove trapped debris from up flow sand filters, compared to filters in which the water flows downwards. Slow sand filtration and rapid sand filtration work essentially in the same way. Water is strained through a layer of sand to remove particles in the water. The treated water is led out from the reservoir for further treatment and distribution. What makes the water flow faster through the filter medium is the size of the sand grains, which is larger in the rapid filters than that of the sand in the slow filters. For rapid sand filters the grains size lies between 0.5 – 1.2 mm in diameter. This filter type processes $5 - 10 \ m^3/m^2$h and $10 - 15 m^3/m^2$h for enclosed pressure filters (van der Merwe, 2020).

Table 2.1: Characteristics of rapid and slow sand filters

Characteristics	Rapid sand filter	Slow sand filter
Filtration rate [m/h]	5–15	0.08–0.25
Media effective size [mm]	0.5–1.2	0.2–0.5
Bed depth [m]	0.6–1.9	0.9–1.5
Run length	1–4 days	1–6 months
Ripening period	15 min – 2 h	Several days
Regeneration method	Backwashing	Scraping
Maximum raw-water turbidity	Unlimited with proper pretreatment	10 NTU

Adsorption

Sands are used to adsorb a variety of materials. This includes applications in drying, purification and separation. They can remove water to very low partial pressures and are very effective desiccants, with a capacity of up to more than 25% of their weight in water. They can remove volatile organic chemicals from air streams, separate isomers and mixtures of gases. Basically, the adsorptive filtration is operated under anoxic conditions for removal of iron and manganese where oxidation of ferrous iron and manganous manganese is suppressed i.e., in case of filtration of ground water (Demir, 2016).

A widely used property of sands is that of gas separation. The porous structure of sands can be used to "sieve" molecules having certain dimensions and allow them to enter the pores. This property can be fine-tuned by variating the structure by changing the size and number of cations around the pores. Other applications that can take place within the pore include polymerization of semi conducting materials and conducting polymers to produce materials having unusual physical and electrical attributes (Demir, 2016).

Nature of natural zeolites raw materials

The name zeolite comes from the two Greek words "zein" and "lithos" which mean "boiling stone". These zeolites are hydrated double silicates consisting of an alkali or alkali earth oxide, alumina, silica and water. Zeolites can treat undesirable cations in drinking water. Their effectiveness is recognized for the removal of certain heavy metals and radioactive elements in industrial water and iron removal and manganese water drilling. Zeolites form with many different crystalline structures, which have large open pores (sometimes referred to as cavities) in a very regular arrangement and roughly the same size as small molecules (Kwakye-Awuah et al., 2019).

Natural zeolites are environmentally and economically acceptable hydrated alumino-silicate materials with exceptional ion-exchange and adsorption properties. Natural zeolites are low-cost aluminosilicate structure is negatively charged and attracts the positive cations that reside within. Their effectiveness in different technological processes depends on their physical-chemical properties that are tightly connected to their geological deposits (Margeta et al., 2013). The unique three-dimensional porous structure gives natural zeolites various application possibilities. Because of the excess of the negative charge on the surface of zeolite, which results from isomorphic replacement of silicon by aluminum in the primary structural units, natural zeolites belong to the group of cationic exchangers. It may be concluded that better knowledge of natural zeolite properties together with growing needs for selective, stable ion exchangers in pollution reduction, water treatment, energy production, agriculture (Sangeetha and Baskar, 2016).

Natural zeolite is a new and very good natural filter medium available for the filtration of water. It offers superior performance to sand and carbon filters, giving purer water and higher throughput rates with less maintenance required. It has many advantages over sand and can be used to directly replace sand in a normal sand filter. Natural zeolites are characterized with high cation-exchange ability and molecular sieve properties; they are low-cost materials, easily available in large quantities. That is why zeolites are widely used for drinking water and wastewater treatment (Wang and Peng, 2010).

Natural zeolite minerals are recovered from deposits by selective opencast or strip-mining methods. The raw material is then processed by crushing, drying, powdering and screening. Some beneficiation processes for zeolites have been developed but these are not yet employed commerciality (Barloková and Ilavský, 2010).

2.8.   Conventional iron and manganese treatment processes

In general, one can say that if there is a problem of manganese in drinking water there will also be a problem of iron in the water. Removal of iron is less difficult than removal of manganese. Removal of manganese is almost impossible without either using an oxidizing agent (which is usually potassium permanganate($KMnO_4$)) or increasing the pH. Oxidation of iron and manganese is followed by the process of filtration that is accomplished by using sand. With the help of these filtration media insoluble oxides of iron and manganese are removed (Kim et al., 2020).

The conventional treatment methods for removal of suspended and colloidal material from water include chemical coagulation of small colloidal particles, flocculation of the small particles to form larger flocs or aggregates, followed by sedimentation and sand filtration. When the water contains a large amount of suspended material, larger suspended particles such as sand particles can be removed by means of settling without coagulation and flocculation. Very often, the removal process is carried out in two major steps: iron is eliminated first either in a physical-chemical or a biological process and then manganese is removed in a physical-chemical process. However, it is clear that application of a two-step process is more expensive and it is therefore advisable to carry out tests to determine whether it is possible to remove both iron and manganese together in one step (Barloková and Ilavský, 2010). For two-stage removal of iron and manganese, there are three main conventional removal processes:

a)   The purely physico-chemical process,

b)   biological removal of iron and chemical removal of manganese, and

c)   The purely biological process.

Table 2.2: Treatments for iron and manganese in drinking water

Cause	Indication	Treatment
Dissolved iron and manganese	Water clear when drawn but reddish or blackish particles appear as water stands Reddish-brown or black stains on fixtures or laundry	Phosphate compounds (use for < 3 mg/L iron) Water softener (use for < 5 mg/L combined concentration of iron and manganese) Oxidizing filter- manganese greensand or zeolite (use with < 15 mg/L combined concentrations of iron and manganese) Aeration/filtration (use with < 25 mg/L combined concentrations of iron and manganese)
Dissolved(colloidal) iron and manganese (organic complexes of these minerals)	Water is reddish or blackish color from the tap and color remains longer than 24 hours (no particles precipitate)	Chemical oxidation and filtration
Oxidized iron in the water supply	Water from the tap contains reddish or blackish particles that settle out as water stands	Particle filter
Corrosion of pipes and equipment	Water from the tap contains reddish or blackish particles that settle out as water stands	Raise water pH and use a particle filter
Iron or manganese bacteria	Reddish-brown or black slim in toilet tanks and sink and tub drains	Shock treatment and filtration

2.9.   Removal of iron and manganese by oxidation with aeration

According to (Alp and Melching, 2011) aeration is defined as using atmospheric air as the oxygen source and built oxygenation, this an important process in water and wastewater treatment to transfer oxygen from the gasses to the liquid phase between the atmosphere and water. Aeration brings water and air in close contact, to remove dissolved gases (such as carbon dioxide) and oxidizes dissolved metals such as iron, hydrogen sulfide and volatile organic chemicals (VOCs). Aeration system is widely used for cleansing the pollutant loads from wastewater treatment plant and mixed culture of sewage activated sludge, that supplemental aeration could be an effective approach to improve DO concentration. Aeration Oxidizes iron

(Fe) and manganese (Mn). Good aeration of the water is also important for slow, sand filtration to be effective, especially if there is not enough oxygen in the surface water. Water can easily be aerated by shaking it in a vessel, or by allowing it to trickle through perforated trays containing small stones (Hasan et al., 2014).

Aeration of iron and manganese with air is by far the most cost-effective method since there is no chemical cost; however, there are disadvantages. The oxidation process can be slowed and the reaction tank has to be quite large (if there are high levels of manganese). In addition, small changes in water quality may affect the pH of the water and the oxidation rate may slow to a point where the plant capacity for iron and manganese removal is reduced. Iron is easily oxidized by atmospheric oxygen. Aeration provides the dissolved oxygen needed to convert the iron and manganese from ferrous and manganous (soluble) forms to insoluble oxidized ferric and manganic forms. Oxygen transfer can usually be achieved using a simple cascade or diffusion of air into water, without the need for elaborate equipment. Stripping of gases or volatile compounds, however, may require a specialized plant that provides a high degree of mass transfer from the liquid phase to the gas phase (Vries et al., 2017).

Alternatively, compressed air can be diffused through a system of submerged perforated pipes. These types of aerators are used for oxidation and precipitation of iron and manganese. Air stripping can be used for removal of volatile organics (e.g., solvents), some taste- and odor-causing compounds and radon. Aeration processes to achieve air stripping need to be much more elaborate to provide the necessary contact between the air and water. The most common technique is cascade aeration, usually in packed towers in which water is allowed to flow in thin films over plastic media with air blown counter-current. The required tower height and diameter are functions of the volatility and concentration of the compounds to be removed and the flow rate (Vries et al., 2017).

Aeration effectively removes odor due to hydrogen sulphide but only partially removes, or leaves unaffected, tastes and odors caused by organic matter, biological growths or chlorination. Efficient aeration takes place in fast-flowing streams, particularly when the water splashes over rocks, weirs, etc., and it plays an important part in the self-purification of rivers. From stagnant streams and impounding reservoirs, and occasionally from underground

sources, poorly oxygenated water is obtained, and aeration is then a valuable part of the purification processes and improves the palatability of the waters (Mohd, et al., 2015).

Spray aerators

Spray aerators are usually efficient with respect to gas transfer such as carbon dioxide removal or oxygen addition. However, they require a large installation area, are difficult to house, and pose operating problems during freezing weather. Spray aerators are effective provided they can be economically designed. As a decorative fountain they can be attractive. They do however have some limitations. To produce an atomizing jet, a large amount of energy is required. The losses and the nuisance problems from the wind carryover of the spray can be considerable. Climatic conditions, particularly in cold regions, limit their usefulness (Jeż-Walkowiak et al., 2015).

Cascade aerator

According to (Rathinakumar et al., 2014). stepped cascade is very versatile in recent years because it very lows cost and speedy construction better than other aeration system. Cascade aerator also can be used to oxidize iron, manganese and to partially reduce dissolved gases (Baylar et al., 2010).

These elements can be removed during softening with lime, but most commonly iron and manganese is removed by filtration after oxidation (with air, potassium permanganate, or chlorine).

Oxidation with chlorine

Iron and manganese in water can also be oxidized by chlorine, converting to ferric hydroxide and manganese dioxide. The precipitated material can then be removed by filtration. The higher the amount of chlorine fed, the more rapid the reaction. Most treatment plants use $1 - 2$ parts of chlorine to 1 part of iron to achieve oxidation. When using this process on water containing organics such as Total organic carbon (TOC) or natural organic material (NOM), the likelihood of creating disinfection by-products (DBPs) increases (Yang et al., 2013).

Oxidation with potassium permanganate

Using potassium permanganate to oxidize iron or manganese is fairly common in Minnesota. Potassium permanganate oxidizes iron and manganese into their insoluble states. The dose must be great enough to oxidize all of the manganese, but not too great as this will produce a pink color in the water in the distribution system. Observing water being treated will indicate if adjustments to the chemical feeders are needed (Yang et al., 2018).

Potassium permanganate is typically more effective at oxidizing manganese than aeration or chlorination. Potassium permanganate is typically more effective at oxidizing manganese than aeration or chlorination. When oxidizing with potassium permanganate, the operation of the filters becomes important since the reaction also continues to take place in the filter media. The normally-used filter media (sand) will remove iron and manganese if the combined concentration is below 1 ppm. Higher concentrations require different type of filter materials (greens and others) and different methods of operation (Yang et al., 2018).

Potassium Permanganate (PP) is considered a stronger oxidant and has many advantages over other oxidants. Oxidation chemistry of iron and manganese by PP can be described as follows:

$$3Mn^{+2} + 2KMnO_4 + 2H_2O \rightarrow 5MnO_2 + 2K^+ + 4H^+ \text{-- (3)}$$

$$3Fe^{+2} + KMnO_4 + 7H_2O \rightarrow 3Fe(OH)_3 + K^+ + MnO_2 + 5H^+ \text{----------------------------------(4)}$$
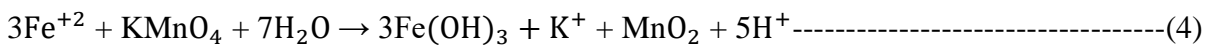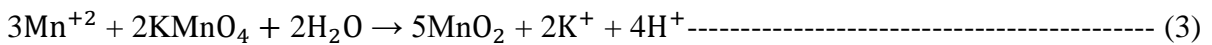
2.10. Removal of iron and manganese by filtration

Physical-chemical filters (sand filters) retain precipitated iron and manganese particles that are formed in water after oxidation. The process is often more effective when the grains of the filter media become coated with iron or manganese oxides, because these deposits have a catalytic effect on the oxidation process. Filters usually consist of layers of sand, supported by layers of gravel (Ahmad, 2012).

