REDUCTION OF IRON AND MANGANESE IN GROUNDWATER THROUGH NON-MECHANICAL AERATION AND FILTRATION METHOD: CASE STUDY OF MAKUENI COUNTY, EASTERN KENYA

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Abstract

Makueni County borders Machakos, Kitui, Taita-Taveta and Kajiado Counties. This area falls in south -eastern Kenya, a semi-arid region characterised by erratic rainfall and inadequate surface water from a few rivers. Groundwater, an option to surface water, occurs in the basement complex terrain of this study area which is highly influenced by secondary porosity bed rocks and recent volcanic activity on the Chyulu hills. However, the quality of groundwater at most locations is not fit for human and livestock consumption. Raw water from two boreholes, Kithunzi and Makindu, was tested using the American Public Health Association (APHA) procedures and found to have high levels of iron (> 5.00 Mg/L) with concentration of Manganese being greater than 0.3 Mg/L. The water was passed through a non-motorized aeration/filtration system comprising of a raised platform made of timber and plastic components designed to increase the contact between air and water in a water-to-air process. Several samples were collected from feed water, after aeration, after filtration (filtrate) and after twenty four. For Kithunzi iron reduced from an average of 5.9 Mg/L to 2.34.Mg/L a drop of 61 %. Similarly for Makindu, iron ions reduced by 56.9 % from an average of 5.72 Mg/L to an average of 2.81 Mg/L. Manganese levels also reduced by an average of 36.4 % and 20 % for the two boreholes respectively. Non – motorized aeration /filtration unit can be used to improve groundwater quality.

Keywords: Groundwater, Aeration, Filtration, Water - to - air, WHO standards. Feed water.

Introduction

Groundwater constitutes 97 % of world's readily accessible freshwater and provides the rural, urban, industrial and irrigation water supply needs around the world[17]. In Kenya groundwater is of considerable importance more so in the Arid and Semi-Arid Lands of Eastern Kenya[15]. Groundwater is comparatively safe and a reliable source of water when compared to surface water and can be available at the point of consumption. This source of water is usually not polluted but if polluted it becomes very difficult to treat to acceptable levels. On the other hand, availability of surface water is dwindling by the day mainly because of climate change and anthropogenic changes such as land use and land cover patterns. However, groundwater quality is changing adversely[2].

Groundwater water quality is dependent on geology of a given area location[14,21,19]. It is defined in terms of physical, chemical and biological parameters[11,26]. The groundwater quality in the study area does not meet the WHO standards[12]. with most of boreholes in Makuenireporting parameter concentrations that are way above permissible WHO limits for example concentration of iron (Fe) has been found to be > 5.00 Mg/ L while the allowable WHO standard is 0.3 Mg/ L. Manganese, flourides, total hardness, electrical conductivity (EC), total dissolved solids (TDS) amongst many other parameters were all found to be above the allowable WHO limits. The boreholes that were used in this research; Kithunzi borehole near Wote (UTMX – 369650 and UTMY – 9749031) and *Sisters of the Most Precious Blood* in Makindu (UTMX – 339485 and UTMY – 9904956) were in different geological areas.

The rocks in Kithunzi, were intermediate Igneous rock and while the rocks at the Sisters' compound were found to be Igneous rock as seen in the lithology map (Figure 1). A detailed study of soils around the two locations showed that the soils in Kithunzi can be described as Ferro-chromic ACRISOLS that is well drained and moderately deep[17] while he soils in Makindu could be described as ferrasols with the rocks being hornblende and gneiss respectively[16, 24].Kithunzi borehole lies in a basement system while the Sister's borehole lies at the boundary between volcanics and the basement system. This basement system is mainly gneisses, schists, and granulates and crystalline of sedimentary origin where two series' are recognized; the Kasigau and Kurase[24].

