

Development of an Appropriate Technique for the Removal of Iron and Other Pollutants from Groundwater

Haruna Garba^{1*} and Dauda Mailafiya Jera²

¹Department of Civil Engineering Faculty of Engineering and Technology Nigerian Defence Academy Kaduna
²Nigerian National Water Resources Institute MandoKaduna.

Submitted: 15-07-2022

Revised: 27-07-2022

Accepted: 29-07-2022

ABSTRACT

A pilot treatment plant model was constructed and the performance of the model as an effective technique for the removal of iron and other pollutants from ground water was found to be effective. With an effective size of 0.45mm, uniformity coefficient of 1.5, and porosity of 0.6, the filter media was able to filter water with high iron concentration and other parameters. The backwash velocity rate for the sand filter media is 1.44 m/s (86.4m/hr). At this rate there was enough pressure for expansion and boiling of the media to dislodge the iron sludge, flocs and other dirt trapped by the filter. Influent into and effluent out of the model at 60cm, 70cm and 80cm depths for nine (9) days were determined. At 60cm depth 99.10% iron removal efficiency was achieved, at 70cm depth 86.10% removal efficiency was achieved and at 80cm depth 90.63% was achieved. Similarly, the model was able to remove physical and organoleptic parameters (colour, turbidity, fluoride manganese, nitrite, Ph, zinc E-coli and total coliform). The technique developed in this study can be adopted to produce a prototype that can be used as an alternative simple and cost effective way of removing iron and other parameters from groundwater.

Keywords: Groundwater, filter media, model, sand, iron, parameter

I. INTRODUCTION

Groundwater is presently one of the major sources of water supply in rural areas throughout Nigeria. Accounting for about 0.6% of the volume of water available on the surface of the earth and the third most important reservoir in the hydrologic cycle and also the major source of fresh water available for Man [1]. However, with all these attributes [2] observed that groundwater has the high concentration of iron content because iron is

common in many igneous rocks and is found in trace amount in sedimentary rocks. Iron is usually found in its ferric (Fe^{3+}) and precipitated form. Iron is also found in its ferrous (Fe^{2+}) form in most groundwater as well as in the deep zones of some eutrophic water reserves that are deprived of oxygen [2].

Iron in drinking water does not have a threat on health. To some extent, iron is an essential nutrient for human body. In surface water, such as rivers and lakes, dissolved iron is hardly ever found, because it reacts with oxygen, to form insoluble compounds and sinks out of the water. However, in ground water such as wells and springs, iron is the most common dissolved chemical. Although not considered to cause health problems in humans, its presence in potable water is rather unpleasant due to the bad odours it spreads, its rusty taste and colour, its feel on skin and hair, and its tendency to stain clothing. In addition, the presence of dissolved iron enhances the growth of iron bacteria, which forms dark-colored slime layers on the inner side of system's pipes. Most countries have accepted a safe drinking water standard (aesthetic, not health related) with a maximum of 0.3 ppm iron content. Water drawn from sources with higher iron content should be treated before entering any municipal water supply system. At the same time, iron is an essential nutrient for humans, with a recommended daily intake of 5 milligrams [3]. Therefore, the official water and environment agencies in many countries have established a secondary limit for iron in drinking water, which is based on aesthetic concerns (Secondary Maximum Contaminant Level – SMCL). In countries such as the US, Canada, Greece, Iran, Russia and others, the SMCL for iron in drinking water is 0.30 mg/L (milligrams per litre) or ppm (parts per million). Rivers iron concentrations exceeding 10 to 200 mg/l of nutrient

solution have been found to be toxic to plants, and amounts in excess of 200 mg/day are considered toxic to man. Iron in foodstuffs includes organ meats, dried legumes, egg York, cocoa, shell fish, milk and milk products, refined flour, potatoes [4]. The iron content of water is important because small amounts seriously affect water's usefulness for domestic and industrial purposes (Driscoll 1989). If iron is present in amount greater than 0.2 or 0.3 ppm, it is usually very objectionable (Cheremisinoff 1995). Some industries cannot even tolerate more than 0.1 mg/l of iron [2]. It interferes with dyeing, tanning, paper manufacturing and process work. [5]. The 1925, 1942, 1946, and 1962 regulations of the U.S. Public Health service always reported the maximum concentration for iron (or iron and manganese combined) as 0.3 mg/L. United State Environmental Agency (USEPA) did not include iron (or iron and manganese) in the National Primary Drinking Water Regulations, but maintained it in the Secondary Drinking Water Regulations of 1989 the limit of 0.3 mg/L based on aesthetic and taste consideration. [6] reported the EC stringent directive of 0.05 mg/l guide level with a maximum concentration of 0.2 mg/l. World Health Organization WHO (1963) also adopted 0.3 mg/L as a maximum acceptable level and 1.0 mg/L as a maximum allowable. The European Community adopted in 1980 a guide of 0.05 mg/L and maximum of 0.20 mg/L. WHO (1984) and (1993)

