IRON REMOVAL IN BOREHOLE WATER: A CASE STUDY OF LUAPULA PROVINCE

M Kapulu[a*], E Lusambo[a] and C Haankuku[b]
[a] University of Zambia, School of Engineering, Department of Agricultural Engineering, P.O. Box 32379, Lusaka, Zambia.
[b] University of Zambia, School of Humanities and Social Sciences, Department of Development Studies, P.O. Box 32379, Lusaka, Zambia.
*mofwe.kapulu@unza.zm ; mofwehenry@gmail.com

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ABSTRACT

A research study was carried out to investigate the operation of Iron Removal Plants (IRP's) in four rural districts of Luapula Province, namely Mansa, Milenge, Mwense and Samfya. The "before-and-after" study design was used to compare the difference in iron concentration before and after IRP intervention, and to assess the latter's performance. Inventory of existing boreholes installed with IRPs was done and two different samples were taken from each water point; one for immediate field analysis, and another for laboratory analysis. Cluster sampling was used in picking respondents for the questionnaire survey in assessing effectiveness of operation and maintenance of the IRP's. Pump flushing was used to ascertain the main source of iron in the water. Different retention times were tested within one hour of sampling in ten minute intervals to assess its effect on iron concentration in the water.

The results from the performance evaluation process of the current IRP's showed 85.6 to 92.5 percent performance efficiency. From the flushing tests conducted, it was observed that the iron concentration in the water increased over time with continuous pumping thereby indicating that the geology of the area was the source of the iron. Results from a t-test statistical analysis showed no significant difference ($P < 0.05$) in iron concentration between water points installed with Indian Mark II pumps in comparison to those installed with the Afridev pumps. Further, there was remarkable iron removal with increased retention time. Strategies used for operation and maintenance of the IRP's were not very effective due to the attitudes and perceptions of the users and Government's capacity to operate the IRP was found to be limited due to inadequate funding and lack of devolution.

Keywords: *iron removal plants; performance evaluation; retention time; iron concentration.*

INTRODUCTION

More than 65 percent of the population of Zambia, estimated at 13.04 million in 2011 (CSO, 2011), live in rural areas. The rural population is characterized by low access to basic services including schools, health centres, safe water supply and sanitation (ADF, 2006). Supply of clean drinking water is one of the highest priorities of the Government of the Republic of Zambia (GRZ). For community water supply systems, groundwater at great depth should always be the preferred source. This is because the water is generally free from pathogenic contamination, although there may be other forms of undesirable pollutants (Sundaresan, *et al.*, 1983). Considering that groundwater offers one of the best sources of safe drinking water with little need for treatment to remove pathogens coupled with the medium running costs, the government through the National Rural Water Supply and Sanitation Programme (NRWSSP) has embarked on the drilling of deep boreholes in rural areas country-wide (MLGH, 2006).

In the course of implementing the NRWSSP, Government efforts are being hampered by the abandonment of deep boreholes in areas with high levels of iron. The water is unpalatable due to its taste and colour. Information from Luapula Province indicates that about 10 percent of boreholes drilled have been abandoned due to the high iron concentration in the water (Sinkala, 2011, pers. comm.).

The government, with donor assistance from Japan, has installed Iron Removal Plants (IRP's) in Luapula Province to reduce the iron content from borehole water. The water with high iron content is aerated when pumped to the first chamber and the oxidised iron in the water is removed when it is filtered in the sand and gravel layer. Depending on the amount of iron in the groundwater, the frequency of washing the sand and gravel filter-bed will vary from 2 to 4 times a month. The washed sand and gravel will be returned to the plant (Yokogi, 2011, pers. comm.).

Iron is one of the most common elements found in the earth's crust. It often exists in soluble form in ground water supplies and may be carried along in surface water. Typical source water concentrations do not pose a health risk but their presence can have other negative effects. The prevalence of iron in drinking water supplies maybe a result of geological formations and the use of metallic pumping equipment for groundwater withdrawal. Concentration of iron in excess of 0.2 to 0.3 mg/l may cause nuisance, even though its presence does not affect the hygienic quality of water.