Groundwater pollution is generally of three categories; organic compounds, microorganisms and organic pollutants. The inorganic pollutants such as iron (Fe), Manganese (Mn) and Magnesium (Mg) are non-degradable which makes them a health risk[1]. High levels of Iron (Fe) and Manganese (Mn) in drinking water lead to health and aesthetic issues[22,1]. Cases of staining of cloths and incrustation of plumbing fixtures have also been reported. Storage of such water in tanks and its flow through distribution systems leads to high turbidity and brownish /black water at the taps[13,23].

This study concentrated on reduction of iron (Fe) and related salts from groundwater from the study area using a technology that would be readily available to people of study area. Several studies on reduction of concentration of iron and other related salts from groundwater using aeration and filtration method have been undertaken; El Naggar (2010) developed low technology for removal of iron and manganese from groundwater in Siwa oasis in Egypt while Ahmed et al, 2002, noted that aeration and filtration reduced iron and manganese levels to below the allowable 0.3 Mg/L and 0.1 Mg/L respectively from a groundwater sample collected from groundwater in the Nile valley.

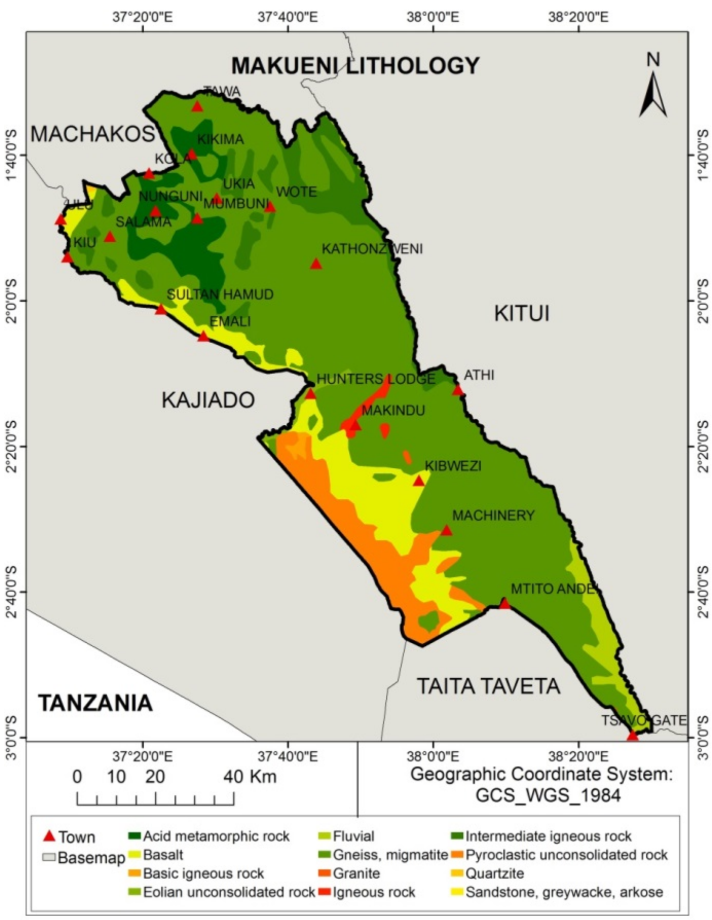

Figure 1 showing the geology of Makueni County.

Research that was carried out on quality on quality improvement using aeration and filtration methods in Malaysia and other jurisdictions noted that water -to-air method was more effective than air -to-water methods of aeration[3, 9,21]. In all these instances aeration was carried out using mechanized aerators which would be expensive in a rural set up.

In this study non–mechanical aeration and filtration process was carried out to determine the effectiveness of aeration based on optimal operation parameters of aeration and filtration such as pH, total dissolved solids, electrical conductivity, colour and turbidity[21]. Iron as found in groundwater is usually in its reduced form: Ferrous iron ion (Fe^{2+}. Iron removal can be accomplished with chemical oxidation of soluble form to its insoluble oxide form[1] . The insoluble form is then removed, usually iron hydroxide ($Fe(OH)_3$), by filtration process. Equation 1 represent the oxidation of iron by oxygen[4].

$$4Fe^{2+} + 2O_2 + 2H_2O \Rightarrow 2Fe_2O_3 + 4H^+ \quad \text{..............................} \quad (1)$$

$$Mn^{2+} + O_2 + H_2O \Rightarrow MnO_2 + 2H^+ \quad \text{..............................} \quad (2)$$

Filtration process is normally varied using sand or silica or quartz or manganese oxide as the filtration media.