recorded guideline of 0.3 mg/L, [7]. Nigerian Standard for Drinking Water Quality NSDWQ permits 0.3 mg/L of iron Fe^{+2} and 0.2 mg/L Manganese Mn^{+2} [8].

However, the problem of iron in water is aesthetic. Iron also gives water a sour test of metal; food cooked with high content iron in water gets unpleasant colour as well as discoloration of clothes during laundry. Consequently people would always abandon the use of the borehole with high concentration of iron and revert back to other available alternatives which may be harmful to them. For example sources such as streams, rivers, ponds, unprotected hand dug wells and so on which are not safe for human consumption. Therefore, there is need to employ the use of appropriate technology to correct the abnormality of iron content in the water provided for the people. Finding solution to this problem will help in solving problem of water crises arising from climate change.

II. STUDY AREA

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

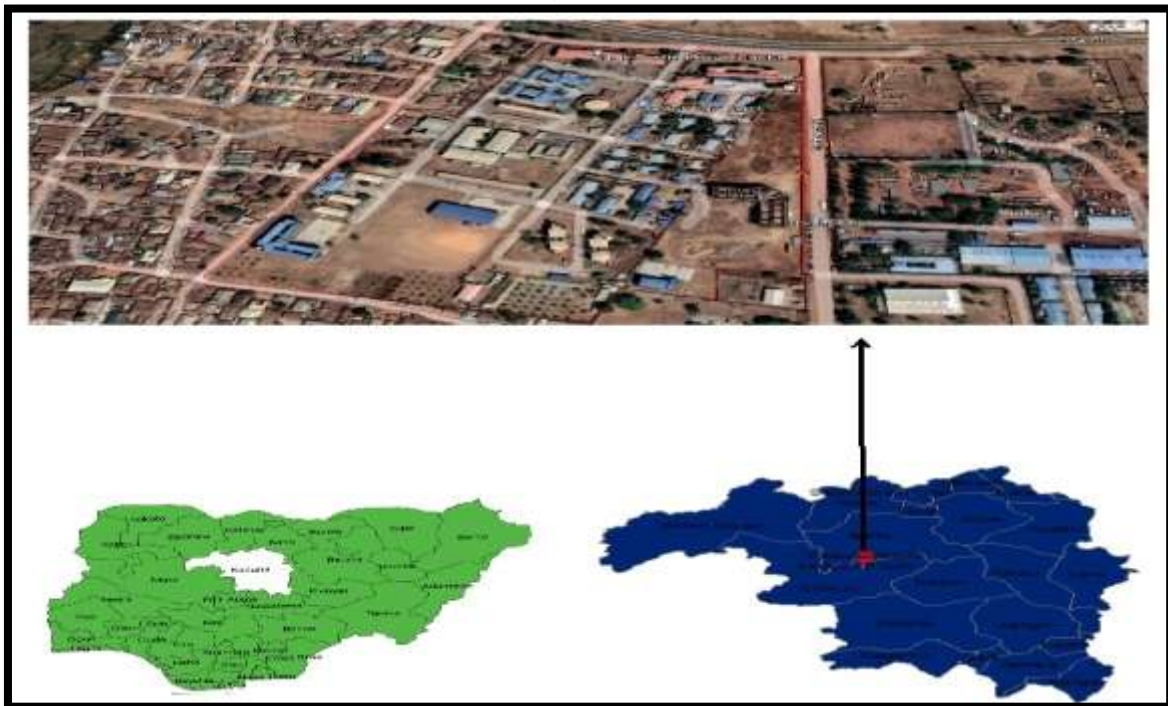


Fig 1 LOCATIONAL MAP OF STUDY AREA

III. MATERIALS AND METHODS

Filter Media

Sand sample was collected from River Kaduna at Ungula Kukumaki about 30 km from Kaduna metropolis. The position of the location of the sampling point as recorded from global positioning system (GPS) is N 10° 36' 01.41 and E 007° 30' 34.31". The following materials were used for determining the physical properties (Effective size. Uniformity coefficient Specific gravity .Porosity. Acid solubility).