Iron can be removed from source water by several technologies. The traditional removal method for iron involves a two-step process:

1. Oxidation or aeration of the soluble ferrous form to the common insoluble ferric form (Hoffman *et al*., 2006). Aeration introduces oxygen in the water to oxidize the ferrous iron. The aeration process to oxidize ferrous iron is generally recommended for water with high concentrations (> 5.0 mg/l) of iron (Sarikaya, 1990) and;

2. Filtration of these formed precipitates. The oxidation step is usually followed by detention (contact time) and filtration (Hoffman *et al*., 2006). Detention and/or filtration are applied for the solid/liquid separation. Detention provides the time for the precipitation of iron, and in addition, effects some iron removal by settling. If the total iron concentration is high, sedimentation tanks with sludge collection and removal facilities are used instead of a simple detention tank (Sarikaya, 1990). Filtration is relied upon to remove the rest of the iron. Filtration options consist of sand (only), anthracite and sand (dual media), manganese greensand, and various synthetic filtration media (Hoffman *et al*., 2006).

It must be stated that the presence of organics in the source water can impair removal of iron by oxidation and filtration. Treatment at a pH of 8 or higher promotes a more rapid oxidation of iron by aeration, if natural organic matter is not present in significant concentrations (Logsdon & Horsley, 1999).

The objectives of this study were to:

- Investigate the main source of iron in the water;
- Evaluate the performance of the current IRP's;
- Assess the effectiveness of the current strategies used for operation and maintenance of the IRP's;
- Examine government's capacity to operate the current IRPs, and;
- Assess the effect of changing the retention time on iron concentration the IRP effluent.

The findings of this study are therefore cardinal allowing policy makers make informed decision with regard to rural water supply in Luapula Province and in issues relating to government program analysis.

METHODOLOGY

The study design used in the research was the "Before-and-After" design which can be described as two sets of cross sectional data collection points on the same population to find out the change in phenomenon or variable(s) between two points in time. The change is measured by comparing the difference in the phenomenon or variable(s) before and after the intervention.

Qualitative methodologies comprised the collection of data from publications and through interviews and discussions. Quantitative methodologies comprised collection of data from water quality tests from water supply points and the iron removal plants

DATA ANALYSIS

The data collected was analysed using Microsoft Excel Toolpak for Statistical and Engineering analysis and GraphPad Statistical Software.

Investigating the main source of iron in the water

The main source of the iron in groundwater was ascertained using the following approaches;

1. Interviews through structured questionnaires and discussions with practitioners and experts in the water sector on their experiences as stakeholders in the supply of water in the rural parts of the province.

2. Pump tests were used to observe the iron content over time. If corrosion of the GI pipes was the reason for high content in the groundwater, the concentration of iron would decrease rapidly after a few minutes of continuous pumping.

3. Geological maps for the study area were also studied to ascertain the composition of the underlying bedrock.

4. Borehole drilling reports under the JICA phase one groundwater development project in the seven districts of the province were reviewed.

Evaluating the performance of the iron removal plants

Inventory of existing boreholes with IRP's under the NRWSSP was done. The criterion used was that of water points with reported high iron concentration. The water points were identified with names and the location of the water points were picked and recorded using a GPS (Global Positioning System) receiver.

Sample size

i. **Initial Sampling:** A total of 4 sites installed with IRP's were sampled for the performance evaluation of the iron removal technology. One set of samples was taken before the water passed through the IRP and another set of samples after the treatment process, giving a total of 8 samples.

ii. **Second round of sampling:** The initial sampling did not provide sufficient data sets for analysis. Therefore, a second set of samples were obtained at two of the sites visited in the initial sampling exercise, using the procedure described in (i) above. At two of the sites visited earlier, the IRP's were out of use and no samples could be collected. In the second round of sampling 30 samples were collected before and another 30 after the treatment process, giving a total of 120 samples for analysis

Sampling

To evaluate plant performance, the first sample was collected at the spout of the hand pump before the water enters the IRP to ascertain the iron concentration before treatment. The second sample was taken after the treatment process as effluent of the IRP. The sampling procedure at each water point started with pumping water from the borehole for five minutes. This was to avoid the risk of the pipe material having an effect on the sampled water in places fitted with the Indian Mark II pumps. This was so because some of the pumps use Galvanised Iron (G.I) pipes. The different samples taken were then immediately analysed on-site to ascertain the actual levels of iron in the water. The sampling was conducted in February/March and November 2012.

Analyses

Analysis of ferrous iron (Fe^{2+}) in water must be performed immediately after sampling due to rapid change from the ferrous ion (Fe^{2+}) to the ferric ion (Fe^{3+}) and other insoluble compounds. If this procedure is not followed the results will be unreliable (Langenegger, 1994).

Field Analysis**:** The solubility of iron minerals is strongly influenced by pH and redox variations. This means, any changes in environmental conditions during sampling could rapidly change the sample composition. Therefore, the measurement of pH, conductivity, temperature and dissolved oxygen should be carried out immediately on-site (Langenegger, 1994).