MATERIALS AND METHODS

Groundwater samples were collected from the two boreholes, Kithunzi borehole and *Most Precious Blood Sisters*' borehole in Makindu, and analysed for physical chemical parameters. The parameters that were tested are: - pH, Electrical conductivity, turbidity, total dissolved solids (TDS), total hardness, alkalinity, Ca, Fe, Mn, Flouride, etc. The parameters were expressed as Mg/L except for the pH, Electrical Conductivity (µs/cm), turbidity (NTU) and colour (TCU). Sampling, preservation, transportation and the analysis of the samples was carried out according to methods described in water and wastewater analysis manual (Eaton et al, 1998). High density polyethylene plastic sampling containers (20 litres) were rinsed two to three times with the groundwater being sampled and then filed up. In situ measurements included pH, EC, TDS and temperature as per WHO's recommendations[28]. The containers were then air-tightly capped. The samples for chemical analysis were preserved and analysed within 48 hours. The Atomic Absorption Spectrophotometer (AAS) was used in the analysis of heavy metals.

Components of the aerator.

The aerator was fabricated using plastic material which could not corrode such as UPVC pipes, taps and buckets. It is only where plastic alternatives were not readily available where galvanized materials were used. The percentage increase in aeration was determined through a preliminary experiment where trays were arranged using the50cm spacing and the dissolved oxygen measured. Table 1 shows the results of this aeration trial while Figure 2 shows the experimental arrangement. A spacing of 0.5 M was consequently used in the laboratory trials. A comparison was also made between aeration when trays had aggregates and when such aggregates were missing. The percentage increase in dissolved oxygen when trays had aggregates was 39.8 % which rose marginally when the trays had no aggregates to 41.3 %

Table 1. Results of aeration

Position of tray	Trays with Aggregates		Trays without aggregates	
	Dissolved oxygen Mg/L	Percentage increase	Dissolved oxygen Mg/L	Percentage increase
Tray on top	1.51		1.25	
Tray 50 cm from top	1.79	15.5	1.40	12
Tray 100 cm from top	1.94	11.4	1.61	15
Tray 150 cm from top	2.19	12.9	1.84	14.3
Overall percentage increase		39.8 %		41.3 %

The volume of water for one run was 120 litres which flowed into plastic trays that were filled with two layers of aggregates. The top layer being of uniformly distributed sand that passes through 1.0 mm sieve and is retained by 0.8 mm sieve and the other layer 18mm coarse aggregates. Three trays were arranged 50 cm apart and then the water fell onto a container shaped as a frustum that is 50 cm in depth. Sand was arranged to achieve maximum filtration and the effluent passed through two buckets that were arranged one after the other and partitioned into two in order to achieve maximum filtration. The water so filtered was collected into a bucket. Samples were collected before aeration, after aeration, after filtration and again after 24 hours. These samples were tested for pH, turbidity, electrical conductivity, TDS, colour, alkalinity, total hardness, iron, manganese, magnesium, calcium Sodium, Flouride and nitrates .

