The role of handpump corrosion in the contamination and failure of rural water supplies

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There has been much discussion over many years regarding the origin of elevated iron concentrations in rural water supplies in sub-Saharan Africa and Asia. High iron concentrations are often assumed to be naturally occurring in groundwater, despite several studies over the last 30 years which also point to the role of handpump corrosion in aggressive groundwater. Handpump standards specify that galvanized iron pump materials should not be used in groundwater due to the risk of corrosion, yet this advice is not always followed. High iron concentrations, whether naturally occurring, or present as a result of corrosion, have an impact on taste, odour, and appearance of water and can promote the growth of unpleasant iron metabolizing bacteria. These effects often result in the abandonment of boreholes, sometimes only a year old, and a return to unprotected and unsafe water sources. Where boreholes are not abandoned, the effects of corrosion can cause pump materials to degrade to the point where the pump becomes inoperable. These outcomes are clearly inconsistent with the provision of sustainable water supply services as a fundamental human right. This paper provides a synthesis of work undertaken in this area over the last 30 years and recent practical experience of WaterAid in investigating these problems in water supplies in north-eastern Uganda.

Keywords: handpump corrosion, iron, water quality, Uganda

The problem of high iron concentrations in rural water supplies is well known across many countries in Africa and elsewhere. Although elevated concentrations of iron are not considered a particular health risk, aesthetic issues may result in a reluctance to use a water point and in severe cases, abandonment of the water point for an alternative, and potentially unsafe, source. Typical problems include metallic taste, discoloured and turbid water (Figure 1), discoloration of water following pumping, and discoloration of food and clothing. The World Health Organization

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Figure 1 Example of turbid discharge, Aberan village, Amuria District, Uganda

(WHO, 2011) does not set a health-based limit for iron but states that concentrations above 0.3 mg/l impact on taste and cause staining of laundry. Some national governments set limits slightly above this value for untreated rural water supplies, for example, in Uganda a value of 1 mg/l is specified (UNBS, 2008).

Iron is present in soils and rock formations in two forms: reduced soluble ferrous iron (Fe^{+2}) or oxidized insoluble ferric ion (Fe^{+3}). The highly soluble and colourless nature of ferrous iron can mean that, if conditions are right, groundwater can hold significant concentrations yet appear clear and colourless. When such groundwater is pumped out and exposed to the atmosphere, oxygen will convert the ferrous iron to ferric iron, which reacts with other components in the water to form insoluble iron hydroxides. These precipitate out to cause red/brown cloudiness in the water and staining. This oxidation process can take some time, so apparently clear water can be produced at the pump, but then discolours later, once the water has been standing.

Two sources of high iron concentrations are possible in pumped groundwater: from a natural source in the aquifer or as the result of the corrosion of susceptible pump components in aggressive groundwater. In some circumstances, a combination of both is possible. It is important to distinguish which of these is the source in any particular case as this will point to potential solution(s). For example, where a natural origin is identified, implementers may install iron removal plants on handpumps. In other circumstances, it may be the handpump itself which is causing, or significantly adding to, the problem. This has been observed particularly where India Mark II handpumps are deployed, but other models of handpump may also be affected.

A recent synthesis (Furey, 2014) of online discussions on handpump technologies among rural water supply specialists and practitioners between 2012 and 2014 concluded that water quality, particularly related to high iron, aggressive groundwater, and corrosion, was a major issue. Problems with corrosion and/or high iron were reported from 13 countries in sub-Saharan Africa, Bolivia, and India. Particular needs identified from the discussions were:

- better testing and monitoring of groundwater quality so that galvanized iron (GI) pump components are not installed in aggressive groundwater;
- a clearer understanding of whether high iron levels are caused by natural conditions or by pump corrosion;
- the replacement of GI pipes and pump rods in all existing pumps in aggressive groundwater.

This paper sets out to document some of the key reports that originally highlighted the corrosion problem and which are still relevant to practitioners today, together with some of the solutions that have been reported in the literature. A case study from Uganda is presented where a simple pumping test has been used to identify the source of high iron concentrations in several village water supplies. Finally, the paper discusses a number of areas in project implementation where improvements to procedures could be made that would prevent this problem persisting into the future.