- Standard British sieve series with aperture size of ; 2.36mm, 1.7mm, 1.18mm, 0.6mm, 0.425mm, 0.212mm, .0150mm, and 0.075mm for the sieve analysis.
- Mechanical electric shaker.
- Beam balance.
- Specific gravity bottles.
- Measuring cylinders.
- Beakers.
- Concentrated hydrochloric acid (HCL).

Method of determining effective size and uniformity coefficient.

A 100g portion of dried the sample (100g) was subjected to sieve analysis in order to determine the effective size (E_s) and uniformity coefficient (U_c). The samples were sieved through standard British sieves with the following apertures: 4.75mm, 2.36mm, 1.18mm, 0.600mm, 0.425mm, 0.300mm, 0.212mm, 0.075mm. The sieves were arranged in the order listed above in decreasing sieve opening from top to bottom. The test sieve shaker was used to shake and sieve the sand sample for a period of 10 minutes. The percentage by weight passing each sieve was determined using electronic weighing balance and the results was plotted against sieve size on a logarithmic paper. The sieve size which allowed 10% of the sand sample by weight (d_{10}) to pass through as interpolated from the plot gives the effective size (E_s) of the sample. Similarly, the sieve size which allowed 60% of the sand sample by weight (d_{60}) to pass through was also obtained. The uniformity coefficient U_c is the measure of the size range of the medium. It is the ratio of d_{10} and d_{60} (Equation 1).

$$U_c = \frac{d_{60}}{d_{10}}$$

Method of determining specific gravity.

The weight of empty specific gravity bottle was measured using a electronic balance and recorded as W_1 . Three quarter of the bottle was filled with sand sample and the weight was recorded as W_2 . Water was added to the sand

sample up to the brim of the bottle making the sand completely submerged in the water and was recorded as W_3 . Finally, the bottle was filled with water only and was recorded as W_4 . The specific gravity is calculated by (Equation 2)

$$S.G = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$$

Method of determining of porosity.

The method adopted for determining the porosity is the Wisconsin Model Academic Standards (WMASs). A 100 ml graduated beaker was filled with the sand sample at the mark of 75 ml. A cylinder of 100 ml was filled at the 100 ml mark with water. Water was poured from the graduated cylinder into the beaker containing the sand sample until it reaches the level where the sand was placed (75 ml mark). The volume of the water needed to saturate (fill the pores of) sand was recorded directly from the cylinder. Volume of voids in the sand was recorded as V_v . Total volume was recorded as V . Porosity n in (%). (Equation 3)

$$n = \frac{V_v}{V} \times 100. \quad 3$$

Method of determining acid solubility.

A method recommended by the American Water Works Association (1949) was adopted in the acid solubility of the sand samples. 100g of the sand samples was taken and washed with distilled water to remove dust and fine materials. The sample was then oven dried and weighed on a laboratory electronic balance. The weighed sample was then immersed in 40% (by volume) hydrochloric acid (HCL) for a period of 24 hours at room temperature. Then, the sample was thoroughly rinsed with distilled water, oven dried and finally re-weighed to determine loss in weight. The solubility was then calculated as follows (Equation 4)

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

Method of determining iron and other pollutants

Water samples was collected from the borehole where the iron removal plant was sited (Fig 3).