Removing iron and manganese from drinking water instead of sequestration it is recommended if the water contains over 0.3 ppm of iron or 0.5 ppm of manganese. These elements can be removed during softening with lime, but most commonly iron and manganese is removed by filtration after oxidation. In sand filtration there is complete physical, chemical and biological treatment in one unit. The demerit in slow sand filters is that of requirement of extensive bed

areas and non-availability of graded sand and labor intensive clearing operation (Syazwan et al., 2020).

Sequestering Agents: Many products polyphosphate treatment are marketed as "sequestering" agents. All these products use some form of polyphosphate. These products are a relatively inexpensive way to treat water for low levels of iron and manganese. Polyphosphates are a blend of phosphoric acid and other compounds that surround iron, keeping it "sequestered" or trapped; therefore, it's unavailable to react with oxygen and become a problem. This treatment will not remove the metallic taste often associated with excessive iron levels because the iron is not removed. It should not be used for water containing dissolved iron concentrations in excess of 2 mg/L or a combination of iron and manganese of more than 3 mg/l (Khatri et al., 2017).

Polyphosphate usually is introduced into the water system using a chemical injection pump. Injection should occur as close to the well discharge point as possible and before the pressure tank or hot water heater. Determining the amount of phosphate needed to lower your iron and manganese level may take a little trial and error. The water will have a slippery feel if too much is added. In addition, heat from cooking will release the iron and manganese and allow it to react with oxygen and form particles. Be aware that polyphosphates are derived from phosphorus and may contribute to a depletion of available oxygen in nearby water bodies (Volpe, 2012).

 Ion Exchange

Dissolved iron and manganese in water can be exchanged for sodium on an exchange resin or zeolite. This process of iron and manganese removal is the same ion exchange process that removes hardness or calcium and magnesium. Iron and manganese are removed during normal operation of the water softener. They, along with calcium and magnesium, later are removed from the exchange medium during regeneration and backwashing (Virolainen et al., 2021).

One of the disadvantages of depending on ion exchange for iron and manganese removal is precipitation by oxygen. If iron bacteria are present, the problem is even worse. If you have problems with iron bacteria, they can be controlled by using chlorine or some other oxidizing agent (García-Mendieta et al., 2012).

Heavy metals

A wide variety of inorganic heavy metals substances may be found in water in very small or trace amounts. Even in trace amounts, they can be a danger to public health. Some toxic substances occur from natural sources but many others occur due to industrial activities and/or improper management of hazardous waste. heavy metals that are toxic, namely, cadmium (Cd), chromium (Cr), lead (Pb), mercury (Hg), silver (Ag). They have a wide range of dangerous effects that differ from one metal to another. The term heavy metals refer to any metallic chemical element that has a relatively high density and is toxic or poisonous at low concentrations (Neag et al., 2020).

Heavy metals are natural components of the Earth's crust. Heavy metals cannot be degraded or destroyed. To a small extent they enter our bodies via food, drinking water and air. As trace elements, some heavy metals such as copper, selenium, zinc are essential to maintain the metabolism of the human body. However, at higher concentrations they can lead to poisoning. Heavy metal poisoning could result, for instance, from drinking water contamination, high ambient air concentrations near emission sources, or intake via the food chain. Heavy metals are dangerous because they tend to bio-accumulate (He et al., 2016).

Heavy metals cause acute effects in the respiratory, gastrointestinal, cardiovascular, and nervous systems. Chronic exposure to heavy metals in drinking water has been linked to serious dermatological conditions, including Blackfoot disease. Epidemiological studies have linked heavy metals in drinking water with cancer of the skin, bladder, lung, liver, and kidney. Some heavy metals adsorbed in the human body tend to accumulate in the tissues, whereas others such as organic arsenic are rapidly and almost completely eliminated via the kidneys (He et al., 2016).

Potable water

It is safe to drink, pleasant to taste, and usable for domestic purposes. Safe drinking water is one of the primary necessities for human beings to survive, live healthy life and be productive. However, large number of the world's population faces shortage of this basic need. In the case of iron and manganese in groundwater it is often sufficient with aeration and filtration of the water to lower the level of these substances to acceptable levels (Porcelli and Judd, 2010).

Good quality of drinking water is very necessary for improving the life of people and to prevent from diseases. It is necessary that the quality of drinking water should be checked at regular time interval, because due to use of contaminated drinking water, human population suffers from variety of water borne diseases. It is necessary to know the details about different physico-chemical parameters, which are used for testing of water quality (Biyani et al., 2017).

CHAPTER THREE

MATERIAL AND METHODS

3.1 Description of study area

The study area is located in gilgel beles, the administration town of metekle zone of the Benishangul Gumuz Regional State. The region is located in the Western part of Ethiopia 546 km far from Addis Ababa, at the Latitude of 11°9'16.28"N and longitude of 36°20'49.56"E, the total population of the town is 32,026, climate condition, average annual temperature 28.5°C, Average annual rainfall 1222 mm.
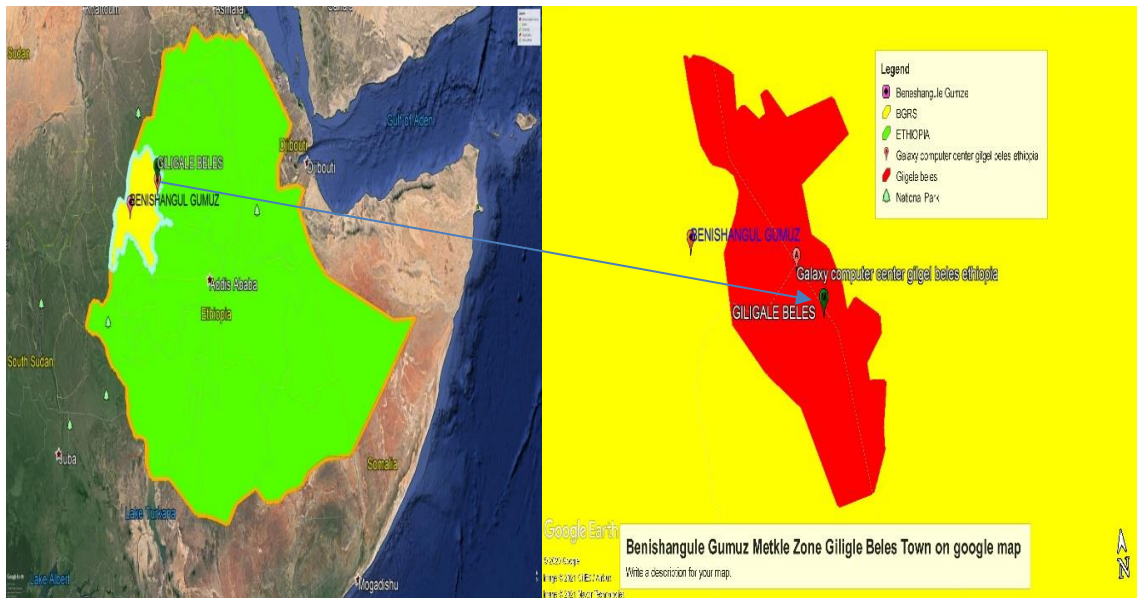
Figure 3.1: The map of BGRS metekle zone gilgel beles town

3.2 Material/Equipment's

- 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).

3.3 Chemicals and Reagents

- 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.

3.4 Methods

Aeration and sand filtrations were the best principal methods used to make the technology effectively and easily to operate for iron and manganese removal was that originally dissolved iron and manganese are transformed into undissolved compounds that can be removed through single-stage or two-stage separation. Aeration of these compounds was done under strict conditions with respect to water properties and type of equipment for iron and manganese removal (Biyani et al., 2017).
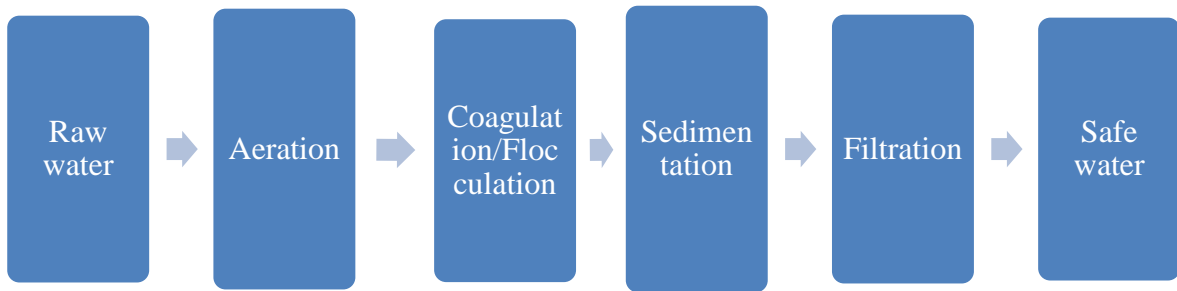
Figure 3.2: The conventional water quality treatment process

3.4.1 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 $Fe(OH)_3$. 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 (Syazwan et al., 2020).

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

$$Fe^{+2} \rightarrow Fe^{+3} + e^- \text{--- (5)}$$

$$Fe^{3+} + 3OH^- \rightarrow Fe(OH)_3 \text{--- (6)}$$

$$Fe^{+2} + 3H_2O \rightarrow Fe(OH)_3 + 3H^+ + e^- \text{-- (7)}$$

$$Mn^{+2} \rightarrow Mn^{+4} \text{--(8)}$$

$$Mn^{2+} + 2H_2O \rightarrow MnO_2 + 4H^+ + 2e^- \text{--- (9)}$$
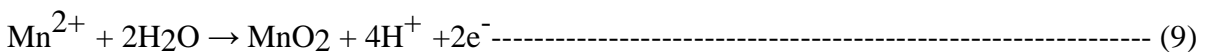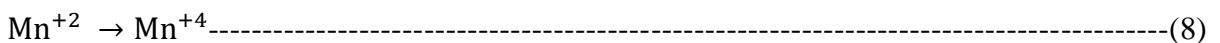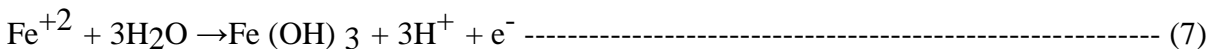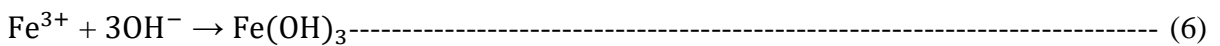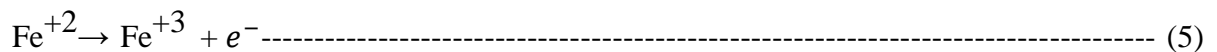
3.4.1.1 Spray aerator

By spray aerators the water was sprayed in the form of fine droplets into the air, thus creating a large O_2-liquid interface for gas transfer such as carbon dioxide removal or oxygen addition. Consists of stationary nozzles connected to a distribution grid through which the water is sprayed into the surrounding air at velocity of 3 – 5 m/s. The water trickles down through a tower packed with an open plastic media while air is forced up through the media. Aeration also remove iron, manganese and volatile organic chemicals (Ahmad, 2012).

3.4.2 Preparation of filter media or filter bed

Filters were retained particles containing iron and manganese that are suspended in the water after oxidation. The process was often more effective when the grains of the filter media become coated with iron or manganese oxides, because these deposits have a catalytic effect on the oxidation process. Filters usually consist of a layer of sand (which retains suspended particles) supportive by layers of gravel. The filter media such as supportive gravel, coarse and fine sand for both the adsorption and the filter basins.

Natural sand filter media was prepared with the following step, the sand and gravel were selected, the sand and gravel were washing, the sand and gravel was dried, the sand particle was converted to each particle size and filter the sand with sieve analysis (0.5, 1.18, 9.50 mm size). Sand filters were more efficient and more cleanly on time when the coarse sand and fine sand becomes too thin, fresh washed and sieved sand was added to the filter unit.

3.5 Sampling data collection procedure

The removal of Fe and Mn from groundwater was used for these experimental procedures;

The raw water samples were collected in plastic bottles from the problematic locations of deep groundwater samples that contained a high concentration of iron and manganese, the bottle was rinsed or washed by the water to be sampled before the water was collected. Therefore, 2 liters and 25 liters were collected from groundwater samples. Therefore, aeration was done before filtration Then, after aeration 25 liters of aerated groundwater samples were collected.

After aeration all water quality parameters were analyzed to see the variability. The aeration of groundwater promotes the precipitation of ferrous and manganese Then, aerated water

samples were added to the filter media after rinsing or cleaning by deionized water continuously for several times with the sample water and one-liter treated water sample was collected in each filter media then were check the concentration of each parameter.

Finally, the concentrations of iron and manganese precipitate was removed from groundwater. The quality of raw water (Fe and Mn content) and treated water at outlets from separate filtration columns was monitored during the experiments. At the same time, the amount of water at inlets to filtration columns and water discharge at outlets from the columns were measured by water parameters.