To measure pH, conductivity, temperature and dissolved oxygen, a WTW multi-line 340i set was used. The multi-line meter probes were submerged into a bucket filled with sampled water. The display showed the results for the different parameters.

On-site water quality testing for iron was performed using an on-site WAG Tech test kit comprising a colour disc, comparator and iron reagents. When using the test kit, one blank sample and one sample with a reagent were used. If ferrous iron was present an orange colour appeared. The comparator then showed the intensity of the colour and compared it with the blank without reagent.

Laboratory Analysis**:** In order to stabilise the pH of the water samples and thereby prevent iron from precipitating before analysis in the laboratory, the samples were preserved with 1-2 ml of Nitric acid (the iron would not react when collected in the sampling bottles as the pH is reduced making any metal present in the sample inert). To analyse the total iron concentration, the sampling bottles were taken to an independent laboratory at the University of Zambia - the Civil and Environmental Engineering laboratory - to ascertain the total iron content in the water samples before and after treatment. The testing procedure for iron was conducted using the colourimetric method. Table 1 indicates the summary of water parameter analysis methods used in the study.

Table 1: Summary of water parameter analysis methods

Parameter	Analysis Type	Preservation Type	Analysis Apparatus
Temperature	In field	No preservation	Multimeter
pH	In field	No preservation	Multimeter
Conductivity	In field	No preservation	Multimeter
DO	In field	No preservation	Multimeter
Fe(II)	In field	No preservation	WAG Tech kit
Fe(II)	Laboratory	Nitric acid	Spectrophotometer

Assessing the effectiveness of the current strategies used for operation and maintenance of the IRP's
Multistage (cluster) sampling was used in picking respondents for the questionnaire survey as given by De Vaus (2002) in assessing the effectiveness of the strategies used for operation and maintenance of the IRP's.

The basic procedure of sampling the population in Mansa, Milenge, Mwense and Samfya districts for which there was no sampling frame of residents, involved the following steps.

1. The districts where divided into the already existing rural constituencies (clusters) where the IRP's have been installed.

2. Selection of water points in the clusters was done based on information from the NRWSSP Coordinator and the JICA phase one ground water development project.

3. Selection of specific water points with installed IRP's that were accessible within each of the clusters selected at stage 2.

4. At each selected water point two members of the user community and a caretaker were selected to participate in a structured questionnaire interview.

Examine the capacity of Government to operate the IRP's
The capacity of Government to operate the current IRT's was examined using structured questionnaire interviews and discussions with stakeholders (practitioner's and experts) in the water sector. A list of key stakeholders involved in rural water supply intervention was compiled and these were interviewed. The stakeholders included the following;
1. Government through the MLGH Rural Water Supply and Sanitation Unit
2. Provincial and Local Authorities
3. Other Government line Ministries
4. Non-Governmental Organisations (NGO's)

Effect of changing the retention time on the iron concentration in the IRP effluent
Different retention times were tested to ascertain their influence on iron concentration. This was done during one hour, where the IRP was emptied, and after filling it up again, sampling was made every ten minutes to achieve different retention times. Analyses were done both in the field and in the laboratory.

RESULTS AND DISCUSSIONS

The main source of iron in the water
From the interviews and discussions with practitioners and experts involved in the water sector in the province, the main source of the iron was from the geology of the area. This was based on their experiences and practices in water supply in the province.

In investigating the main source of iron in the water, pumping tests were conducted, where water was continuously pumped from the borehole for five minutes. As given by Andersson & Johansson (2002), if corrosion of the GI pipes was the reason for high content in the groundwater, the concentration of iron would decrease rapidly after a few minutes of continuous pumping and if the geology is the source the opposite would happen.

It was observed during pumping that the iron concentration in the water increased over time with continuous pumping. Thus from the pumping tests conducted it was ascertained that the main source of iron in the water was from the geological formations (aquifer iron) in the area.

Data on the type of pump used for groundwater withdrawal was collected to ascertain any pump influence on iron concentration in the water. In the province two types of pumps are used namely:

1. Afridev pump which uses stainless steel or fibre reinforced glass connecting rods and threaded coupling ends which are available for corrosive water conditions and lightweight application and;

2. Indian Mark II pump which uses galvanised iron rods for raising and lowering the plunger and galvanised iron riser pipes for conveying the pumped water at depth to the surface (Andersson & Johansson, 2002).

