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Performance of Iron removal plants on groundwater: field assessment in Central Uganda

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Groundwater is often considered of better quality as a source of drinking water but in many locations, it contains iron and other impurities that make communities abandon some water sources. The abandonment of such water sources in effect reduces access to safe water coverage in rural areas as communities return to using unprotected sources. Uganda is one of the countries with high iron concentrations in groundwater but it remains the most important source of potable water. A study to assess the performance of Iron Removal Plants (IRP), involving field analysis of water samples for selected physicochemical parameters and interviews revealed that the performance of IRP is a function of efficacy of the treatment process and the water source management system. Further research will optimize the efficacy and increase the performance of the IRP improved U2 boreholes for rural areas in Uganda.

Introduction

Groundwater is often considered a better source of drinking water because it does not contain harmful pathogens and generally does not need treatment. However in many locations, it contains iron and other impurities either from geological formations or from down-hole-pump components. The underlying geological formations dissolves iron as rainwater infiltrates the soil, causing iron to seep into aquifers that serve as sources of groundwater for water wells (Nemade et al. 2009). Some underground strata conditions favour reduction of the natural ferric iron deposits to the ferrous state (soluble state). On the other hand, Fader (2011) has documented cases of corrosion of down-hole-pump components contributing to the problem of iron.

In places where concentrations of iron exceed the recommended value of 0.3mg/l (WHO 1996), communities have abandoned some water sources due to the unpleasant taste of the water and unappetizing colour added to the food. The abandonment of such water sources in effect reduces access to safe water coverage in rural areas as communities can return to using unprotected sources. According to the Ministry of Water and Environment (MWE) of Uganda, consumers in water scarce areas can accept concentrations of up to 2mg/l of iron in groundwater for domestic use (MWE 2013).

Although Uganda is one of the countries with high iron concentration, in some parts up to about 50mg/l; groundwater still remains the most important source of potable water. It is particularly important in rural areas where deep and shallow water wells serve about 66% of the population with access to safe water supply (MWE 2015). The iron problem in groundwater produces insoluble rusty oxide-red, yellow or brown which stain and streak on laundry and plumbing fixtures. Presence of iron in water contributes to turbidity and increases maintenance costs. Some key factors have been noted to escalate the effect of iron in groundwater, including; Iron Related Bacteria (IRB), Sulphate Reducing Bacteria (SRB) and pH (Yuzwa 1991; Cullimore 1993; Misstear et al. 2006; Fader 2011). There is a strong correlation between pH and corrosion to the extent that even pH values as low as 6.5 can be considered moderately corrosive (Langenegger 1994).

A number of methods of removing iron from groundwater including the use of ash have been reviewed and literature points towards a point of source treatment as the most appropriate approach (Das et al. 2006;

Fader 2011). However, the conventional treatment involving aeration and sand filtration is normally employed to remove dissolved / oxidised iron, colour and turbidity. The major advantages of this treatment approach include its simplicity, low investment and operational cost and no or less application of chemicals. In the treatment processes, Fe2+ is oxidized with the dissolved oxygen present in the water to form insoluble ferric hydroxides, which are removed by sedimentation and / or rapid (sand) filtration. The ferric hydroxide particles are removed through mechanisms including straining, interception, sedimentation, Brownian diffusion, hydrodynamic retardation, surface-interaction forces and possibly biological factors (Sharma et al. 2002).

Attempts to solve the problem of iron in groundwater in Uganda have been either the installation of iron removal plants (IRPs), replacement of the corrosive down-hole-pump of the boreholes with PVC / stainless parts or the conversion of the Uganda manufactured India Mark II (U2) pumps to the Uganda manufactured India Mark III Modified (U3M) pumps coupled with chlorine dosing. The Ministry of Water and Environment (MWE) of Uganda has been involved in the installation of some iron removal plants in the country. Some few plants are still working but others got operation and maintenance challenges, particularly regarding the filter media. The iron removal plant is a simple, economic design that is constructed on site from fired bricks and perforated sheets to facilitate aeration, and hanging over a filter media of size 1-3cm. Water flows into the chamber through an inlet pipe that has perforations all along its length for discharging the flow. When the chamber is full, water spills out into the outer chamber over sharpened weirs on 3 sides of the inner chamber. The second chamber has sand media for filtering the water. In addition, a synthetic net is provided to accumulate the precipitated materials.