In developing the iron removal facility requires full evaluation of the raw water quality. Tests was conducted on the raw water to ascertain the quality of parameters (Iron and Manganese concentrations, colour, TOC levels, pH, H_2S levels, NH_4^+ concentration, hardness, and dissolved oxygen concentrations). Results of the raw water analysed is presented in Table 1. All the tests were conducted according to Standards Methods for the Examination of Water and Wastewater [9]

Table 1 Raw water from the borehole

Parameters	Unit	Sample of water from borehole	Maximum Permitted Level	Remarks
Clour	TCU	Reddish brown	15	Astatically unacceptable
Odour			Objectionable	Pungent smell of iron
Test			Objectionable	Metallic test of iron
Temperature	°C		Ambient	
Tubidity	NTU	46.8	5	Above limit
Conductivity	µS/cm	151.7	1000	
Calcium	mg/L	10		
Fluoride (F)	mg/L	0.81	1.5	Ok
Iron (Fe⁺²)	mg/L	2.5	0.3	83.33% above limit.
Magnesium (Mg ⁺²)	mg/L	9	20	Ok
Manganese (Mn ⁺²)	mg/L	0.026	0.2	Ok
Nitrate (NO ₃)	mg/L	2.90	50	Ok
pH	-	6.7	6.5-8.5	Ok
Sodium (Na)	mg/L		200	
Sulphate (SO ₄)	mg/L	0.00	100	Ok
Total Alkalinity	mg/L	43		
Total Dissolved Solids	mg/L	75.7	500	Ok
Total Hardness	mg/L	45	150	Ok
Zinc (Zn)	mg/L	3.48	3	Above limit
Escherichia coli	cfu/100ml	0	0	Ok
Total coliform	cfu/100ml	40	10	Above limit

Pilot filtration testing model.

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

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

Backwash rate design

With specific gravities of 2.6 which is within the stipulated standard, the filter medium has enough weight to withstand high pressure

during the process of backwashing which may cause loss of material. Backwash rate was designed using the above specific gravity and D₉₀. From the results it was discovered that the backwash velocity rate for the sand filter media is 1.44 m/s (86.4m/hr). The stipulated standard for the backwash rate is 37 – 49 m/hr. At this rate there will be enough pressure for expansion and boiling of the media to dislodge the iron sludge, flocs and other dirt trapped by the filter. From the above result, the media can withstand the acceptable backwash rate without the fear of losing material. Manometers manifolds were fixed at various heights so that filtered water may be collected at various heights (depths) per unit time. This is for the purpose of designing the depth of the filter. Figure 2 below is the schematic Crosssection of the model while Figure 3 is the constructed pilot model plant

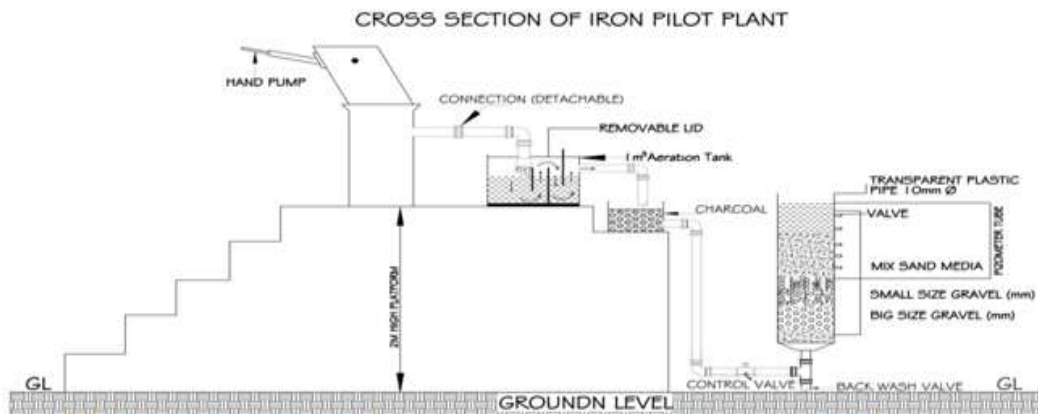


Figure 2 Schematic Cross Section



Figure 3; Constructed iron removal pilot model plant

IV. RESULT AND DISCUSSION

Kaduna river sand

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

[10] reported that “the majority of rapid sand filters in use today contain sand with an effective size of 0.35 - 0.50mm, although some have sand with E_s as high as 0.70mm”. Aves (1965) presented a porosity range of 0.35 - 0.50. However, American Water Works Association [11] guidelines gave the effective size (E_s) range from 0.45 – 1.00mm, uniformity coefficient (U_c) 1.20 – 1.70, and porosity of 0.42 – 0.47. From the sieve analysis result, it was discovered that the sand filter media has E_s value of 0.45mm, U_c is 1.50 and porosity is 0.46. All the above results fall within the acceptable standard ranges. [12] Reported that,

a uniformity graded soil will have its coefficient of uniformity of less than 2.0. This means that both the filter media are uniformly graded since they have the value of 1.50.