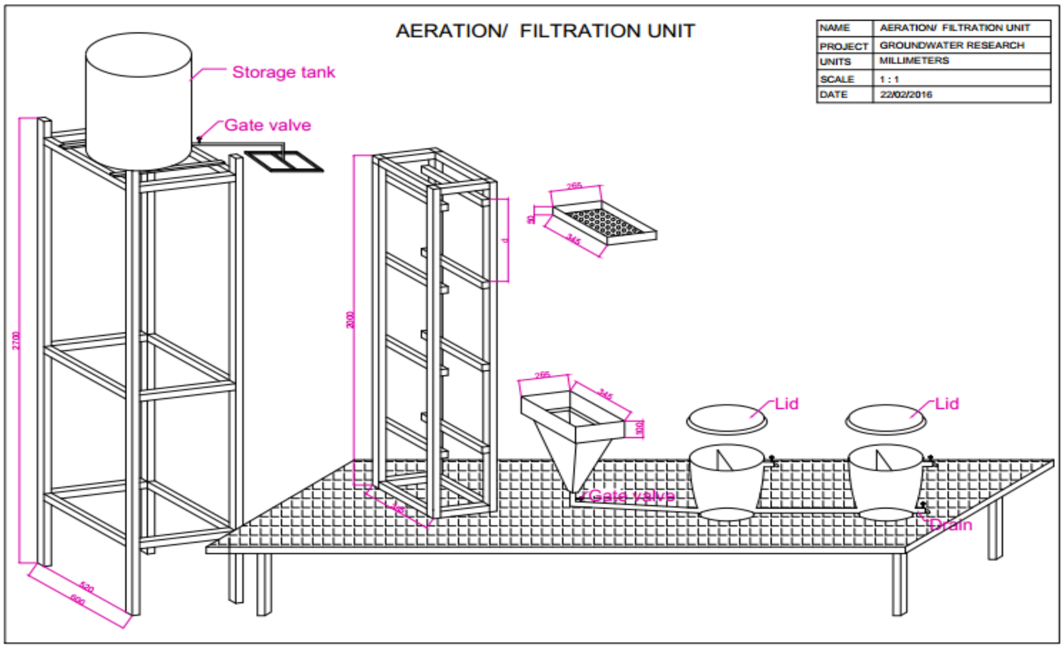

Figure 2 showing experimental arrangement.

RESULTS AND DISCUSSION.

Water from Kithunzi borehole had high turbidity (67 NTU) as can be seen in Table 2 and had a yellowish colour which made it unsightly. The yellowing was attributed to high level of iron (Fe) in the water. While the *Sister's* borehole had a much lower value of turbidity (16 NTU) but still crops that were irrigated using water from the borehole had stunted growth. However, the iron content in the two boreholes was well above maximum allowable by WHO, Kenya Bureau of Standards (KEBS) of 0.3 Mg/L as can be seen in Table 2 with the Iron content in Kithunzi being 5.34 Mg/L and at Sister's house at Makindu being 5.37 Mg/ L. Flouride was also of concern because the fluoride levels in the two boreholes was way above the allowable 1.5 Mg/L [28,10] with values of fluoride for Kithunzi and Sisters boreholes being 6.5 Mg/L and 8.2 Mg/L respectively. Table 2 shows the water quality for the two test borehole for several indicative parameters.

Table 2 Results of physical parameters for the two boreholes

Parameter			
	Kithunzi	Sister's borehole	WHO Standard
Ph	6.84	6.75	6.5 – 8.5
Turbidity (NTU)	67	16	5
Colour (TCU)	25	5	15
Electrical Conductivity (µS/cm)	2310	9520	1000
Total Dissolved Solids	1420	6025	600
Iron (Fe) (Mg/L)	5.34	5.37	0.3
Manganese (Mg/L)	0.15	0.01	0.4
Magnesium (Mg/L)	1.78	1.85	
Alkalinity (Mg/L)	325	404	
Total Hardness (Mg/L)	880	950	500
Nitrates NO_3^-(Mg/L	8.73	14.22	50
Ca (Mg/L)	21.88	10.25	300
Na (Mg/L)	211	399.5	200
F (Mg/L)	6.5	8.2	1.5
Sulphate SO_4^-(Mg/L)	187.09	119.03	250

Ec – Electrical Conductivity (µS/cm) TDS – Total Dissolved Solids
NTU- Nephelometric Turbidity Unit TCU – True colour units

The other indicator parameters such as Electrical conductivity (Ec) and Total Dissolved Solids (TDS) were also way above the permissible limits of 1000 Mg/L for Electrical conductivity and 600 Mg/L for the Total Dissolved Solids. The electrical conductivity was 2310 Mg/L for Kithunzi and a high of 9520 Mg/L for Sister's house at Makindu.