The concentration of Fe and Mn besides other elements were analyzing before and after the treatment, every ml sequentially then the concentrations of the aqueous phase were measured by Palin test (photometer 7100) it is includes all major water quality parameter, it is made in England, making water quality testing simply and easily by following the method (Katswangene et al., 2021).

3.6 Study design

Study design was laboratory based experimental.

3.6.1 Experimental setup

The depth of filter bed plan dimensions was 10, 15, 20, 25, 30 cm deep. The downflow filter consists of a layer of supportive gravel having a grain size of 10 cm at the bottom, the thickness of supportive gravel diameter also 4.75 to 9.50 mm was immersed before sand and coarse sand with size 1-1.18 mm was inserted before fine sand and the size of fine sand varies from 0.3 – 0.5 mm on top. The effective size with 1.18 mm and uniformity coefficient between 1.2 to 1.8 and the effective size with 0.5 mm and uniformity coefficient between 1.30 to 1.75.

The basin is further equipped with a treated water outlet, an overflow outlet 5 cm below of the filter bed. To protect erosion of filter's top layer during filtration of water, a layer of flat stone was raised above the sand.

Finally, filled the aerated water at optimum height, wait for 1-5hr contact time if more than there will be better finding, filter the supernatant water.
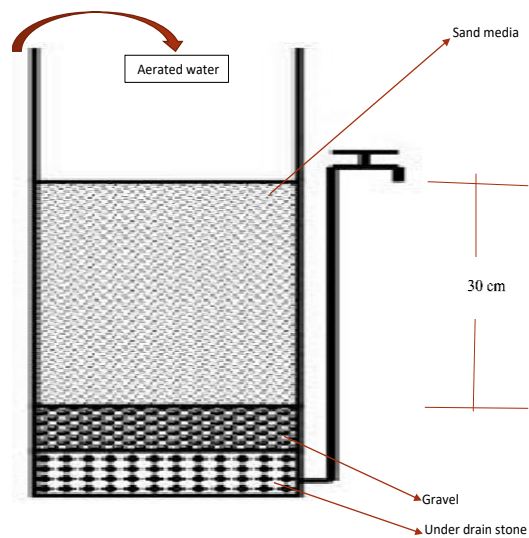
Figure 3.3: Sketch of simple rapid filtration processes by using natural sand material

In this figure 3.3 was indicated that simple rapid filtration processes by using natural sand materials like as sand filter (fine, coarse) and supportive gravel. It was highly efficient, then after filtrations there was safe to drinking water.

The overall efficiency of the system at removing both iron and manganese in groundwater at gilgel beles town. The following shows calculations used to obtain the efficiency of natural sand filtration.

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

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

3.7 Study period

The study was conducted from **February, 2021** up to **September, 2021**.

Figure 3.4: Sand materials after sieve analysis in the laboratory

In this figure 3.5 was presented that, the sieve analysis technique involves several layers of sieves with different grades of sieve opening sizes. The finest sized sieve lies on the bottom of the stack with each layered sieve stacked above in order of increasing sieve size. The coarse sand was placed on the top sieve and sifted; the individual particles of the material was separated onto the final layer that the particle could not pass through. The base of the instrument contains, which facilitates the filtering.

Figure 3.5: During preparation of sand and gravel mesh sieve analysis

3.8 Study variable

This study was having two main types of variables conducted in the removal of iron and manganese from the groundwater by using aeration and natural sand filtration.

3.8.1 Independent variable

Measured pH, color, turbidity, conductivity, temperature, chloride, nitrate and sulfate

3.8.2 Dependent variable

The concentration of iron and manganese removal

3.9 Data presentation and analysis

The procedure of the analysis was based on WHO Guideline and Ethiopian Standard. This includes test for determining the iron (Fe), manganese (Mn), color, turbidity, pH, electrical conductivity (EC), temperature, chloride, nitrates, sulfate of raw and treated water samples. After analyzed the concentration, was analyzed statistically using Microsoft excel 2019 and 2020 version. The data was presented using graphical.

3.10 Ethical consideration

The study was conducted after getting permission from ethical committee of Jimma University, Institute of Technology and environmental engineering chair.

3.11 Quality assurance (QA)

The quality of the data was assured through reanalysis of samples, replicate the samples by using standard operating procedures. Calibration and accuracy were used and the samples were duplicated and the average values were reported to ensure reproducibility.

3.12 Plan for dissemination of findings

The findings of the study were presented to School of Civil and Environmental Engineering, Jimma Institute of Technology, Jimma University and the complied report were given to any responsible governmental institution or NGO for further investigation for practical application to the removal of iron and manganese from groundwater.

CHAPTER FOUR

RESULT AND DISCUSSION

The physico-chemical analysis of before and after aeration and filtration drinking water sample was depicted in Table 4.1. To improve the quality of deep wells drinking water with high contents of iron and manganese, the use of iron and manganese filtration systems must be considered therefore, selecting the most appropriate design depend on the economical availability of materials and easy to construct all this relation of efficiency.

Table 4.1: The physico-chemical analysis of the raw water sample 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	^{o}C	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

The result which was presented in table 4.1 shows that the results of the water test done on samples obtained from the gilgel beles town water supply and assessment parameters tested initially in order to confirm the claims of iron and manganese presence in the groundwater. It was evident that the raw water was highly polluted with iron and manganese when compared with WHO Guideline and Ethiopian Standard for drinking water quality permissible limits for these parameters and also treated groundwater sample was under in these permissible limits. We were concerned here only for iron and manganese removal by using aeration and sand filter materials to improve safe drinking water.

4.1 Iron and manganese removal

The initial concentration of iron and manganese raw water sample was 5.79 mg/L and 4.11 mg/L respectively. The beginning of an experiment the high concentration of iron and manganese in groundwater decreased by aeration with 4.58 mg/L for iron and 3.32 mg/L for manganese up on filtration, it was reduced to 0.09 mg/L for iron and 0.11 mg/L for manganese. The result was presented in figure 4.1 show that the maximum removal percentages of iron and manganese during the experiment was good for coarse sand varying from 98.44% for iron and 97.31% for manganese and the correlation coefficient, $R^2>0.994$ for iron and $R^2>0.999$ for manganese. Therefore, the removal percentage of iron were the highest than manganese. The natural sand was the best filter media since it resulted in the highest percentage and excellent results for the removal of iron and manganese the filter media was achieved with a treatment for 0 to 30 cm of sand filter depth.
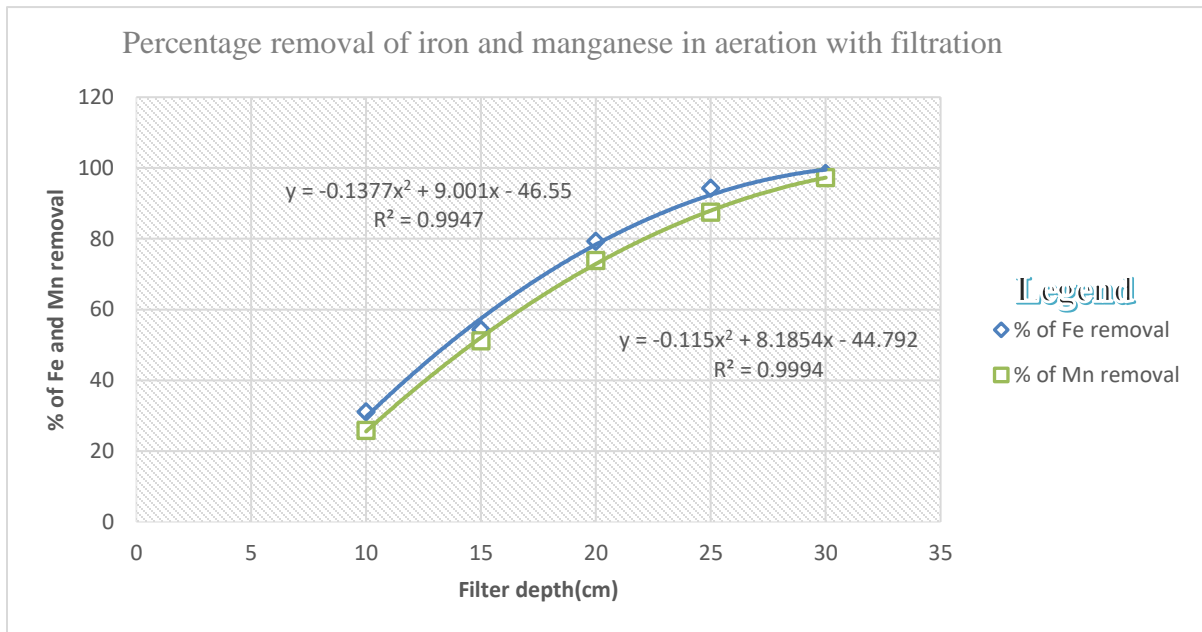
Figure 4.1: The percentage of iron and manganese removal by aeration and filtration

The result was presented in figure 4.1 show that aeration with filtration by using natural sands it was the most effective and efficient removal of iron and manganese for different depths of filter from groundwater was compared to the Ethiopian standard for drinking water quality and WHO guideline value on comparing these values with the permissible limits, the values of all the parameters were under the permissible limits However, the aeration with filtration system

substantially decrease the iron and manganese concentration with increasing the percentage of iron and manganese removal and increasing the filter depth could be improved even more to meet the potable water standards.

This experimental laboratory used the water-to-air method is designed to produce small drops of water that fall through the air through simple water distributer sprinkler with very low cost, it is effective in aeration. Iron and manganese in groundwater are initially oxidizing using aeration following the removal by filtration. After the oxidation process, the insoluble iron and manganese oxides can be precipitated was removed through the sand filter.

The measurement of iron and manganese concentrations at various depths in the filter bed allowed establishment of an iron and manganese removal depth zone necessary to obtain treated water of good quality. The water was passed through the filter beds of all the control units and experimental filter units. Then the filtrate from all the units were analyzed separately for iron and manganese concentration at a depth of filter 10, 15, 20, 25 and 30 cm with the filter run according to the standard methods (Jeż-Walkowiak et al., 2015).

4.2 Effect of pH on the removal of iron and manganese

According to (Omer, 2019) pH is one of the most important parameters of water quality. pH ranges from 0 to 14, with 7 being neutral. pH of less than 7 indicates acidity, whereas a pH of greater than 7 indicates a base solution. Adjusting the pH to alkaline levels also reduces the corrosivity of the water to pipes and plumbing.

Table 4.2: Effect of pH on removal of Fe and Mn by aeration with filtration process

	Types of raw materials/natural sand materials					
	Coarse sand			Fine sand		
Filter depth	Fe (mg/L)	Mn (mg/L)	pH	Fe (mg/L)	Mn (mg/L)	pH
0	4.58	3.32	8.06	4.58	3.32	8.0
10	3.99	3.04	8	4.3	3.2	7.8
15	2.64	2.0	7.8	3.1	2.6	7.5
20	1.12	1.07	7.6	2.04	1.8	7.2
25	0.33	0.51	7.05	0.71	0.58	6.5
30	0.09	0.11	6.85	0.18	0.2	7

The pH of the water influences how much time was needed for the reaction to be completed. After oxidation of the iron and manganese, the water must be filtered to remove the precipitated iron and manganese.