For depth selection, Kawamura’s constant 950 of (1975) and [11] was used alongside with the effective size of each filter media. The depth of the sand should range from 500 – 700mm. These values are also in conformity with value suggested by [13] which is 600 – 1800 mm respectively.

[12] Suggested that the specific gravity of filter media should not be less than 2.5, and acid solubility of less than 5% (loss by weight). The result obtained from test on the filter media showed that both the specific gravity and acid solubility are within the acceptable limit. The filter media has the specific gravity is 2.6 and acid solubility (loss by weight) is 0.23%. The gravel which is the under drain has specific gravity of 2.7 and porosity of 0.60. Only 60 cm depth was used. After 60 minutes of treatment 0.14 mg/L of the iron was reduced to 0.00 mg/L that is 100%. 92.86% was removed after

180 minutes, 78.57% was removed after 240 minutes, and 71.43% was removed after 300 minutes and 92.86% after 360 minutes (Fig 4). Results of the effluent sample after subjecting it

through the treatment process based on the Standards for the Examination of Waters and Wastewater is presented in Table 2

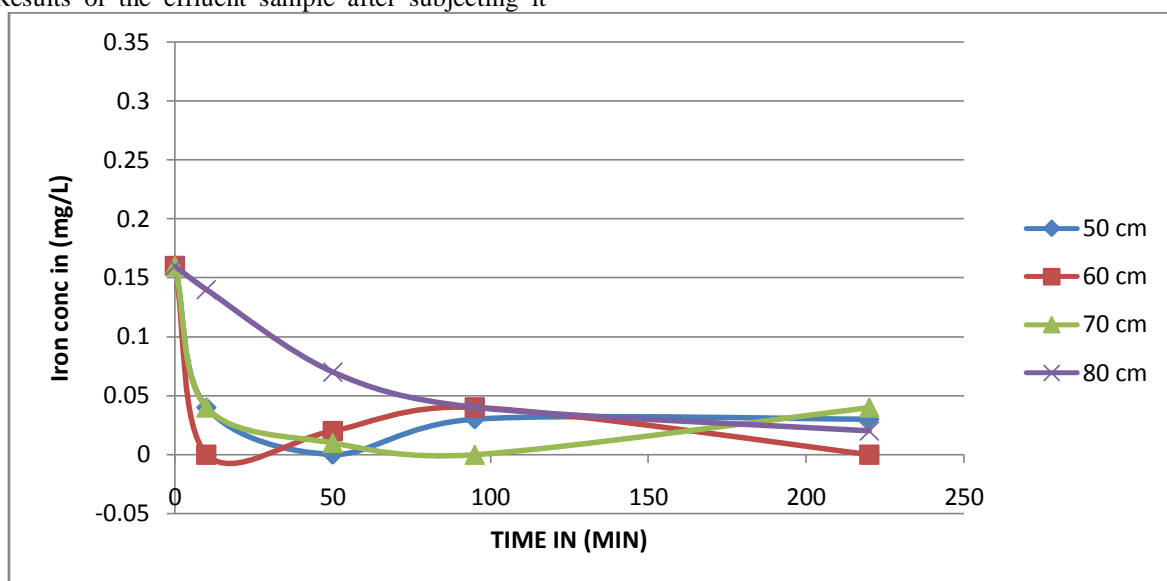


Figure 4 Iron removal rate.

Table 2 Result of the water quality parameters of raw water, and treated water.

Parameters	Unit	Sample of water from borehole	Sample of treated water	NSDWQ Maximum Permitted Level	WHO Maximum Permitted Level	Remarks
Clour	TCU	Reddish brown	5	15	15	Removed
Odour			0	Objectionable	Inoffensive	Removed
Taste				Objectionable	Inoffensive	Removed
Temperature	°C		29.5	Ambient	Ambient	Ok
Turbidity	NTU	46.8	2.8	5	5	94% was Removed
Conductivity	µS/cm	151.7	174.4	1000	1000	Ok
Fluoride (F ⁻)	mg/L	0.81	0.25	1.5	1.5	Ok
Iron (Fe ⁺²)	mg/L	2.5	0.00	0.3	0.3	100% Removed
Manganese (Mn ⁺²)	mg/L	0.026	0.00	0.2	0.1	100% Removed
Magnesium(Mn ⁺²)	mg/L	9	20	0.2	0.2	Ok
Nitrate (NO ₃)	mg/L	2.90	0.76	50	11.3	72% was removed
pH	-	6.7	8.09	6.5-8.5	6.5-8.5	Ok
Sodium(Na)	mg/L	0.00	200			
Sulphate (SO ₄)	mg/L	0.00	0.00	100	250	Ok
Total Dissolved Solids	mg/L	75.7	85.4	500	1000	Ok
Total Hardness	mg/L	45	68	150		Ok
Total Alkalanity	mg/L	43				
Zinc (Zn)	mg/L	3.48	0.07	3	3	98% was