In the iron removal intervention in Uganda, some IRP were constructed in some districts where high iron contents of 1 - 45mg/l were reported, and a reduction of 40 - 87% was initially recorded (MWE 2013). However, a number of challenges were later noted with the slow rate of flow of water through the filter media, cleaning the filters were found to be difficult and they could only be cleaned when the water quality raised complaints from the community. It followed that some of the constructed sources were later abandoned due to excessive iron as people started to complain of the usual reddish / yellowish colour, “sour” tastes, discolouration of clothes and food, and soap would not produce lather for washing.

This study was to assess the performance of the few IRPs that continued to function, explore how they have been managed and other learning experiences to inform an upscaling strategy to other parts of the country. The study considered districts where high iron concentrations have been reported and specifically identified boreholes fitted with U2 pumps with reported problems of high iron concentration. The findings of this study will provide information for further improvement in the design, operation and management of the IRP to optimize its efficacy for rural water supply in Uganda.

Methodology

A desktop study of the districts with reported cases of high iron concentration in groundwater was conducted and three districts where some form of interventions have been done, were purposively selected: Mpigi and Rakai in central Uganda and Kamwenge in South western Uganda. The intervention in Mpigi and Rakai was the construction of IRP to the U2 boreholes and the intervention in Kamwenge was the replacement of galvanised iron (GI) pipes of the U2 boreholes with PVC pipes. In consultation with the District Water Officers (DWO) of the study districts, five sites were selected for the study: Two (2) boreholes in Mpigi, two (2) boreholes in Kamwenge and one (1) borehole in Rakai district. The study was conducted in December 2015 and involved field analysis of water samples from the five water sources for Total Iron, Alkalinity, Temperature, pH and Dissolved oxygen (DO). Water samples from the study sources were analysed at 30 minutes intervals following continuous pumping to record the changes in concentration of the parameters with continuous usage of the water points. The study also used observations for corrosions on the down-hole-pipes of the pump system, and interviews with pump mechanics, caretakers and some users; to triangulate the findings of the field analysis for a better understanding of the performance. Except for borehole at Site 4 in Kamwenge, all the boreholes were closed the previous night prior to the field measurements and sample collection. Hence the initial measurements (0 minutes) are indicative of the quality of the water during storage from these other sources.

Field analysis of the physicochemical parameters used HACH DR/890 colorimeter kit for Total Iron; palintest for Alkalinity; HANNA, HI 991003, pH/pH-mV/ORP/Temperature meter for temperature and pH; and HANNA, HI 9146, Microprocessor, Dissolved oxygen meter for DO (HACH 2013; HANNA 2010). Parameters of the water sources were measured every 30 minutes of continuous pumping for two (2) hours except for Site 4 where samples were analysed for only the first 30 minutes. Trends of the physicochemical parameters with time of continuous pumping for both the IRP fitted and unfitted U2 boreholes is used to discuss the performance of the IRP improved U2 hand pump boreholes.

Key findings

Trends of physicochemical parameters during continuous pumping of unimproved U2 boreholes

The study showed that the sampled boreholes are with pH levels (5.72±0.15), typical of groundwater sources and not being too low (pH<3) to be aggressive. Also the temperature variability between sampling times and also between the sources (23.0 - 25.1°C) is not that much implying minimal impact from surficial or ambient conditions. The groundwater from the sampled boreholes is with relatively high levels of dissolved oxygen (>2mg/l) which renders it a fresh water source. The sampled boreholes are generally with a high pH buffering capacity as indicated by the high alkalinity levels (>40mg/l) (Figure 1) leading to resistance to significant pH change.

With regard to boreholes in Mpigi (Sites 1 & 2), there was a general decrease in pH, alkalinity and Total Iron with time. The quality of the water sampled out of the boreholes with time is indicative of the water flowing through the aquifer. However, it suffices to note that the quality variations are also dependent on the amounts of water pumped out of the aquifer prior to the sampling times. In Kamwenge, quality of the water in the borehole at Site 3 exhibited an increase in pH, dissolved oxygen and alkalinity with time. However, the Total Iron and alkalinity levels were with a decreasing and increasing trend most likely due to the quantities of water being pumped out of the aquifer prior to the sampling times. The borehole at Site 4 in Kamwenge (Not closed the previous night prior to the field measurements) illustrates that continuous pumping of the borehole resulted in improved quality of the water with time giving a better indication of the water quality within the aquifer. It suffices to note that in this particular borehole, the initial measured Total Iron levels were low compared to the rest of the boreholes which likely led to a decrease to undetected levels in the subsequent sampling times. Interviews with the operator also revealed that the down-hole-pump system of the borehole at Site 4 had been replaced with PVC pipes that explain the low levels of Total Iron concentration in this particular borehole.