The result was in figure 4.2 shows that the effect of pH on the removal of iron and manganese concentration using natural sand by 0 to 30 cm filter depth in the coarse sand. It was shown that the iron concentration with 0.09 mg/L and manganese concentration 0.11 mg/L was removed with 8.5 up to 6.85 of pH value. The pH values of all the drinking water samples are found to be in the range between 6.5 to 8.5 of the standards. Therefore, decreasing water pH value with decreases the concentration of iron and manganese but increasing the natural sand filter depth at 30 cm.
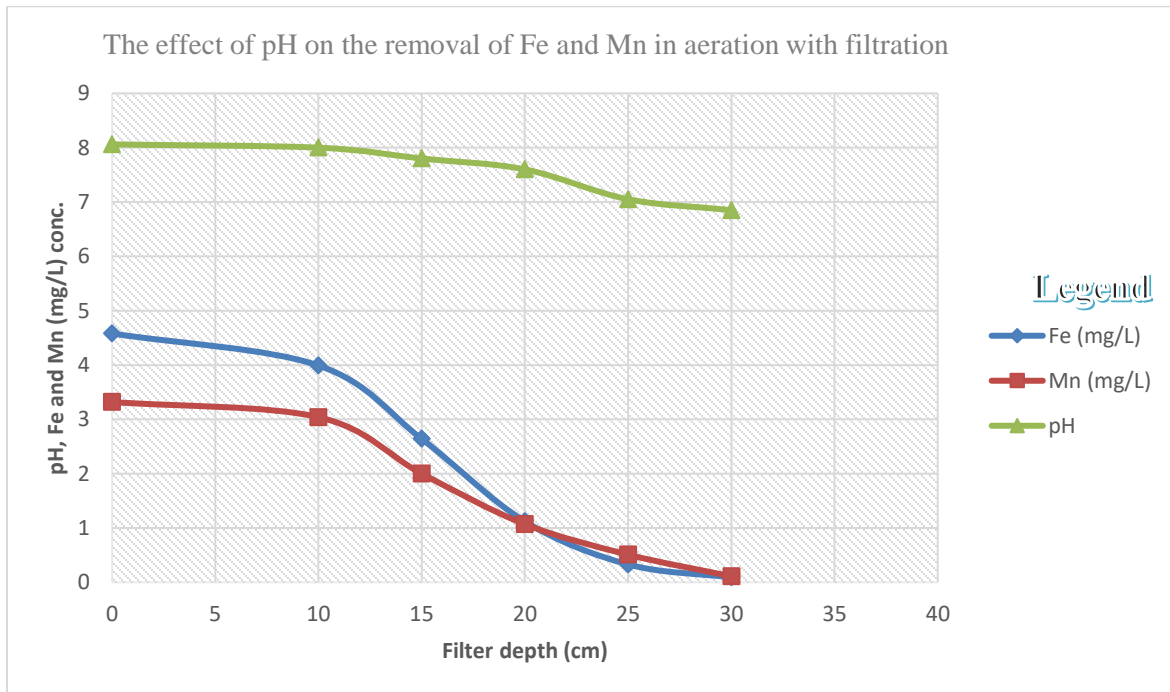
Figure 4.2: Effect of pH on removal of Fe and Mn by aeration with filtration process

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. The pH serves as an index to denote the extent of pollution by acidic or basic waste. The pH values were found between 7.84 and 8.88. The pH shows slightly alkaline nature of all samples (Omer, 2019).

4.3 Effect of color on the removal of iron and manganese

The iron and manganese reduction causes the cut back of color measurements. True color is measured after filtering the water sample to remove all suspended material. Color is graded on scale of 0 (clear) to 70 color units. Pure water is colorless, which is equivalent to 0 color unit.

Table 4.3: Effect of color on removal of Fe and Mn by aeration with filtration process

	Types of raw materials / natural sand materials					
	Coarse sand			Fine sand		
Filter depth	Fe (mg/L)	Mn (mg/L)	Color (TCU)	Fe (mg/L)	Mn (mg/L)	Color (TCU)
0	4.58	3.32	15.06	4.58	3.32	15.0
10	3.99	3.04	12.4	4.3	3.2	13
15	2.64	2.0	8.9	3.1	2.6	9.3
20	1.12	1.07	4.5	2.04	1.8	5.0
25	0.33	0.51	0.2	0.71	0.58	2.4
30	0.09	0.11	0.0	0.18	0.2	0.07

The color and turbidity both reduced due to the removal of iron and manganese from groundwater. The results were presented in figure 4.3 The results for using the aeration with filtration process of iron and manganese concentration removal by using natural sand happens very fast. The process of iron and manganese removal using natural sand materials like as coarse sand and fine sand also happens fast and enhanced by increasing filter depth at 0 to 30 cm. Decreasing the concentration by 0.09 mg/L and 0.11 mg/L of iron and manganese respectively, was removed. However, the effect of water color was decreased by 15.5 up on 0 TCU due to natural sand filtration process in case of low cost, easily available and no need chemical addition. However, the filtration system substantially reduced the iron and manganese concentration and could be improved even more to meet the potable water standards. Normally the color is depending on the suspended particles of the water. Therefore, the concentration of iron and manganese decreased when color of water decreases at the sand filter depth increase.
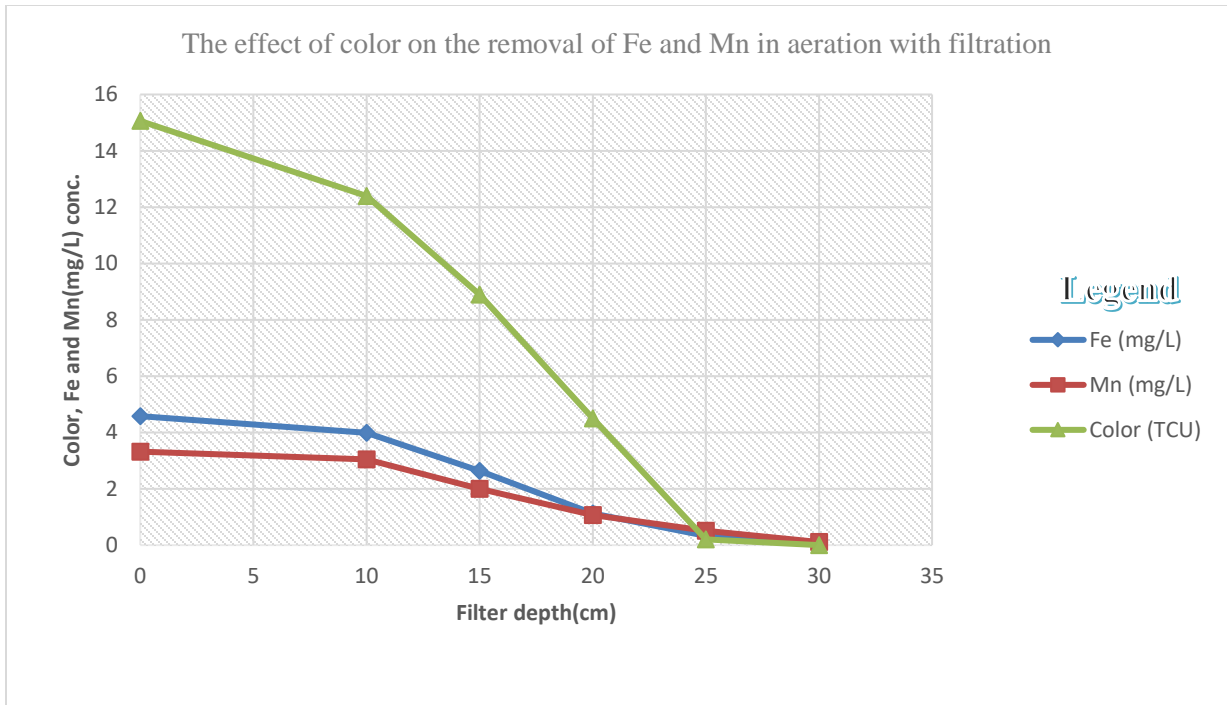
Figure 4.3: Effect of color on removal of Fe and Mn by aeration with filtration process

4.4 Effect of turbidity on the removal of iron and manganese

The removing of iron and manganese was effect on water turbidity, it was reducing water turbidity. Turbidity is significantly affected the removal of iron and manganese from groundwater. Turbidity is the cloudiness of water caused by a variety of particles and is another key parameter in drinking water analysis.

Table 4.4: Effect of turbidity on removal of Fe and Mn by aeration with filtration

	Types of raw materials / natural sand materials					
	Coarse sand			Fine sand		
Filter depth	Fe (mg/L)	Mn (mg/L)	Turbidity (NTU)	Fe (mg/L)	Mn (mg/L)	Turbidity (NTU)
0	4.58	3.32	5.36	4.58	3.32	5.36
10	3.99	3.04	3.9	4.3	3.2	4.2
15	2.64	2.0	2.2	3.1	2.6	3.05
20	1.12	1.07	1.3	2.04	1.8	1.7
25	0.33	0.51	0.0	0.71	0.58	0.5
30	0.09	0.11	0.0	0.18	0.2	0.0

The result was presented in figure 4.4 shows that the results of experiments that discuss the effect of water turbidity decreasing with iron and manganese removal of water samples. The turbidity also may produce the coloring effect. However, the turbidity of treated water was reduced to 0 NTU from 5.4 NTU in raw water. The concentration of iron and manganese was decreased up to 0.09 mg/L and 0.11 mg/L respectively, but increasing the filter depth at 0 up on 25 and 30 cm with the increasing quality of water in the removal of iron and manganese from groundwater by aeration and filtration process. Therefore, the aeration and filtration process are reducing turbidity also increasing removal efficiency of turbidity but in coarse sand and fine sand turbidity was decreased Turbidity was the main factor that influenced the removal of iron and manganese from the raw water. In the aeration with natural sand filtration, turbidity decreased as the sand depth increased and filtration rate decreased but the removal of iron and manganese increased.
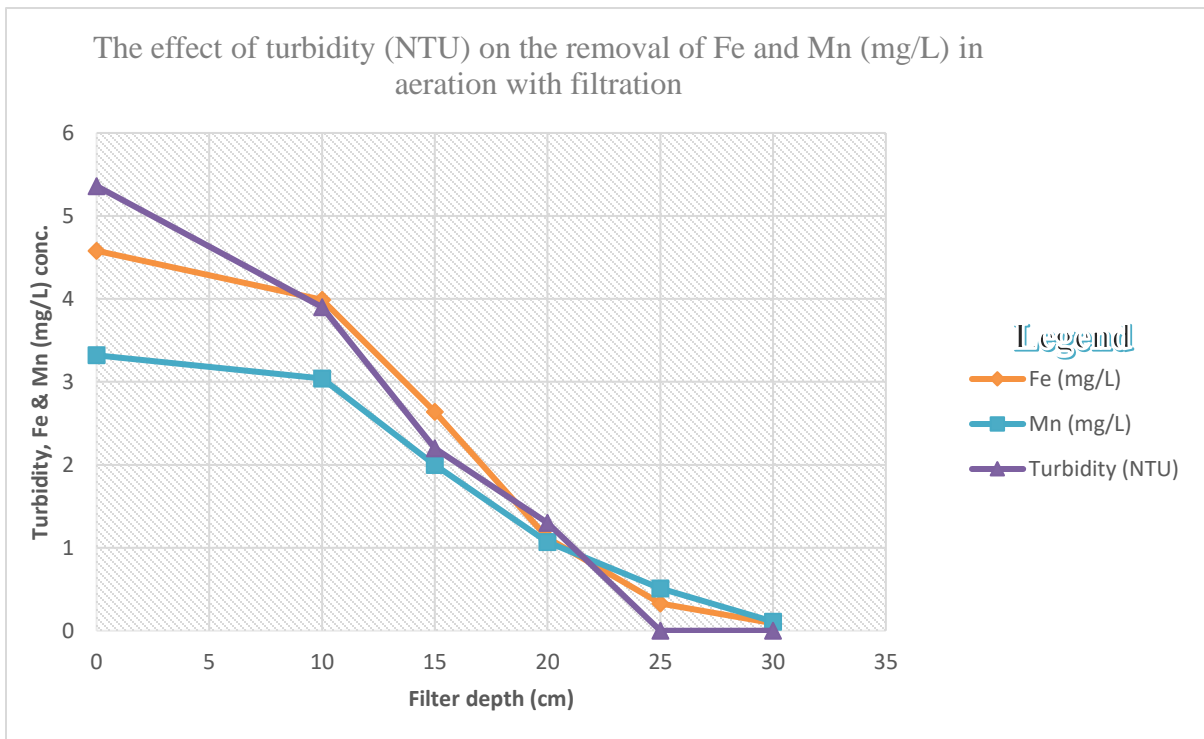

Figure 4.4: Effect of turbidity on removal of Fe and Mn by aeration with filtration process

The mineral water, which was expected to be the cleanest water, thus had lowest turbidity values. The results indicate that after treat water turbidity of all the samples studied was below the maximum standard limit of 5 NTU.

According to (Dandwate, 2012) the turbidity of raw water can be as low as a 1 or 2 NTU in groundwater and up to several hundred in turbid surface water, e.g., after a rain storm. The turbidity of drinking water should be <1, and preferably <0,1 NTU. Turbidity more than 5 NTU can be visible to the average person while turbidity in muddy water, it exceeds 100 NTU. Groundwater normally has very low turbidity because of the natural filtration that occurs as the water penetrates through the soil.

4.5 Effect of conductivity on the removal of iron and manganese

Electrical conductivity is the ability of any medium, water in this case, to carry an electric current. Pure water is not a good conductor of electricity. The conductivity increases as the concentration of ions increases. Therefore, it is one of the main parameters used to determine the suitability of water for irrigation and firefighting. The conductivity of a material depends on several factors including temperature and the presence of impurities.

Table 4.5: Effect of conductivity on removal of Fe and Mn by aeration with filtration

	Types of raw materials / natural sand materials					
	Coarse sand			Fine sand		
Filter depth	Fe (mg/L)	Mn (mg/L)	Conductivity (µs/cm)	Fe (mg/L)	Mn (mg/L)	Conductivity (µs/cm)
0	4.58	3.32	382.6	4.58	3.32	382.6
10	3.99	3.04	379	4.3	3.2	381
15	2.64	2.0	375	3.1	2.6	377
20	1.12	1.07	368	2.04	1.8	364
25	0.33	0.51	370	0.71	0.58	361
30	0.09	0.11	359	0.18	0.2	359

The results were presented in figure 4.5 It was shown that by using natural sand filtration process can remove iron and manganese in natural sand increasing up and down was decreased water conductivity by 368 to 359 µs/cm with decreasing the concentration of iron and manganese by 0.09 and 0.11 mg/L respectively, but increasing filter depth by 30 cm. Conductivity once increased and other case decreased also iron and manganese concentration

decreased.