Table 2 indicates data collected under phase one of the JICA project for the groundwater development in Luapula Province on the type of pumps used for groundwater withdrawal. The data was further aggregated and presented on the basis of the percentage number of pumps having a concentration of iron greater than >0.2 mg/l (the recommended WHO guideline value is 0.3 mg/l. The data was analysed to show the influence of pump type on iron concentration.

The data collected showed that water points installed with the Indian Mark II had a higher proportion of boreholes with high concentration of iron (25%) in comparison to those installed with the Afridev pump (16%). However, the t-test was used to find out whether there was a significant difference ($P < 0.05$) in iron concentration in borehole water with the use of the Indian Mark II or the Afridev pumps. Table 3 indicates results showing no significant difference between the use of the Indian Mark II and Afridev pumps on iron concentration in borehole water.

Table 2: Data on pump types used for groundwater withdrawal in Luapula Province

	Iron Concentration (mg/l)										**% pumps with conc. >0.2mg/l**	**Total pumps**
Pump Type	0	<0.2	1	2	3	5	7	8	10	>10		
Indian Mark II	11	82	10	11	1	2	2	0	2	3	25	124
Afridev	2	61	4	6	0	0	1	1	0	0	16	75

Table 3: t-test analysis on pump type influence on iron concentration

	Indian Mark II	**Afridev**
Mean	3.88	1.50
Variance	17.55	5.14
Observations	8	8
Pooled Variance	11.35	
Hypothesized Mean Difference	0	
Degrees of freedom	14	
t Stat	1.41	
P(T<=t) one-tail	0.09	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.18	
t Critical two-tail	2.14	

Based on JICA phase 1 groundwater development project data for iron concentration >0.2 mg/l

Figure 1 indicates the comparison on the use of the Indian Mark II and Afridev pumps and their influence on iron concentration in borehole water.

Performance evaluation of the iron removal plants

Initial Sampling

Two samples were collected one from the borehole and one from the IRP to ascertain the levels of iron concentration before and after treatment. Table 4 indicates the results obtained from the four sites used in the initial sampling.

Second Sampling

Four water points were earmarked for sampling but during the field visit two of the four were out of use. Table 5 indicates performance evaluation of two IRP units sampled with 30 data sets collected at each water point.