The Feed water was passed through the aeration process at a rate of 1.5 L/sec. The sample that was collected after aeration indicated deterioration by becoming more turbid than at the start of the process. Water in Figure 3 shows the feed water at the beginning of the process being clearer (less turbid) than the water after aeration (beaker in the middle). The water after filtration is clear and the turbidity is 5 NTU or slightly above 5 NTU. After 24 hours the water becomes even clearer with turbidity values being less than 5 NTU in all the cases.

All the values of the feed water samples in all the runs had Electrical Conductivity (EC) values as well as total dissolved solids (TDS) greater than the allowable; 1000 Mg/L for EC and 600 Mg/L for TDS.

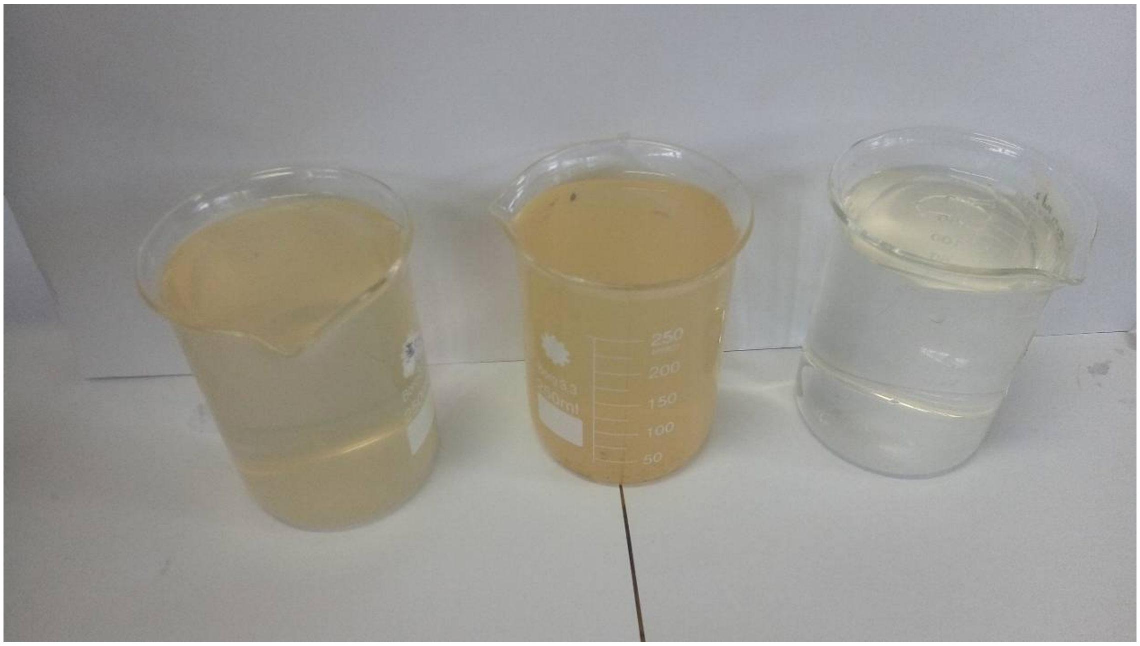

Figure 3: Changes in turbidity as the water passes through the different stages

The aeration /filtration unit was meant to oxidize ferrous ions to ferric ions. Tables 3 and 4 show summaries of results of aeration/filtration tests. The results show Iron (Fe) concentrations of the feed water (water that is feed into the unit), iron (Fe) concentration after aeration and iron (Fe) concentration after filtration. Figures 4 and 5 show the reduction of concentration of iron for the two boreholes. The percentage decrease in amount of iron (Fe) in the water is greater than 50% in all the runs with the average being 61 % and 56.9 % for Kithunzi and Sisters' boreholes respectively. A value of 61 % reduction in concentration of iron (Fe) is high. However, higher values have been achieved but this could be attributed to the fact that the aeration was not mechanized. High values (>85 %) have been recorded[1,21].