The effect of conductivity (µs/cm) on the removal of Fe and Mn (mg/L) in aeration with filtration
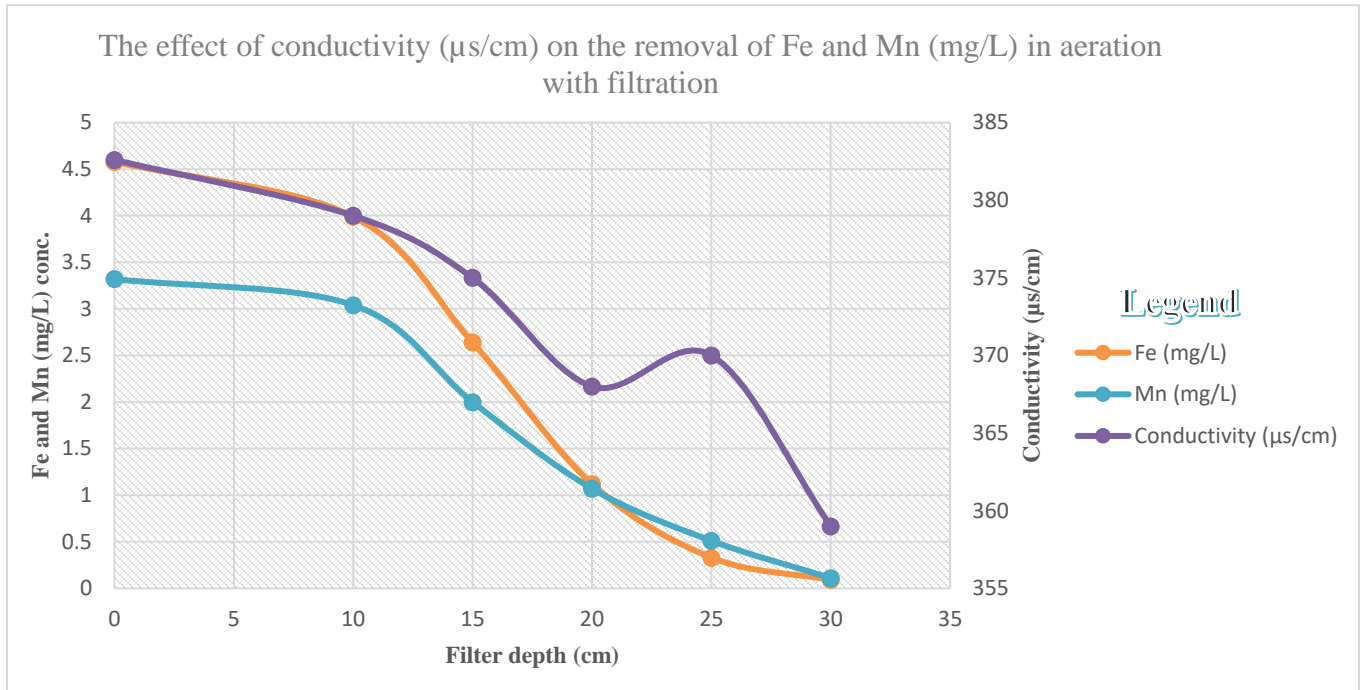
Figure 4.5: Effect of conductivity on removal of Fe and Mn by aeration with filtration proces

According to (Dandwate, 2012) Electrical conductivity is a measure of water's capacity to convey an electric current. This property is related to the total concentration of ionized substances in water. The more dissolved salts in water, the stronger is current flow and higher the EC. In short, EC of water increases with salts.

4.6 The effect of temperature on the removal of iron and manganese

Cool water is generally more potable than warm water. High water temperature enhances the growth of microorganisms and may increase taste, odor, color and corrosion problems (WHO). The temperature was found to be in the range between 25.5 and 31.4 ℃.

Table 4.6: Effect of temperature on removal of Fe and Mn by aeration with filtration

| Filter depth | Types of raw materials / natural sand materials | | | | | |
| | Coarse sand | | | Fine sand | | |
	Fe (mg/L)	Mn (mg/L)	Temperature (°C)	Fe (mg/L)	Mn (mg/L)	Temperature (°C)
0	4.58	3.32	27.06	4.58	3.32	27.0
10	3.99	3.04	27	4.3	3.2	26.8
15	2.64	2.0	26.8	3.1	2.6	26.5
20	1.12	1.07	25.6	2.04	1.8	27
25	0.33	0.51	26	0.71	0.58	26.3
30	0.09	0.11	25	0.18	0.2	25.8

The results were presented in figure 4.6 shows that using natural sand material was very efficient to remove iron and manganese at different concentrations to 0.09 and 0.11 mg/L respectively, when increasing up at 26 °C and decreasing water of temperature at 25°C but increasing the filter depth at 0 up on 30 cm from groundwater. The concentration of temperature in groundwater once up and down not proportionally increased.
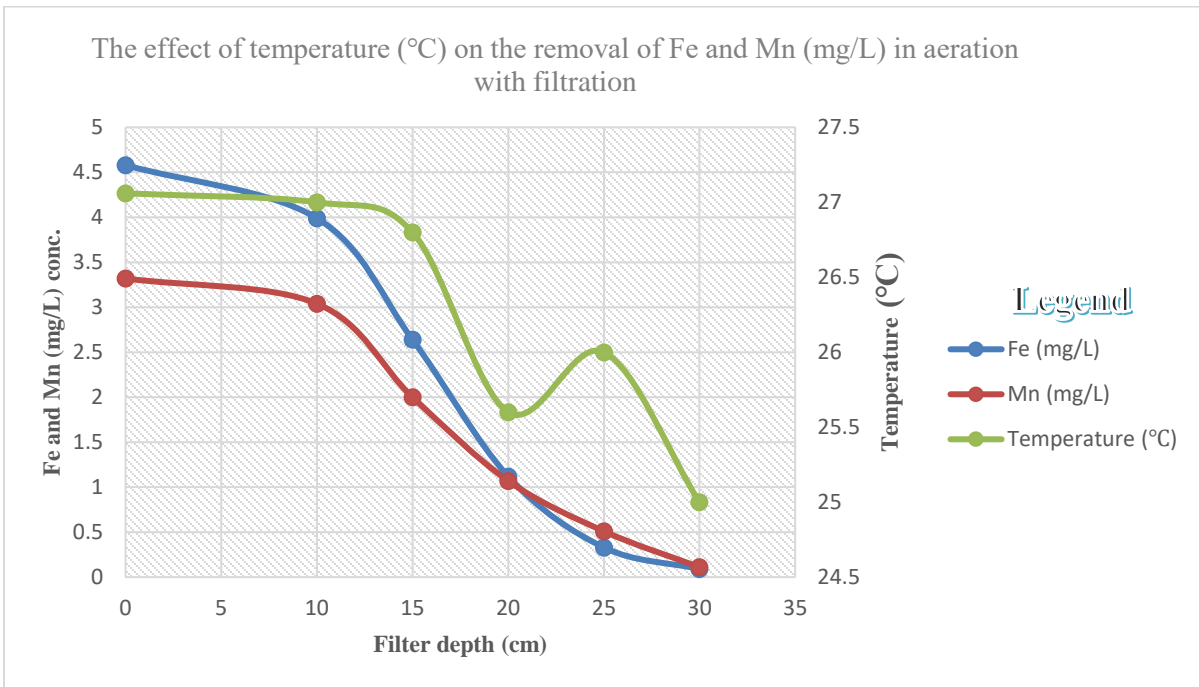

Figure 4.6: Effect of temperature on removal of Fe and Mn by aeration with filtration process

According to (Omer, 2019) Palatability, viscosity, solubility, odors, and chemical reactions are influenced by temperature. Thereby, the sedimentation, chlorination processes and biological

oxygen demand (BOD) are temperature dependent. It also affects the biosorption process of the dissolved heavy metals in water. Most people find water at temperatures of 10–15°C most palatable.

4.7 Effect of chloride on the removal of iron and manganese

Chloride occurs naturally in groundwater, streams, and lakes, but the presence of relatively high chloride concentration in freshwater (about 250 mg/L or more) may indicate wastewater pollution.

Table 4.7: Effect of chloride on removal of Fe and Mn by aeration with filtration

	Types of raw materials / natural sand materials					
	Coarse sand			Fine sand		
Filter depth	Fe (mg/L)	Mn (mg/L)	Chloride (mg/L)	Fe (mg/L)	Mn (mg/L)	Chloride (mg/L)
0	4.58	3.32	0.39	4.58	3.32	0.39
10	3.99	3.04	0.36	4.3	3.2	0.37
15	2.64	2.0	0.31	3.1	2.6	0.34
20	1.12	1.07	0.28	2.04	1.8	0.25
25	0.33	0.51	0.21	0.71	0.58	0.19
30	0.09	0.11	0.12	0.18	0.2	0.16

The result presented in figure 4.7 shows that decreasing iron and manganese concentrations by 0.09 mg/L and 0.11 mg/L respectively, lead to rapid filter. When the effect of chloride concentrations was decreasing with 0.12 mg/L from groundwater but increase the depth of filter run to 30 cm.

The effect of chloride (mg/L) on the removal of Fe and Mn (mg/L) in aeration with filtration
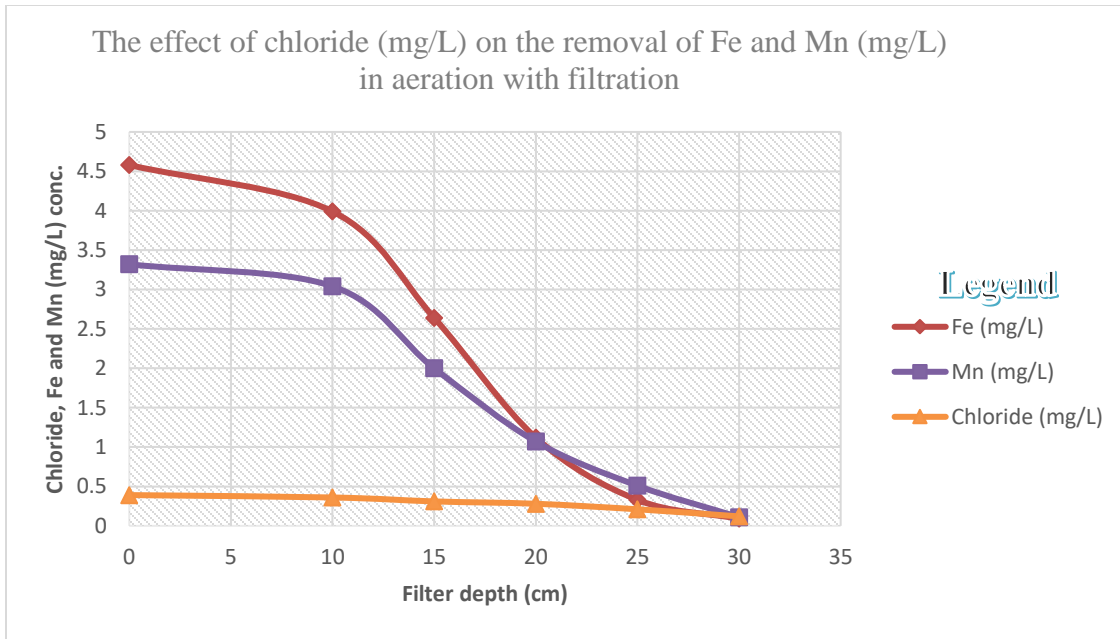
Figure 4.7: Effect of chloride on removal of Fe and Mn by aeration with filtration process

Chlorides may enter surface water from several sources including chloride-containing rock, agricultural runoff and wastewater. Chlorides are not usually harmful to people; however, the sodium part of table salt has been connected to kidney and heart diseases. Small amounts of chlorides are essential for ordinary cell functions in animal and plant life (Dandwate, 2012).

4.8 Effect of nitrate on the removal of iron and manganese

Nitrates can enter the groundwater from chemical fertilizers used in the agricultural areas. Excessive nitrate concentration (more than 10 mg/L) in drinking water causes an immediate and severe health threat to infants. The nitrate ions react with blood hemoglobin, thereby reducing the blood's ability to hold oxygen which leads to a disease called blue baby or methemoglobinemia.