The source at Site 3 in Kamwenge district showed low values of Total Iron concentration of 1.9±0.38, but high alkalinity during the two hours of continuous pumping. Communities in water scarce areas would still consider Total Iron concentrations of less than 2mg/l as acceptable (MWE 2013) but this particular source at Site 3 is abandoned and people instead collect water from a river that is too risky with reported deaths. A local leader explained that women stopped using the borehole because the water makes them pale with very rough skin to the extent that their husbands do not want to share with them beds. They may try to use lotion but cannot always afford and, to save their marriage, they prefer to risk the lives of their children who collect water from the river. Compared to borehole at Site 4 where the source was improved by replacing GI pipes of the down-hole-pipes with PVC pipes, the improved source recorded a Total Iron concentration of less than 2mg/l and alkalinity of 89.00±4.0mg/l but is under continuous usage with no complaints. This finding reveals that a water source may have multiple problems that need to be fully investigated and identified differently, to develop appropriate solutions for each case. Fader (2011) recommended that IRP should not be installed in an application that still has its iron pipes and components.

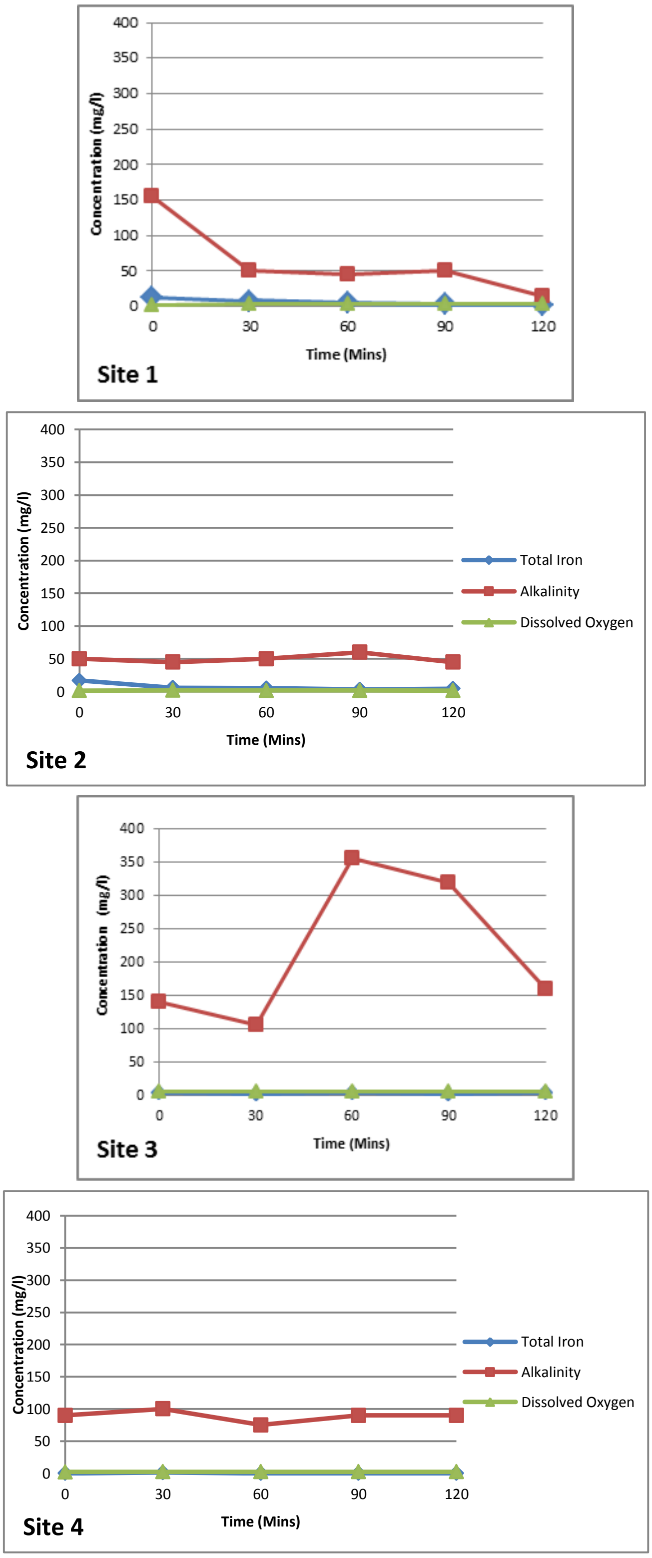

Figure 1. Quality of water sampled from the unimproved IRP boreholes, taken every 30 minutes of continuous pumping