Table3results of Iron (Fe) concentrationtest for Kithunziborehole.

	Iron Concentration Mg/L				
Run	Feed water	After aeration	After Filtration	Percentage (%) decrease	Average Percentage (%) decrease
1	5.68	8.16	2.067	63.6	61
2	5.97	8.47	2.68	55.1	
3	5.48	8.27	1.83	66.6	
4	6.23	8.55	2.11	66	
5	5.98	8.26	1.77	70.4	
6	6.53	8.53	3.15	51.8	
7	7.19	8.84	2.73	62.05	
8	5.08	7.56	2.40	52.8	

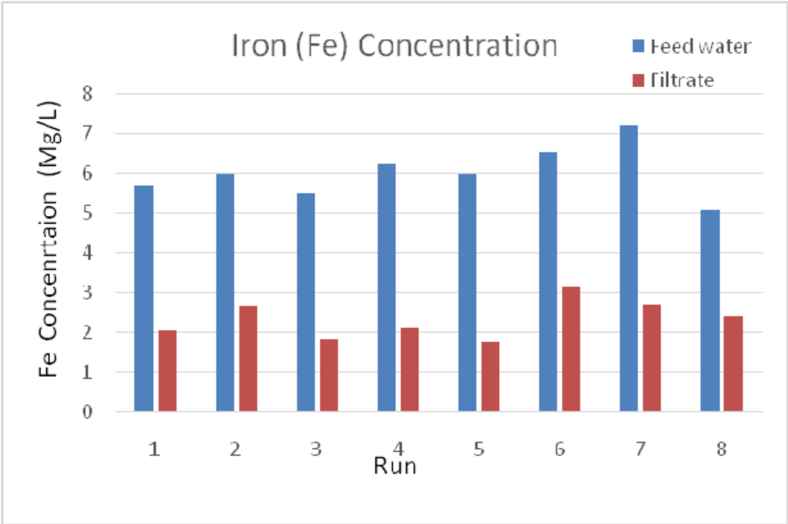

Figure 4. Concentration of iron for the eight runs for Kithunzi borehole.

Table 4 Results of Iron (Fe) concentration test for Sisters' borehole in Makindu.

	Iron Concentration Mg/L				
Run	Feed water	After aeration	After Filtration	Percentage (%) decrease	Average Percentage (%) decrease
1	5.53	8.02	2.24	59.49	56.9
2	5.93	7.95	2.55	57	
3	6.13	8.76	2.71	55.8	
4	6.23	8.43	2.70	56.7	
5	5.73	8.05	2.40	58.1	
6	6.34	8.78	2.56	59.6	
7	4.90	5.90	2.34	52.2	
8	4.98	5.76	2.17	56.42	