Table 4.8: Effect of nitrate on removal of Fe and Mn by aeration with filtration

| | Types of raw materials / natural sand materials | | | | | |
| | Coarse sand | | | Fine sand | | |
Filter depth	Fe (mg/L)	Mn (mg/L)	Nitrate (mg/L)	Fe (mg/L)	Mn (mg/L)	Nitrate (mg/L)
0	4.58	3.32	0.73	4.58	3.32	0.73
10	3.99	3.04	0.69	4.3	3.2	0.71
15	2.64	2.0	0.63	3.1	2.6	0.70
20	1.12	1.07	0.51	2.04	1.8	0.66
25	0.33	0.51	0.4	0.71	0.58	0.45
30	0.09	0.11	0.26	0.18	0.2	0.43

The results were presented in figure 4.8 shows that the effect of nitrate concentrations decreased by 0.26 mg/L with the filtration of groundwater as expected. This occurs as removed iron and manganese so the concentrations were decreases to 0.09 and 0.11 mg/L respectively, accumulate on filter media but increasing the filter depth start 0 to 30 cm. Therefore, the concentration of nitrate in the groundwater was very low. During the removal of iron and manganese by using aeration and natural sand filtration process were reduced the concentration of nitrate nitrogen content from the groundwater.
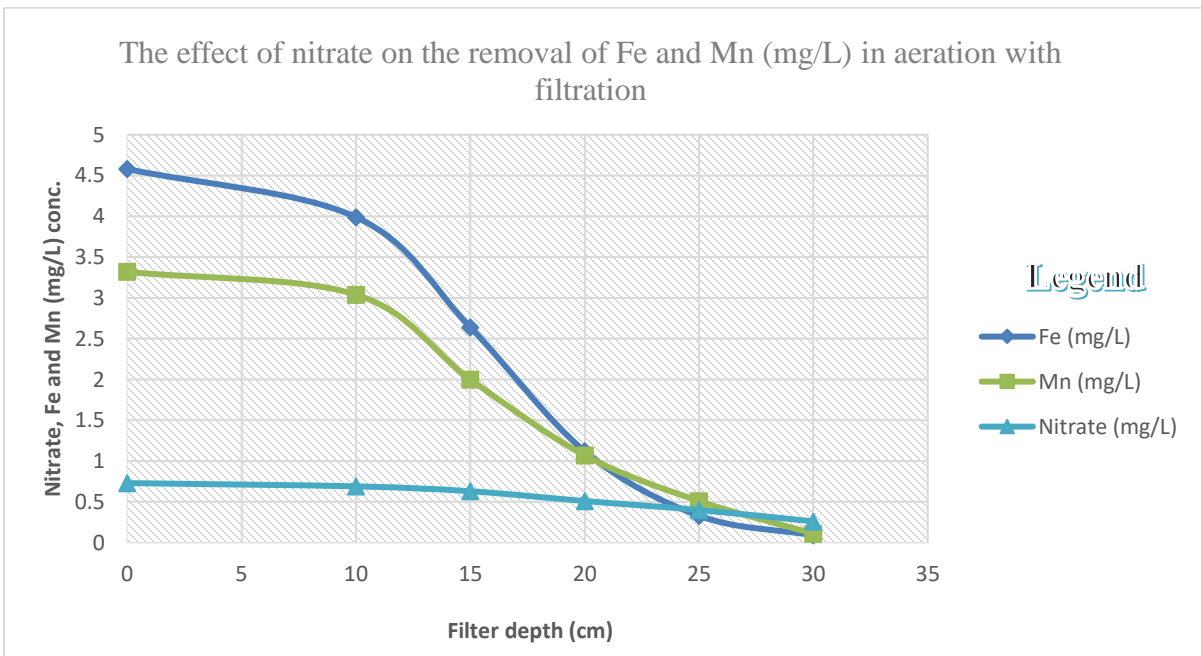

Figure 4.8: Effect of nitrate on removal of Fe and Mn by aeration with filtration process

4.9 Effect of sulfate on the removal of iron and manganese

Table 4.9: Effect of sulfate on removal of Fe and Mn by aeration with filtration

| | Types of raw materials / natural sand materials | | | | | |
| | Coarse sand | | | Fine sand | | |
Filter depth	Fe (mg/L)	Mn (mg/L)	Sulfate (mg/L)	Fe (mg/L)	Mn (mg/L)	Sulfate (mg/L)
0	4.58	3.32	0.55	4.58	3.44	0.55
10	3.99	3.04	0.49	4.3	3.2	0.51
15	2.64	2.0	0.38	3.1	2.6	0.40
20	1.12	1.07	0.34	2.04	1.8	0.29
25	0.33	0.51	0.25	0.71	0.58	0.22
30	0.09	0.11	0.14	0.18	0.2	0.19

The result was presented in figure 4.9 shows that the results of using different filtration depth the concentrations of iron and manganese was removed then the concentrations are decreases to 0.09 and 0.11 mg/L respectively, Therefore, the effect of sulphate in groundwater also decreases at 0.14 mg/L but increasing the filter depth at 30 cm.
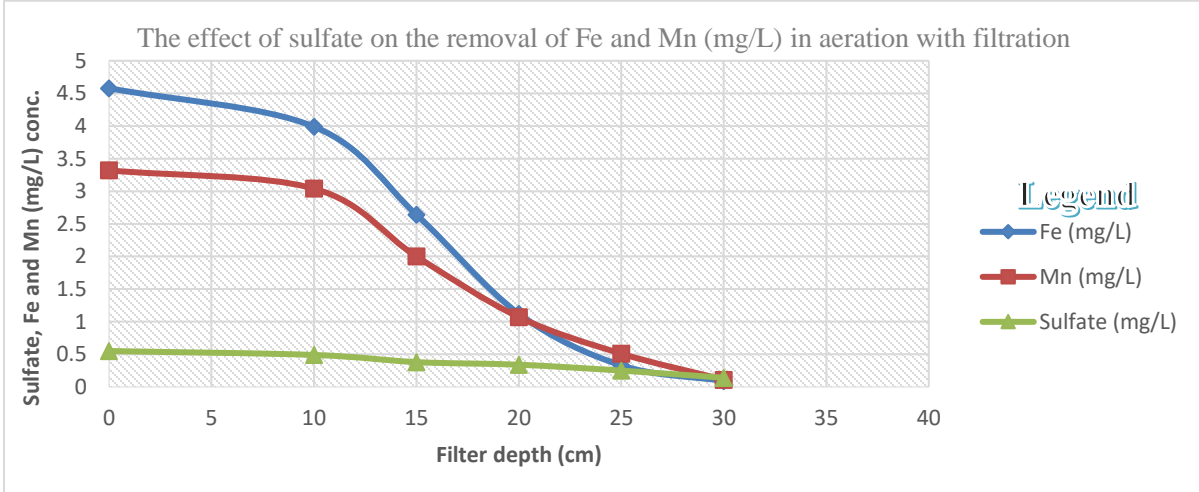
Figure 4.9: Effect of sulfate on removal of Fe and Mn by aeration with filtration process

The high concentration of sulfate in natural water is usually caused by leaching of natural deposits of sodium sulfate (Glauber's salt) or magnesium sulfate (Epson salt). If high concentrations are consumed in drinking water, there may be objectionable tastes or unwanted laxative effects, but there is no significant danger to public health (Obiefuna and Orazulike, 2010).

4.10   Effect of filter run (time) with in filter media

The result in figure 4.10 shows that the effect of time on iron and manganese removal using aeration and natural sand filtration. It was shown that the removal efficiency of iron and manganese was increased to 98.44% and 97.31% respectively, at the time of 5 hr. and increasing the time by 0 to 5hr. The natural sand filtration process of iron and manganese removal using coarse sand and also fine sand was very fast with filtration run and filtration depth. When increasing the time of filtration and increasing the removal efficiency of iron and manganese from groundwater.
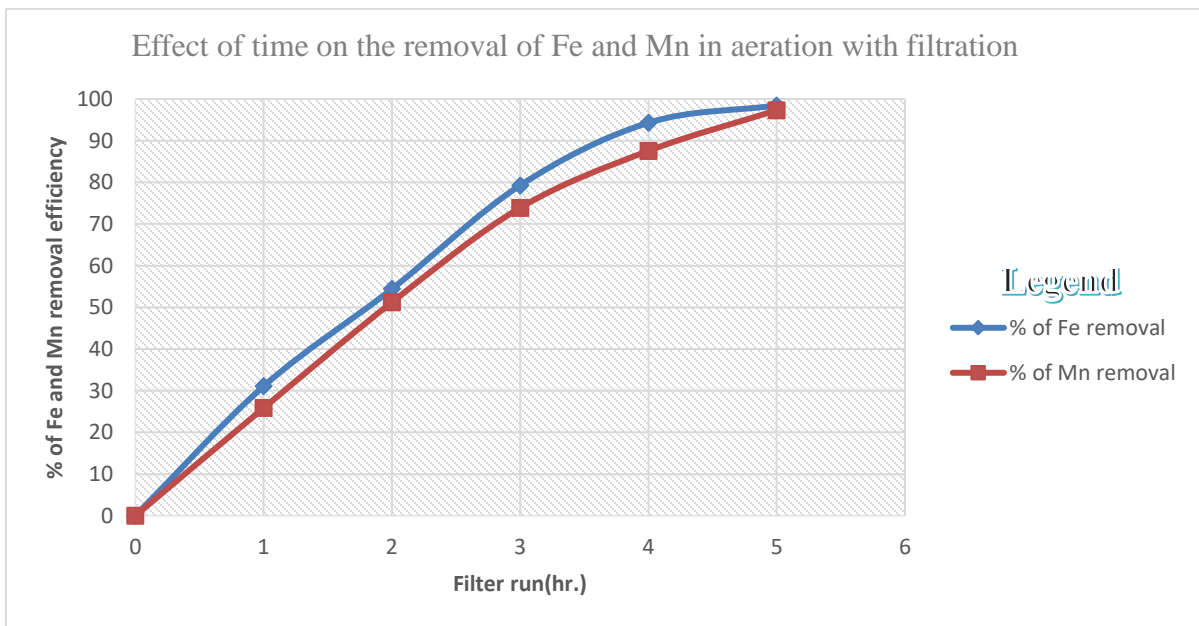
Figure 4.10: Effect of filter run on removal of Fe and Mn by natural sand process

The removal effectiveness of iron and manganese in coarse sand was achieved with a treatment time of after 5 hrs. for each digestion time of the potable water the time and filter depth were important operating for each parameter to considered under the present study. A detention basin can be provided after aeration to allow complete oxidation. These basins should be cleaned regularly to avoid sludge accumulation. Detention time can also be provided with head on the filters rather than requiring a separate tank. Detention time before filtration should be at least 20 minutes, more if possible.

4.11   Effect of natural sand filter depth

The different filtration materials were used for the removal of iron and manganese, including coarse sand, fine sand and supportive gravel particles. Natural activation (without chemical dosage) of chemically inactive filtration materials for iron and manganese removal from groundwater was a rapid process. Each of them, including natural sand materials, have properties that make them viable for different applications based on what they can remove.

Table 4.10: Percentage removal of Fe and Mn aeration with filtration process

Types of raw materials/ natural sand materials								
	Coarse sand				Fine sand			
Filter depth (cm)	Fe (mg/L)	% of Fe removal	Mn (mg/L)	% of Mn removal	Fe (mg/L)	% of Fe removal	Mn (mg/L)	% of Mn removal
0	4.58	0	3.32	0	4.58	0	3.32	0
10	3.99	31.08	3.04	25.85	4.3	25.73	3.2	21.95
15	2.64	54.40	2.0	51.21	3.1	46.45	2.6	36.58
20	1.12	79.27	1.07	73.90	2.04	64.76	1.8	56.09
25	0.33	94.30	0.51	87.56	0.71	87.73	0.58	85.85
30	0.09	98.44	0.11	97.31	0.18	96.89	0.2	95.12

The results were presented in figures 4.11 and 4.12 show that the average removal efficiency of iron and manganese during the experiment was good for coarse sand and fine sand varying from iron removal efficiency including 98.44% for coarse sand and 96.89% for fine sand and manganese removal efficiency including 97.31% for coarse and 95.12% for fine sand respectively, the filter media was achieved with a treatment at 30 cm of sand filter depth. Finally, natural sand filtration process was selected as the best treatment. The result showed that iron and manganese was almost removed by natural sand materials.

Depth of the filter media appears to be very important in determining iron and manganese removal efficiency.