						Removed
Escherichia coli	cfu/100ml	0	0	0	0	Ok
Total coliform	cfu/100ml	40	6	10	10	85% was Removed

V. CONCLUSION

A pilot of iron treatment plant was constructed with transparent materials consisting of the following: storage tank, aerator, flocculation tank, charcoal tank and the filtration column. Raw water from a borehole with high iron concentration was passed through the plant and the results were compared with stipulated drinking water standards guidelines of NSDWQ and WHO. With an effective size of 0.45mm, uniformity coefficient of 1.5, and porosity of 0.6, the filter media was able to filter water with high iron concentration and other parameters. The backwash velocity rate for the sand filter media is 1.44 m/s (86.4m/hr). At this rate there was enough pressure for expansion and boiling of the media to dislodge the iron sludge, flocs and other dirt trapped by the filter. The result of this study can be used to find alternative simple and cheap way for removing iron and other from water especially groundwater.

REFERENCE

- [1]. HarunaGarba, Stephen Norman and FaustinusBayang (2019); Modelling the Transmissivity of an Aquifer using Laboratory Test and Vertical Electrical Sounding International Journal of Science and Research Vol 8 Issue 12 DOI 10.21275/ART20203089.
- [2]. Fletcher G. Driscoll,(1989) Groundwater and Wells, Second Edition, Published by Johnson Filtration System Inc., Minnesota, USA 1989, page 98-99
- [3]. Daniel Ityel; (2011) Ground Water; Dealing with Iron Contamination Science Direct Vol 48 Issue 1 Pp20-28, DOI 101016/S0015-1882(11)70043-X.
- [4]. Ernest Merian,(1991) Metals and Their Compounds in the Environment, VHC Weinheim, Germany, 1991 page 950
- [5]. Paul N. Cheremisinoff,(1995) Handbook of Water and Wastewater Treatment Technology, published by Marcel Dekker, INC., New York, USA 1995 p 41, 56, 398
- [6]. Twort AC, Law FM AND Crowley FW, (1985) Water Supply,Third Edition. Publish in Great Britain by Edward Arnold (publishers) LTD, 41 bed ford square, London WCIB 3DQ, p209, 222-223, 313-314.
- [7]. John DeZuane, (1997) Handbook of Drinking water Quality, second Edition, publish by John Wiley & Sons, INC.USA, 1997, p122-124, 455.
- [8]. Standard Organization of Nigeria (SON), Nigerian industrial standard, Nigerian Standard for Drinking Water Quality ICS 13.060.20, head office No. 52, Lome Street, Wuse Zone 7, Wuse Abuja, Nigeria 2015, p15-22
- [9]. Arnold EG, Lenora SC and Andrew DE (1992) Standards Methods for Examination of Water and Wastewater. American Association Water Environment Federation 8th Edition ISBM0-87553-207-1.
- [10]. HDR Engineering inc, Omaha, NE,(2001) Handbook of Public Water Systems, Second Edition, published by John Wiley & Sons, inc, New York, USA 2001, p 353, 445,451, 470-472, 463.
- [11]. American Water Works Association,(1949) Water Treatment Plant Design, Second Edition, published by McGraw-Hill, Inc 1990 283, 306-317.
- [12]. Evan K. Nyer, groundwater Treatment technology, third edition, published by John Wiley & Sons, Inc. Hoboken, New Jersey, USA 2009 p233
- [13]. S.K Garg, Water Supply Engineering. Kanna publishers, 2-B, NATH MARKET, NAI SARAKA, DELHI-110006. (2007).p 424-429, 511, 526