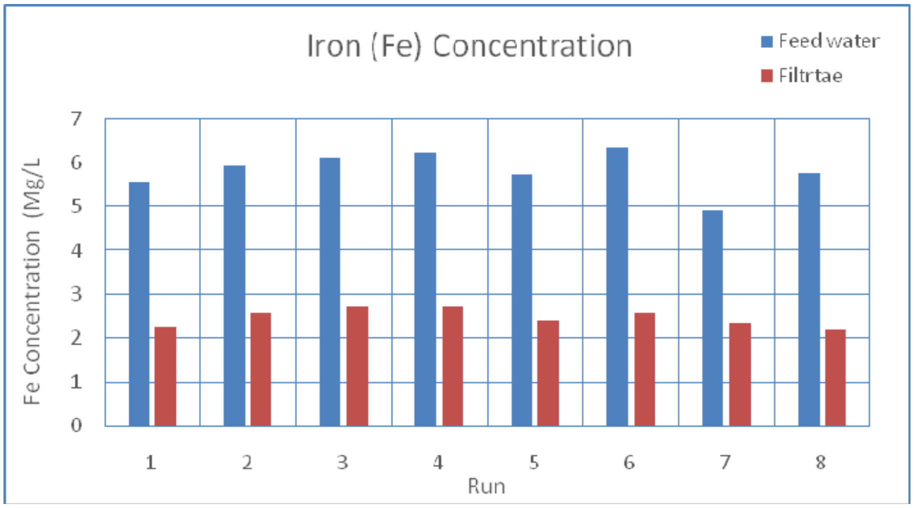

Figure 5. Concentration of iron (Fe) for the eight runs for Sisters' borehole at Makindu.

The average concentration of manganese in the Kithunziboreholes for the feed water was 0.75 Mg/L and for the filtrate was 0.44 Mg/L while for the Sisters' boreholes the corresponding concentrations were 0.29 Mg/L and 0.24 Mg/L respectively. These concentrations are way above 0.1 Mg/L the acceptability threshold[29,10]. These high levels of manganese lead to stains in sanitary wares and clothing and will form a coating on pipes which could peel off as black precipitation. Tables 6 and 7 and Figures 6 and 7 show the reduction of concentration of manganese for the two boreholes after the feed water passes through the unit.

Table 5showing summary of results of Manganese (Mn) concentration tests for Kithunzi borehole.

	Manganese Concentration Mg/L				
Run	Feed water	After aeration	After Filtration	Percentage (%) decrease	Average Percentage (%) decrease
1	0.75	0.58	0.40	40	39.6
2	0.83	0.56	0.48	42.2	
3	0.73	0.54	0.51	30.1	
4	0.76	0.57	0.54	28.95	
5	0.67	0.49	0.48	28.35	
6	0.85	0.65	0.57	32.9	
7	0.78	0.32	0.30	60.5	
8	0.65	0.40	0.30	53.8	

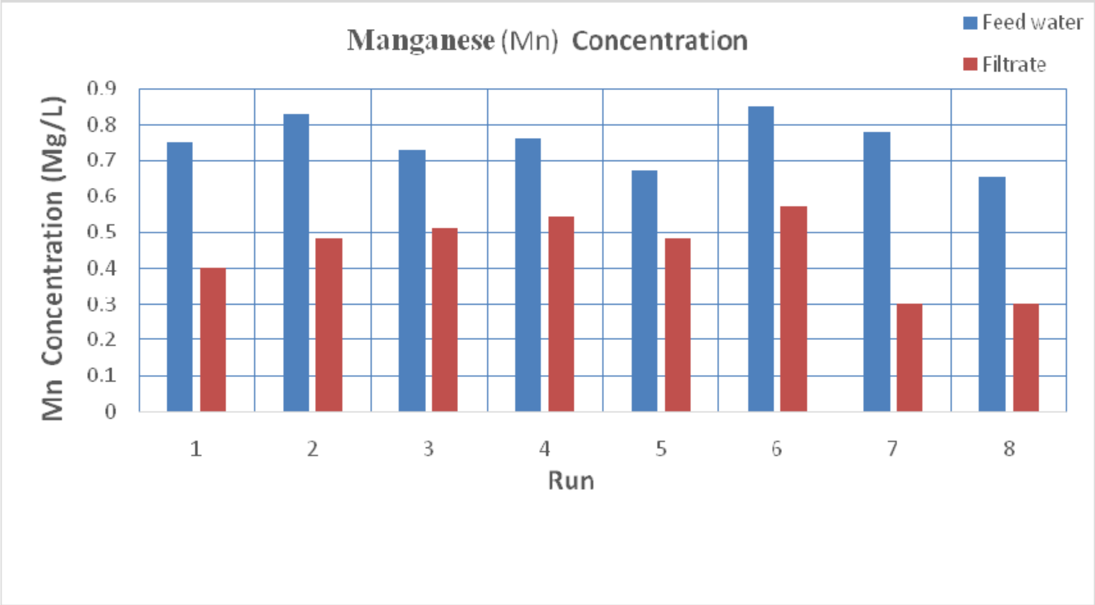

Figure 6. Concentration of Manganese (Mn) for the eight runs for Kithunziborehole.