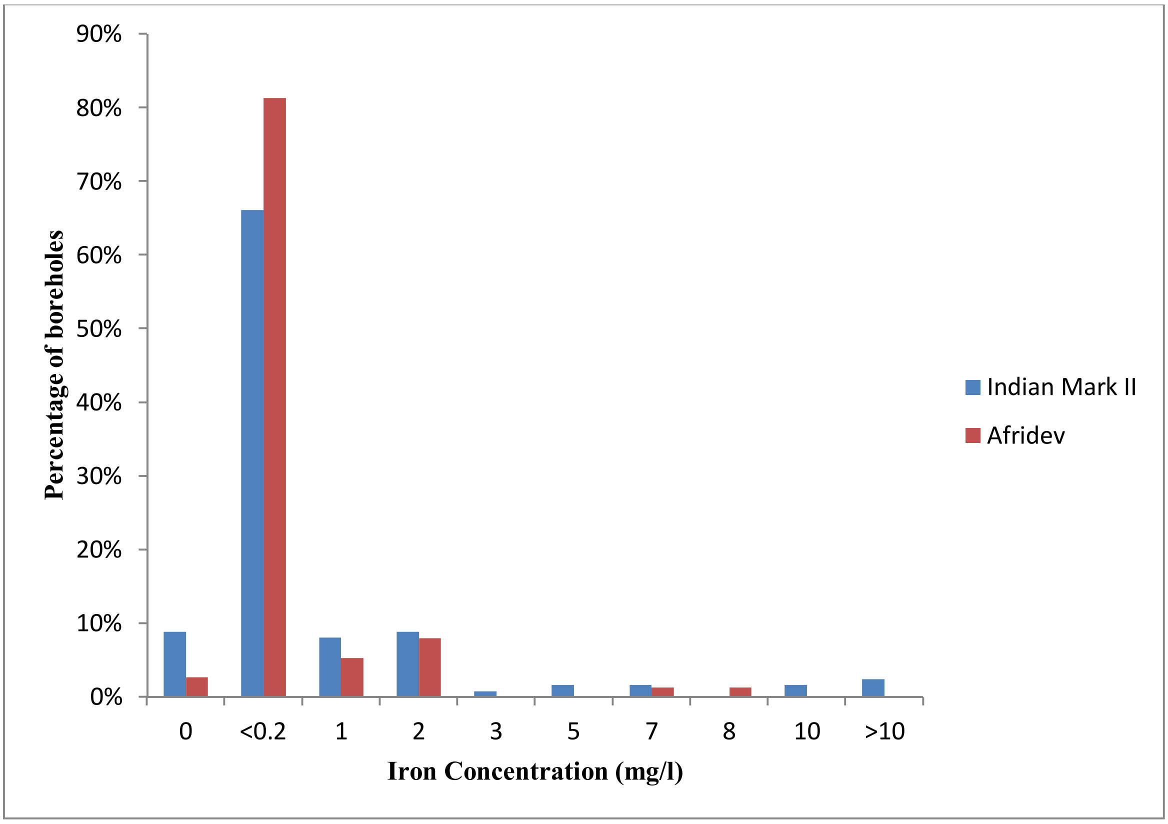

Figure 1: Influence of pump type on iron concentration

Table 4: Ferrous iron removal by IRP

Water Point	Fe^{2+} Conc. (mg/l)		Fe^{2+} Removal
	Before	After	(%)
Kale A	5	1.5	70
Kale B	5	1.7	66
Kampalala 1	10	2.1	79
Kampalala 2	10	2.4	76

Table 5: Data collected for performance evaluation of IRP units

Water Point	Kampalala 1		Kampalala 2	
	Iron Concentration			
	Before	After	Before	After
1	10.0	0.5	10.0	2.0
2	10.0	0.5	10.0	2.0
3	10.0	0.5	10.0	1.5
4	10.0	0.5	10.0	2.0
5	10.0	0.5	10.0	1.5
6	10.0	1.0	10.0	2.0
7	10.0	1.0	10.0	1.0
8	10.0	0.5	10.0	1.5
9	10.0	1.0	10.0	1.0
10	10.0	1.0	10.0	1.5
11	10.0	0.5	10.0	1.0
12	10.0	0.5	10.0	1.5
13	10.0	0.5	10.0	2.0
14	7.5	1.0	10.0	1.5
15	10.0	1.0	10.0	1.0
16	10.0	1.0	10.0	1.0
17	10.0	0.5	10.0	1.0
18	10.0	0.5	7.5	1.5
19	10.0	0.5	10.0	1.5
20	7.5	0.5	10.0	1.0
21	10.0	1.0	10.0	1.0
22	10.0	1.0	10.0	2.0
23	7.5	1.0	10.0	1.5
24	10.0	0.5	10.0	1.0
25	10.0	0.5	10.0	1.0
26	10.0	0.5	10.0	2.0
27	10.0	0.5	10.0	2.0
28	7.5	1.5	10.0	1.5
29	10.0	1.0	10.0	1.0
30	10.0	1.0	10.0	1.0
Mean	**9.67**	**0.73**	**9.92**	**1.43**
Std deviation	**0.86**	**0.28**	**0.46**	**0.07**

The data collected in Table 5 was analysed and further consolidated to ascertain the percentage iron removal at Kampalala 1 and Kampalala 2 IRP units as indicated in Table 6.

Table 6: Result analysis of performance evaluation of IRP units using Sample means of collected data

Water Point	Fe^{2+} Conc. (mg/l) Before	After	Fe^{2+} Removal (%)
Kampalala 1	9.67	0.73	92.5
Kampalala 2	9.92	1.43	85.6

Kampalala 1 and Kampalala 2 IRP's showed performance efficiency of 92.5 and 85.6 percent respectively over 30 data sets analysed. The higher performance of Kampalala 1 IRP could be attributed to longer retention time due to less usage of the unit by the community.

Assessment of the effectiveness of the current strategies used for operation and maintenance of the IRP's

The following results were obtained from questionnaires administered to the IRP user communities and practitioners as well as the prevailing situation in field:

a. There was non-adherence to the operation and maintenance procedure especially in areas where the user communities had alternative water sources. This was seen by the lack of willingness exhibited by the users in the cleaning of the IRP's. Further, the IRP's were also not cleaned at the scheduled times hence reducing their operational efficiency.

b. The supply of the filter medium was not consistent as evidenced in some water points where the medium had run out. In some cases the wrong type of medium was used. This therefore, affected the effective treatment process in the IRP's.

c. Lack of ownership of the facilities by the communities was evidenced by the non-payment of user fees in all the water points as they were waiting for government to maintain the hand pumps and IRPs in places, where these had broken down.

d. The aeration of the water was limited as the contact area was reduced due to the covering of the IRP's with steel gates. This had a consequence of preventing the maximum formation of iron floccs which are removed through sedimentation and filtration.

e. There was a lack of communication between the stakeholders in the maintenance of the IRP's. The channel of interaction between the V-WASHE (Village Water, Sanitation and Health Education), Area Pump Mender (APM) and D-WASHE (District Water, Sanitation and Health Education) was non-existent as evidenced by the down time of some IRP's and hand pumps at some water points that go as far as over 18 months without repair.