The results were in figure 4.11 and 4.12 shows that iron and manganese removal efficiency of two filter materials as a function of depth in filter media. Therefore, natural sand was more

effective in removing iron and manganese from groundwater. It was also found that there was a regular pattern of increase the result of removal efficiency of iron and manganese from groundwater with the increase of filter depth but the concentration of iron and manganese decreased.
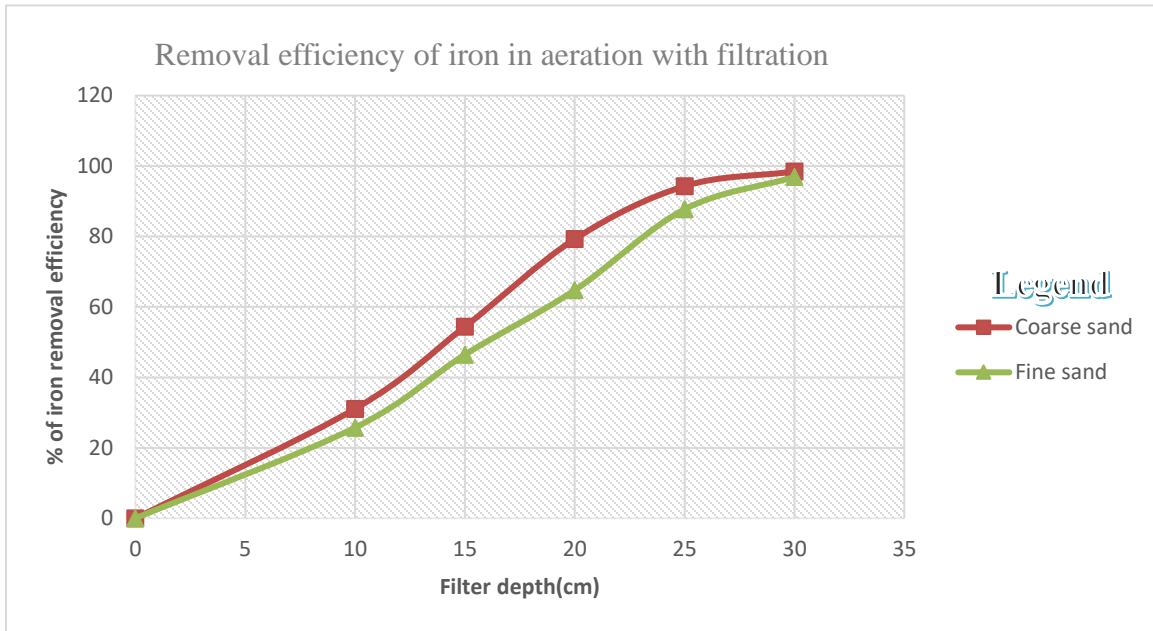

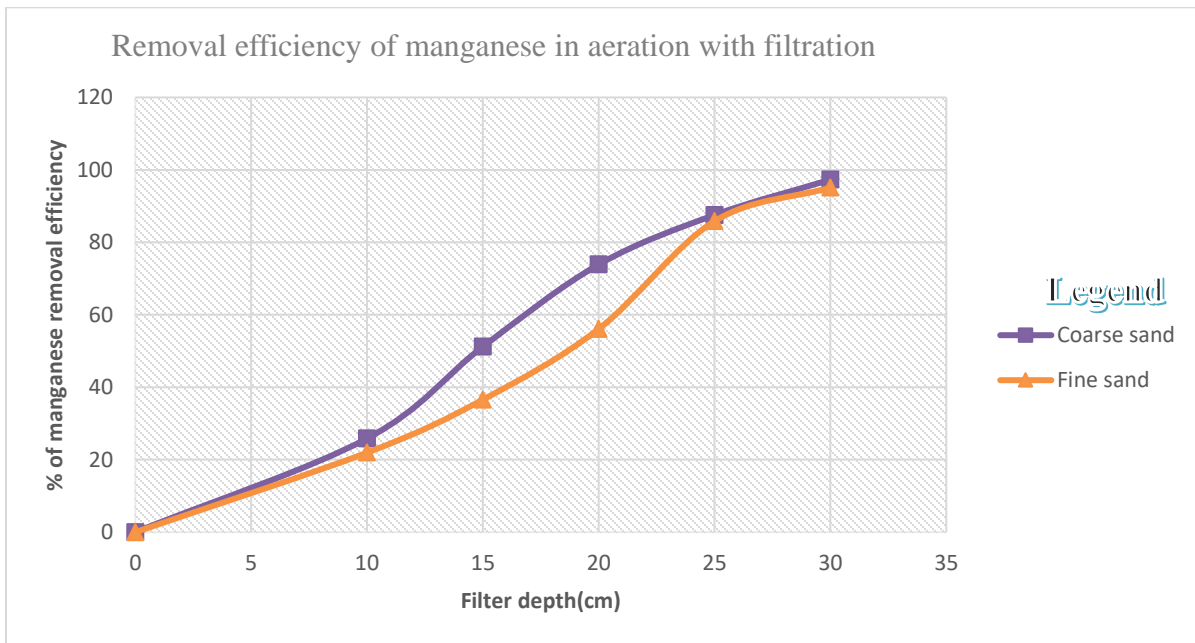Figure 4.11: Iron removal efficiency in aeration with filtration process

Figure 4.12: Manganese removal efficiency in aeration with filtration process

Generally, the effect of filter bed depth on the removal of iron and manganese was relatively higher which resulted in contact time within filter media and hence better iron and manganese removal. The removal efficiency of filter increases with decreasing the filtration rate. Considering natural sand usefulness based on the results obtained in this experiment, it can be said that the effectiveness of natural sand as media for iron and manganese compounds removal was high. The important thing is a proper material selection for different iron and manganese content. It would be advisable to carry out the works over material consisting of a mixture of natural sand materials that could point out the best proportion for an effective groundwater conditioning (Syazwan et al., 2020).

When it comes to filters, the more pores within the treatment media, the more efficient the filtration performance can be. Natural sand medias have many pores; therefore, they do not just capture particles between grains, they also absorb them into their pores to capture them. Therefore, the porous structure of the external contact layer creates very good conditions for the fast and effective of coarse sand for iron and manganese removal compared with other filtration materials due to the many porosities, the particle size and the type of rock formation difference. Natural sand was saved economical cost, easily available the material, without chemical addition to use, health aspects and no need more labor cost.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From this study, it can be concluded that, the natural sand filter media are a good option for effective removal of iron and manganese from groundwater. The results of the research shows that the coarse sand and fine sand are high efficiency and a good potential for iron and manganese removal from groundwater and the residual concentrations of each parameter are well under the permissible limits of WHO and Ethiopian guideline standards.

Therefore, the performance removal efficiency of iron and manganese with 98.44% and 97.31% for coarse sand and 96.89% and 95.12% for fine sand respectively, are increased. However, the coarse sand and fine sand are effective the beginning up to the end of the experiment. Almost all the parameters were reduced during the aeration and filtration process.

The iron and manganese removal filter depth zone were achieved to be about 30 cm for coarse sand at the end of the experiment conducted with a filtration rate. Therefore, an increase of the iron and manganese removal filter depth zone but decrease in filtration rate.

Finally, Aeration and natural sand filtration are more effective and which gives good results in removing iron and manganese from groundwater. It was also found that there was a regular pattern of increase the result of iron and manganese removal efficiency from groundwater with the increase of filter depth but the concentrations of iron and manganese was decreased from groundwater.

Aeration and natural sand filtration techniques can be assembled easily at any site and it is cost effective. Moreover, it was also easy to install and operate. However, by using aeration and natural sand filtration is considered a very good selection for the process of iron and manganese removal.

5.2 Recommendations

Based on the experimental study and entire research process, the following recommendations were made for concerned bodies just under here.

1. The efficiency of the iron and manganese removal process depends on the rate of filtration of adsorption sites or the rate of oxidation of adsorbed iron (II) and manganese (II). Therefore, water quality parameters and filter media are necessary to analyses factors influencing the rate of oxidation of adsorbed iron (II) and manganese (II) in filters.

2. Filter media of adsorptive iron and manganese removal filters are expected to grow with time and depth. The effect of water quality and process conditions on the rate of growth of filter media needs a further detailed investigation the WHO guidelines of drinking water are important for practical implementation.

3. This study showed that the natural sand was more effective in removing iron and manganese and different heavy metals from drinking groundwater and low-cost methods suitable at domestic level. Therefore, a further study on the combined removal of iron and manganese from groundwater by using aeration and natural sand filtration techniques is recommended.

4. Aeration and natural sand filtration techniques saved economical cost, the material is easily available, it is without chemical addition to use, health aspects and no need of more labor cost.

5. Further research in water quality would be very beneficial in the development of a future water resource program in the groundwater. In fact, the origin of iron and manganese needs to be investigated and identifying the sources of contamination will be possible to select and implement the most correct and appropriate solution to these quality issues.

REFERENCES

AHMAD, M. 2012. *Iron and manganese removal from groundwater: geochemical modeling of the Vyredox method.*

ALLEY, E. R. 2007. *Water quality control handbook*, McGraw-Hill Education.

ALP, E. & MELCHING, C. S. 2011. Allocation of supplementary aeration stations in the Chicago waterway system for dissolved oxygen improvement. *Journal of environmental management,* 92**,** 1577-1583.

ANTUNES, V., CANDEIAS, A., OLIVEIRA, M. J., LORENA, M., SERUYA, A. I., CARVALHO, M. L., GIL, M., MIRÃO, J., COROADO, J. & GOMES, V. 2016. Calcium sulfate fillers and binders in Portuguese 15th and 16th centuries: Ground layers from a family painting workshop—Study by multianalytical spectroscopic techniques. *Microchemical Journal,* 125**,** 290-298.

ANUAR, N. M. B. K. 2015. *EFFICIENCY OF SLOW SAND FILTER IN PURIFYING OF TUBE WELL WATER IN KG. FAJAR, GAMBANG, KUANTAN.* UNIVERSITI MALAYSIA PAHANG.

BARLOKOVÁ, D. & ILAVSKÝ, J. 2010. Removal of iron and manganese from water using filtration by natural materials. *Polish Journal of Environmental Studies,* 19**,** 1117-1122.

BAYLAR, A., UNSAL, M. & OZKAN, F. 2010. Hydraulic structures in water aeration processes. *Water, Air, & Soil Pollution,* 210**,** 87-100.

BIYANI, M., PAREEK, E., AGARWAL, D., KHAN, R. & SAINI, M. M. 2017. Biyani Institute of Commerce & Management Pvt. Ltd.

DANDWATE, S. R. 2012. Study of Physicochemical Parameters of Groundwater Quality of Kopargaon Area, Maharastra State, India duringPre-monsoon and Post-monsoon Seasons. *E-Journal of Chemistry,* 9**,** 15-20.

DEMIR, N. M. 2016. Experimental Study of Factors that Affect Iron and Manganese Removal in Slow Sand Filters and Identification of Responsible Microbial Species. *Polish Journal of Environmental Studies,* 25.

DIAZ-ALARCÓN, J., ALFONSO-PÉREZ, M., VERGARA-GÓMEZ, I., DÍAZ-LAGOS, M. & MARTÍNEZ-OVALLE, S. 2019. Removal of iron and manganese in groundwater through magnetotactic bacteria. *Journal of environmental management,* 249**,** 109381.

ELSHEIKH, M. A. E.-S., GUIRGUIS, H. S. & AMER, A. 2020. Removal of iron and manganese from groundwater: a study of using potassium permanganate and sedimentation. *Bulletin of the Faculty of Engineering. Mansoura University,* 42**,** 7-12.

FITO, J., BULTOSSA, G. & KLOOS, H. 2019. Physicochemical and heavy metal constituents of the groundwater quality in Haramaya Woreda, Oromia Regional State, Ethiopia. *International Journal of Energy and Water Resources,* 3**,** 23-32.

GARCÍA-MENDIETA, A., OLGUÍN, M. T. & SOLACHE-RÍOS, M. 2012. Biosorption properties of green tomato husk (Physalis philadelphica Lam) for iron, manganese and iron–manganese from aqueous systems. *Desalination,* 284**,** 167-174.

GIZACHEW, M., ADMASIE, A., WEGI, C. & ASSEFA, E. 2020. Bacteriological contamination of drinking water supply from protected water sources to point of use and water handling practices among beneficiary households of boloso sore woreda, wolaita zone, Ethiopia. *International Journal of Microbiology,* 2020.

HASAN, H. A., ABDULLAH, S. R. S., KAMARUDIN, S. K., KOFLI, N. T. & ANUAR, N. 2014. Kinetic evaluation of simultaneous COD, ammonia and manganese removal from drinking water using a biological aerated filter system. *Separation and Purification Technology,* 130**,** 56-64.

HE, K., CHEN, Y., TANG, Z. & HU, Y. 2016. Removal of heavy metal ions from aqueous solution by zeolite synthesized from fly ash. *Environmental Science and Pollution Research,* 23**,** 2778-2788.

HOMONCIK, S. C., MACDONALD, A. M., HEAL, K. V., DOCHARTAIGH, B. É. Ó. & NGWENYA, B. T. 2010. Manganese concentrations in Scottish groundwater. *Science of the total environment,* 408**,** 2467-2473.

HOQUE, A. 2006. Assessment of iron, manganese and arsenic removal efficiencies of conventional iron removal plants.