Trends of physicochemical parameters during continuous pumping of improved U2 borehole

Most of the IRP improved U2 boreholes in Rakai district were either not functioning or had been abandoned due to operation and maintenance issues except for Kibaale community school and one other (not covered in this study). In the school's case, management was committed to carrying out the recommended operations and maintenance of the plant. The school water officer was confident to say that the IRP improved U2 boreholes in the communities were abandoned because nobody was responsible for their operation and maintenance.

"People only come to the source when it is functioning well and when the filter media needs cleaning or replacement, no one is bothered. At the school, we always plan to wash the filter media whenever there is a sign of clogging or change of colour of the water coming out of the IRP and these measures have helped to ensure that the IRP is performing as expected" Water officer, Kibaale community school.

The school management has proved that the IRP can work well with proper operation and maintenance and they have gone ahead to install and oversee another plant for a community at Site 5 in Kibanda Sub County. The school management has also trained the local leaders of the community on how to manage the improved IRP U2 borehole to ensure it serves the purpose. The efficacy of the IRP improved water source that was constructed by the school at Site 5 was assessed. The results show that the plant can reduce the Total Iron concentration and also increase the amount of dissolved oxygen in the treated water (Figure 2).

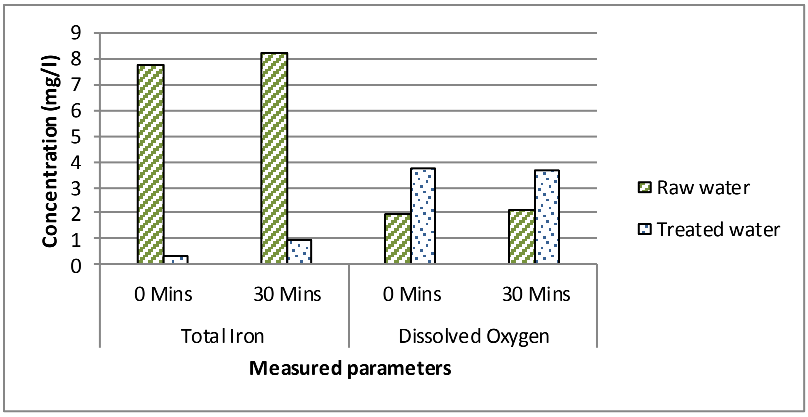

Figure 2. Quality of water sampled from the IRP improved borehole at Site 5 in Rakai district

Measurements of the selected physicochemical parameters taken over a 30 minutes interval showed relatively small variability with a sharp increase in alkalinity of 105mg/l to 175mg/l in the raw water. Values of the measured parameters in the treated water are with increased dissolved oxygen levels and reduced total iron levels given the nature of the treatment unit operations and processes. A slight increase in Total Iron concentration in the raw water sample after 30 minutes can be explained by the recharging of the aquifer. While the increase in Total Iron of the treated water after 30 minutes could be due to the influence of the volume of water exposed to free air in the aeration unit prior to sampling. This is also noted with the slight decrease in dissolved oxygen after 30 minutes as more oxidation process occurs in the treated water. Further study will optimize the efficacy during continuous pumping process of the IRP and its general performance to enhance the sustainability of the improved water source.

The preliminary findings of this study reveal that whereas the IRP improved U2 borehole can be a solution to the high iron concentrations in rural areas, their management under the Community Based Management (CBM) model is in doubt. Van den Broek & Brown (2015) also observed that management of community water sources under the Community Based Management (CBM) model demonstrate a blue print for breakdown in Uganda. The need to develop a more appropriate management model that tries to address the current management gaps and also incorporate what has been found to work in the functioning IRP boreholes is crucial.

Conclusion

Challenges of high iron concentration in groundwater may have multiples causes and interventions need to adequately investigate the various problems in order to develop appropriate solutions. And the solutions may require multiple inventions including replacement of down-hole pump components, construction of IRP and use of proper source management model for sustainability, as opposed to the traditional Community Based Management in sub-Saharan Africa. Further research will attempt to optimize the efficacy and increase the performance of the IRP improved U2 boreholes for rural areas in Uganda.

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