Government's capacity to operate the current IRP's

The following deductions were made during discussions with experts and practitioners in the water sector in Luapula Province:

1. A unit had been established to oversee the operation and maintenance of IRP's. However, there was a lack of a program for monitoring, where these IRP's had been installed.

2. The technical know-how among staff was there but lack of devolution was hampering effective operations.

3. Government support to the programme is highly donor dependent and without donor support government would not be able to install the IRP's due to high installation costs.

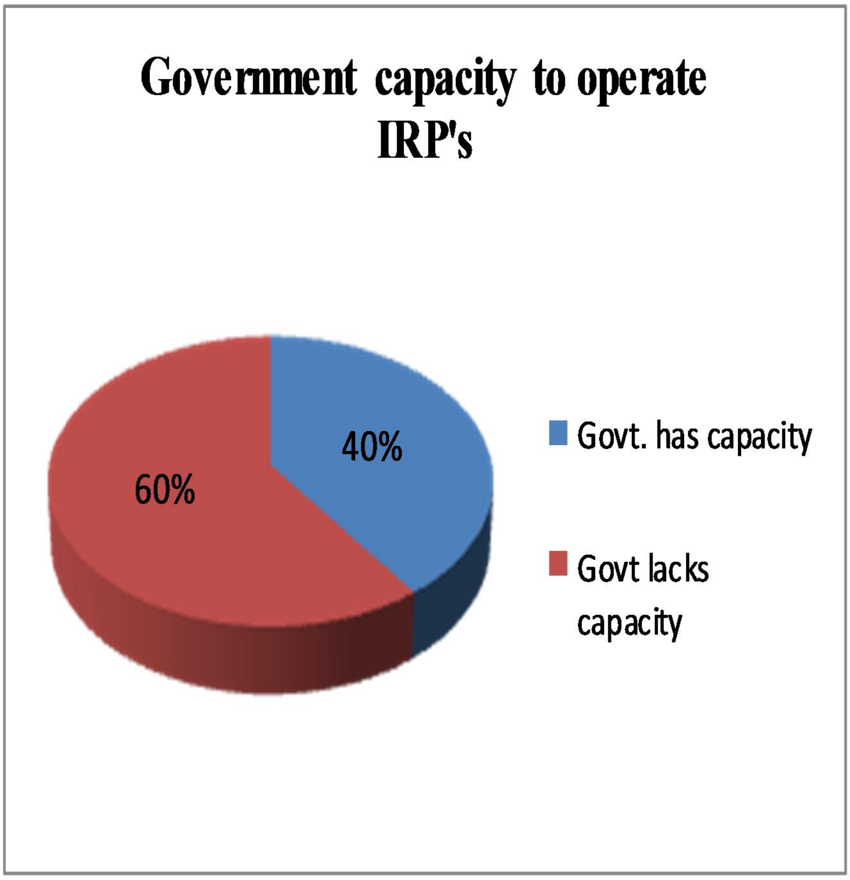

Figure 2: Government capacity to operate IRP's

60 percent of the responses from the structured questionnaire interviews administered to practitioners and experts indicated that the GRZ had limited capacity to operate the IRP's as shown in Figure 2. From the foregoing, 40 percent of the respondents indicated that Government had the capacity to operate the IRP's.

Effect of changing the retention time on iron concentration in the IRP effluent

Table 7 indicates results obtained showing that iron removal in the IRP increased with increased retention.

After 60 minutes of water retention in the IRP the ferrous removal was 91 percent as shown in Table 7. Removal of Fe^{2+} was most effective during the first 20 minutes of IRP filter run. A graph of Fe^{2+} removal for different retention times is shown in Figure 3.