JEŻ-WALKOWIAK, J., DYMACZEWSKI, Z. & WEBER, Ł. 2015. Iron and manganese removal from groundwater by filtration through a chalcedonite bed. *Journal of Water Supply: Research and Technology—AQUA,* 64**,** 19-34.

KAMEL, E. M. 2012. Simultaneous Removal of Iron and Manganese from Ground Water by Combined Photo-Electrochemical Method. *International Journal of Chemistry***,** 2306-6415.

KARAKISH, A. A. Subsurface removal of iron and manganese from groundwater–case study. Ninth International Water Technology Conference, IWTC9, 2005. Citeseer, 415-429.

KATSWANGENE, P. K., OLEKO, W. R. & KAZADI, M. Z.-A. 2021. Spatiotemporal Portrait of the Quality of Water Supplied by REGIDESO/Butembo, Democratic Republic of the Congo. *Advances in Microbiology,* 11**,** 225-242.

KHATRI, N., TYAGI, S. & RAWTANI, D. 2017. Recent strategies for the removal of iron from water: A review. *Journal of Water Process Engineering,* 19**,** 291-304.

KIM, H., KO, R.-A., LEE, S. & CHON, K. 2020. Removal efficiencies of manganese and iron using pristine and phosphoric acid pre-treated biochars made from banana peels. *Water,* 12**,** 1173.

KWAKYE-AWUAH, B., SEFA-NTIRI, B., VON-KITI, E., NKRUMAH, I. & WILLIAMS, C. 2019. Adsorptive removal of iron and manganese from groundwater samples in Ghana by zeolite Y synthesized from Bauxite and Kaolin. *Water,* 11**,** 1912.

LI, C., WANG, S., DU, X., CHENG, X., FU, M., HOU, N. & LI, D. 2016. Immobilization of iron-and manganese-oxidizing bacteria with a biofilm-forming bacterium for the effective removal of iron and manganese from groundwater. *Bioresource technology,* 220**,** 76-84.

MALKOV, V. & SADAR, M. 2010. Control of Iron and Manganese Ozone Removal by Differential Turbidity Measurements. *Ozone: science & engineering,* 32**,** 286-291.

MARGETA, K., LOGAR, N. Z., ŠILJEG, M. & FARKAŠ, A. 2013. Natural zeolites in water treatment–how effective is their use. *Water treatment,* 5**,** 81-112.

MOGHNY, T. A., MOHAMED, A. M. G., SALEEM, S. S. & FATHY, M. 2017. Abu Zenima synthetic zeolite for removing iron and manganese from Assiut governorate groundwater, Egypt. *Applied Water Science,* 7**,** 3087-3094.

MOHD SANUSI, A., ADLAN, M. N., MOHD REMY ROZAINY, M. & JAMIL, R. Removal of iron and manganese using cascade aerator and limestone roughing filter. Materials Science Forum, 2016. Trans Tech Publ, 509-513.

NEAG, E., TÖRÖK, A. I., TANASELIA, C., ASCHILEAN, I. & SENILA, M. 2020. Kinetics and Equilibrium Studies for the Removal of Mn and Fe from Binary Metal Solution Systems Using a Romanian Thermally Activated Natural Zeolite. *Water,* 12**,** 1614.

NITZSCHE, K. S., WEIGOLD, P., LÖSEKANN-BEHRENS, T., KAPPLER, A. & BEHRENS, S. 2015. Microbial community composition of a household sand filter used for arsenic, iron, and manganese removal from groundwater in Vietnam. *Chemosphere,* 138**,** 47-59.

OBIEFUNA, G. I. & ORAZULIKE, D. 2010. Physicochemical characteristics of groundwater quality from Yola Area, Northeastern Nigeria. *Journal of Applied Sciences and Environmental Management,* 14.

OBIRI-NYARKO, F., KWIATKOWSKA-MALINA, J., MALINA, G. & KASELA, T. 2015. Geochemical modelling for predicting the long-term performance of zeolite-PRB to treat lead contaminated groundwater. *Journal of contaminant hydrology,* 177**,** 76-84.

OJO, O. 2002. Construction and maintenance of Borehole in Anambra State (PTF sponsored project experience) M. Sc Seminar Report University of Ibadan. *Dept. Agric. Environ. Eng,* 18.

OMER, N. H. 2019. Water quality parameters. *Water quality-science, assessments and policy***,** 18.

PORCELLI, N. & JUDD, S. 2010. Chemical cleaning of potable water membranes: A review. *Separation and Purification Technology,* 71**,** 137-143.

RATHINAKUMAR, V., DHINAKARAN, G. & SURIBABU, C. 2014. Assessment of aeration capacity of stepped cascade system for selected geometry. *International Journal of ChemTech Research CODEN,* 6**,** 254-262.

SANGEETHA, C. & BASKAR, P. 2016. Zeolite and its potential uses in agriculture: A critical review. *Agricultural Reviews,* 37**,** 101-108.

SAREWITZ, D., CLAPP, R., CRUMBLEY, C., KRIEBEL, D. & TICKNER, J. 2012. The sustainability solutions agenda. *New Solutions: A Journal of Environmental and Occupational Health Policy,* 22**,** 139-151.

SHAH, C. 2017. Which Physical, Chemical and Biological Parameters of water determine its quality.

SHAHIN, K., ELSAYED, A., ZEINELDIN, A. & ISMAIL, S. Sustainable Treatment for High Iron Concentration in Groundwater for Irrigation Purposes. 2019 ASABE Annual International Meeting, 2019. American Society of Agricultural and Biological Engineers, 1.

SHARMA, S., PETRUSEVSKI, B. & SCHIPPERS, J. 2018. Advance groundwater treatment. *Retrived on October*.

SYAZWAN, M., ROZAINY, M. M. R. & JAMIL, R. Removing Iron and Manganese by Using Cascade Aerator and Limestone Horizontal Roughing Filters. IOP Conference Series: Materials Science and Engineering, 2020. IOP Publishing, 012006.

TEKERLEKOPOULOU, A. & VAYENAS, D. 2007. Ammonia, iron and manganese removal from potable water using trickling filters. *Desalination,* 210**,** 225-235.

VAN DER MERWE, E. 2020. Identifying potentially valuable flavour fractions from South African botanical extracts using LC Taste as a rapid screening method.

VIROLAINEN, S., WESSELBORG, T., KAUKINEN, A. & SAINIO, T. 2021. Removal of iron, aluminium, manganese and copper from leach solutions of lithium-ion battery waste using ion exchange. *Hydrometallurgy,* 202**,** 105602.

VOLPE, D. 2012. Assessment of Iron and Manganese Sequestration.

VRIES, D., BERTELKAMP, C., KEGEL, F. S., HOFS, B., DUSSELDORP, J., BRUINS, J., DE VET, W. & VAN DEN AKKER, B. 2017. Iron and manganese removal: Recent advances in modelling treatment efficiency by rapid sand filtration. *Water Research,* 109**,** 35-45.

WANG, S. & PENG, Y. 2010. Natural zeolites as effective adsorbents in water and wastewater treatment. *Chemical engineering journal,* 156**,** 11-24.

YANG, J.-F., HE, M., WU, T.-F., HAO, A.-P., ZHANG, S.-B., CHEN, Y.-D., ZHOU, S.-B., ZHEN, L.-Y., WANG, R. & YUAN, Z.-L. 2018. Sulfadiazine oxidation by permanganate: Kinetics, mechanistic investigation and toxicity evaluation. *Chemical Engineering Journal,* 349**,** 56-65.

YANG, X., GUO, W., ZHANG, X., CHEN, F., YE, T. & LIU, W. 2013. Formation of disinfection by-products after pre-oxidation with chlorine dioxide or ferrate. *Water research,* 47**,** 5856-5864.

Experimental Result and Laboratory Pictures

1 Experimental Result

Table 4.11: The physical and chemical parameter of raw water sample with aeration

Parameter	Unit	Trial 1	Trial 2	Trial 3	Average
pH	-	8.1	7.8	8.3	8.0
Color	TCU	15.4	14.8	15	15.0
Turbidity	NTU	5.4	5.5	5.2	5.36
Conductivity	μs/cm	385	383	380	382.6
Temperature	^oC	26.5	28	26.7	27.0
Iron	mg/L	4.5	4.45	4.81	4.58
Manganese	mg/L	3.36	3.2	3.4	3.32
Chloride	mg/L	0.43	0.39	0.37	0.39
Nitrate	mg/L	0.77	0.73	0.7	0.73
Sulfate	mg/L	0.59	0.55	0.52	0.55

Table 4.12: The physico-chemical parameter of raw water after aeration and filtration

	Types of filter materials / natural sand materials									
	Coarse sand					Fine sand				
	Filter depth(cm)					filter depth(cm)				
Parameter	10	15	20	25	30	10	15	20	25	30
pH	8	7.8	7.6	7.05	6.85	7.8	7.5	7.2	6.5	7
Color	12.4	8.9	4.5	0.2	0.0	13	9.3	5.0	2.4	0.07
Turbidity	3.9	2.2	1.3	0.0	0.0	4.2	3.05	1.7	0.5	0.0
Conductivity	379	375	368	370	359	381	377	364	361	360
Temperature	27	26.8	25.6	26	25	26.8	26.5	27	26.3	25.8
Iron	3.99	2.58	1.2	0.33	0.11	4.3	3.1	2.04	0.88	0.23
Manganese	3.04	2.2	1.07	0.53	0.20	3.2	2.6	1.8	0.57	0.28
Chloride	0.36	0.31	0.28	0.21	0.12	0.37	0.34	0.25	0.19	0.16
Nitrate	0.69	0.63	0.51	0.4	0.26	0.71	0.70	0.66	0.45	0.43
Sulfate	0.49	0.38	0.34	0.25	0.14	0.51	0.40	0.29	0.22	0.19

ANNEX 2

During aeration process by using spray aerator from groundwater

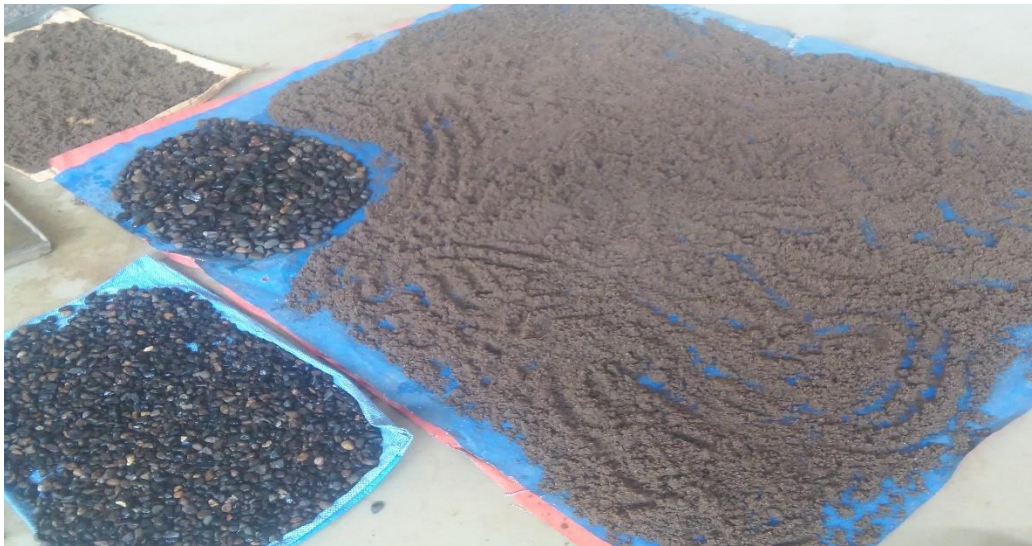

During selecting natural sand raw materials

During washing and preparation of sand and gravel raw materials

During dried raw materials by using oven   **The mesh sieve size in the lab.**

During drying raw materials

During immersing the gravel and inserting the sand materials in filter media

During filling aerated water at optimum height and collecting the sample in each filter media

During experimental analysis and laboratory pictures

During experimental analysis and laboratory pictures

Test procedure of iron and manganese

Iron

1. Fill the test tube with sample to the 10 ml mark.

2. Add one iron MR No 1 tablet, crush and mix to dissolve.

3. Add one iron MR No 2 tablet, crush and mix to dissolve.

4. Stand for 10 minutes to allow full color development.

5. Select Phot 39 on Photometer.

6. Take Photometer reading in usual manner (see Photometer instructions).

7. The result is displayed as mg/L Fe.

Manganese

1. Fill test tube with sample to the 10 mL mark (see Note 1).

2. Add one Manganese No 1 tablet, crush and mix to dissolve.

3. Add one Manganese No 2 tablet, crush and mix to dissolve then cap the tube.

4. Stand for 20 minutes to allow colour development (see Note 2).

5. Select Phot 20 on Photometer.

6. Take Photometer reading in usual manner (see Photometer instructions).

7. The result is displayed as mg/L Mn.