Table 6showing summary of results of Manganese (Mn) concentration for Sisters' borehole in Makindu.

	Manganese Concentration Mg/L				
Run	Feed water	After aeration	After Filtration	Percentage (%) decrease	Average Percentage (%) decrease
1	0.27	0.24	0.24	11.1	17.4
2	0.37	0.27	0.27	27	
3	0.29	0.23	0.23	20.7	
4	0.28	0.237	0.237	15.4	
5	0.27	0.21	0.21	22	
6	0.29	0.245	0.245	15.5	
7	0.26	0.23	0.23	11.3	
8	0.287	0.24	0.24	16.4	

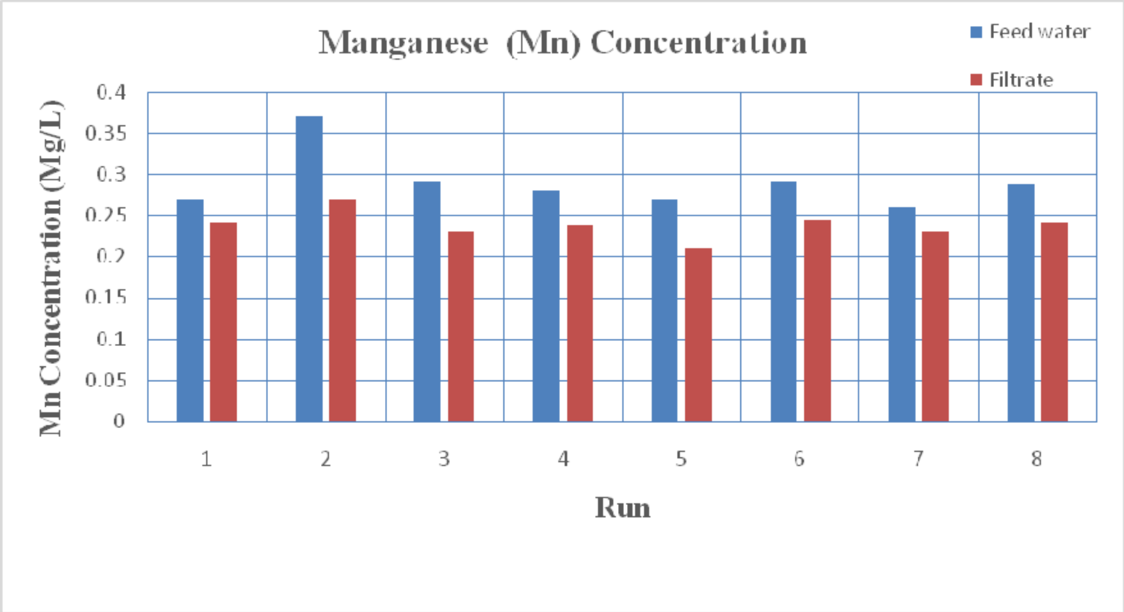

Figure 7. Concentration of manganese (Mn) for the eight runs for Sisters' borehole at Makindu.

CONCLUSION AND RECOMMENDATION.

Non -motorized aeration and filtration process has reduced iron by a significant percentage 61% for Kithunzi borehole and 56.9 % for Sisters' in Makindu. On the other hand, manganese reduced by 39.4 % for Kithunzi and by 17.4 % for Sister's in Makindu respectively. To achieve higher percentages of iron and manganese removal in ground waterit is recommended that sustainable ways of increasing levels of aeration be investigated. This include but not limited to use of wind power and solar power to drive a compressor that can be used to aerate the water before filtration.

ACKNOWLEDGEMENT

The authors wish to thank the Jomo Kenyatta University of Agriculture and technology (JKUAT) for providing the research funds that have been used in carrying out this research.

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