Table 7: Effect of retention time on iron concentration at the Kampalala 1 IRP

Time [min]	**Fe^{2+}** [mg/l]	**Fe^{2+} Removal** [%]	**Temp.** [°C]	**DO** [mg/l]	**Conductivity** [µS/cm]
10	6.0	40	24.0	2.20	126.0
20	3.7	63	24.5	2.24	131.2
30	2.6	74	24.0	2.22	122.8
40	2.1	79	25.0	2.40	128.1
50	1.4	86	24.0	2.16	130.4
60	0.9	91	24.3	2.33	134.3

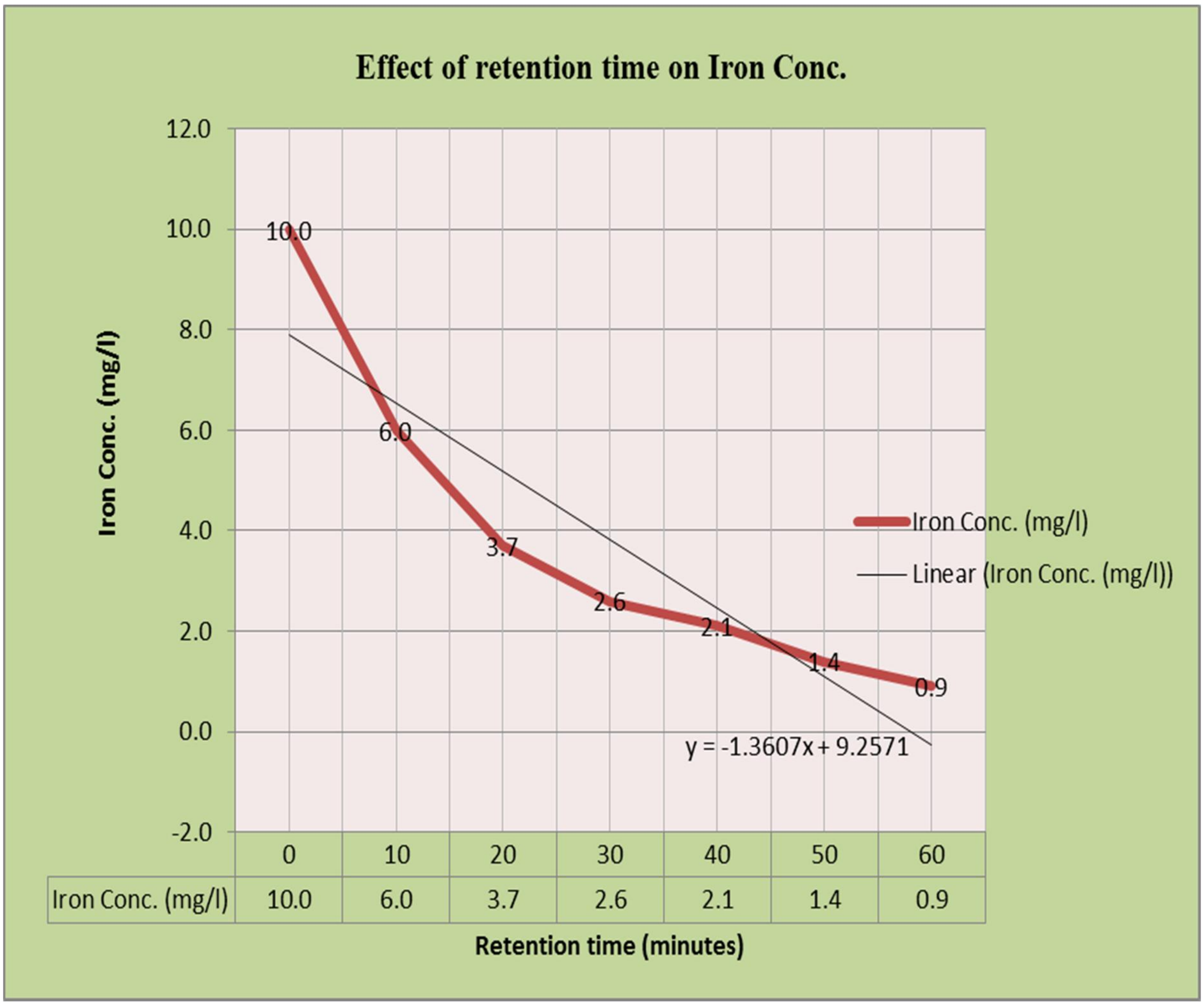

Figure 3: The effect of retention time on iron concentration - Kampalala 1 IRP

The Kampalala 2 IRP showed that after 60 minutes of water retention the ferrous removal was 90 percent as indicated in Table 8.

Table 8: Effect of retention time on iron concentration at the Kampalala 2 IRP

Time [min]	Fe^{2+} [mg/l]	Fe^{2+} **Removal** [%]	**Temp.** [°C]	**DO** [mg/l]	**Conductivity** [µS/cm]
10	5.4	46	23.2	2.61	122.7
20	3.2	68	24.0	2.72	121.6
30	2.4	76	23.8	2.65	124.9
40	2.0	80	24.4	2.58	120.3
50	1.5	85	23.7	2.66	119.7
60	1.0	90	24.1	2.63	123.9

Figure 4 shows the removal of Fe^{2+} which was most effective during the first 20 minutes of IRP filter run.

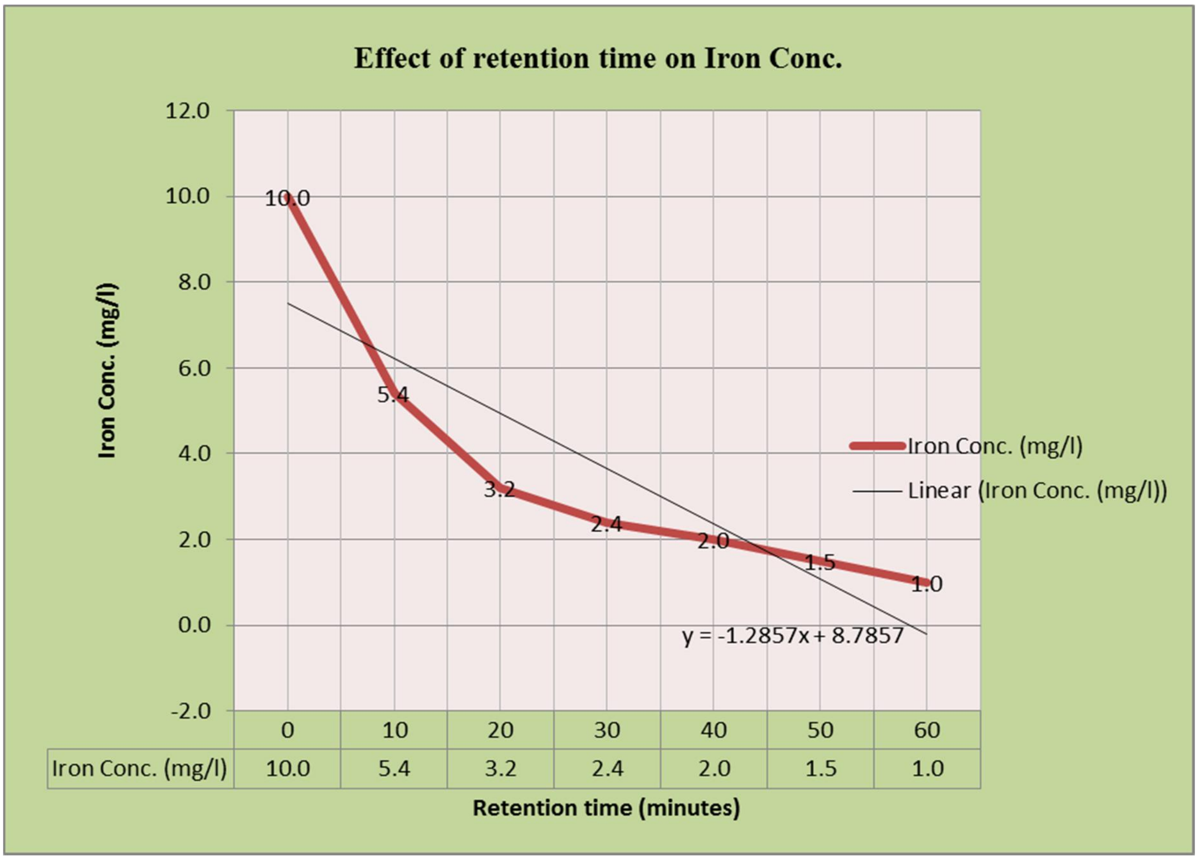

Figure 4: The effect of retention time on iron concentration - Kampalala 2 IRP

From the results analyzed it was observed that there was remarkable ferrous iron removal with increased retention time with the most effective removal occurring during the first 20 minutes of IRP filter run. Retention therefore effects more treatment through sedimentation of the ferric iron and subsequent screening out (entrapping) of the iron particles by the filter medium.

CONCLUSIONS

a) The source of iron is the geology as indicated by the pumping tests, with there being no significant difference ($P < 0.05$) between the use of the Indian Mark II pump or the Afridev pump on iron concentration in borehole water.

b) The performance evaluation of the IRP's showed performance efficiency of between 85.6 and 92.5 percent respectively.

c) The strategies for operation and maintenance are not very effective due to the attitudes and perceptions of the users. Further, Government's capacity to operate the IRP is limited due to inadequate funding (and lack of devolution).

d) The results analysed showed remarkable iron removal with increased retention time with the most effective removal occurring during the first 20 minutes of IRP filter run thereby improving its efficiency.

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