Background

The most significant contribution to the specific understanding of corrosion in relation to handpump components stemmed from a groundbreaking World Bank/UNDP Project: ‘Laboratory and Field Testing and Technological Development of Community Water Supply Handpumps’, UNDP-INT/81/026 (the ‘Handpumps Project’), undertaken between 1981 and 1986. The project tested and monitored some 2,700 handpumps (of 76 types) in 17 countries over 5 years. The final project report (Arlosoroff et al., 1987) included a significant emphasis on the corrosive effects of aggressive groundwater, which it characterized as ‘much more widespread and much more damaging than previously suspected in both Africa and Asia’. The report highlighted the importance of corrosion-resistant materials and concluded that, while assessment of corrosivity of groundwater is a complex matter, pH is a ‘valuable indicator of aggressivity’; pH below 6 is likely to be ‘highly aggressive’ while pH above 7 is unlikely to contribute to corrosion. Sample bidding documents for the procurement of handpumps were also developed as a project output (World Bank, 1986) and advised that pH be considered in handpump selection.

Based on data from the Handpumps Project, the issue of aggressive groundwater and corrosion was explored further by Langenegger (1987) who estimated that in southern and central Ghana 66 per cent of handpump breakdowns were directly or indirectly attributable to corrosion and that in Niger and southern Ghana 30 per cent of handpump waterpoints were rarely used or completely abandoned due to excessive iron. Langenegger (1987: 6) described a common symptom of handpump corrosion: ‘the red water problem’ that is ‘well known by many villagers early in the morning after the pumps had not been used during the night’. Langenegger considered that the major consequence of handpump corrosion (in West Africa) was not necessarily the increased frequency of breakdowns, but the deterioration in groundwater quality, which could lead users to abandon the source. In his report

Table 1 pH-based index for applicability of galvanized downhole components

pH	*Application of galvanized material*	*Aggressivity of water*
pH > 7	Suitable	Negligible
6.5 < pH ≤ 7	Limited	Little to medium
6 < pH ≤ 6.5	Not recommended	Medium to heavy
pH ≤ 6	Not recommended	Heavy

Source: Langenegger, 1987

Langenegger recognized the complexity of corrosion, its dependence on a number of parameters, and the lack of a universal index for predicting corrosion in all water quality conditions. Based on data collected during the Handpumps Project, Langenegger considered that pH, which is easily measured in the field, was a useful corrosion indicator and he developed a set of guidelines for the use of galvanized iron riser pipes and pump rods, reproduced as Table 1.

In 1994, the World Bank published one of the most extensive and complete research-based resources on handpump corrosion. The report (Langenegger, 1994) was based on field and laboratory experience gained during the Handpumps Project and specifically in West Africa. It provides details of the characteristics of corrosion and the various geological, chemical, electrochemical, and biological factors associated with it. Some key conclusions were as follows:

- Natural iron concentrations in groundwater in the region were rarely greater than 1 mg/L.
- High iron concentrations in handpumps were usually caused by handpump corrosion and this could be confirmed using a simple pumping test and evaluating the change in iron concentration over time.
- Galvanization does not protect riser pipes and pump rods from corrosion where pH < 6.5 and provides limited protection for pH of 6.5–7.
- Lower handpump usage results in more serious high-iron problems.
- Stainless steel pump rods had corrosion rates an order of magnitude lower than galvanized pump rods.
- A simple pH index (Table 1) was sufficient to determine the potential for electrochemical corrosion, which is the type of corrosion that is primarily responsible for the elevated iron concentrations found in many wells.

Solutions to the problem of elevated iron concentration from handpump corrosion have been implemented in a number of countries. The Ghanaian Government introduced handpump standardization in the early 1990s that included the Afridev Pump, which is fully corrosion-resistant, and a modified version of the India Mark II with stainless steel components (Harvey et al., 2002). The Afridev pump has also been standardized in Mozambique, Nigeria, Tanzania, Ethiopia, and a number of other countries (Baumann and Furey, 2013). In Zambia, a switch to stainless steel components by some donor-funded programmes resulted in increased lifespans for new installations (Harvey and Skinner, 2002). In Malawi the use of uPVC well casings and PVC pump components was successful in reducing iron problems (Chilton and

Smith-Carington, 1984; Lewis and Chilton, 1989). In Mozambique, corrosion of downhole components was observed in a study of 100 wells (Parker, 2011) and the government has recommended replacement with the standardized Afridev pump, which has non-corrosive components. In India, following experience with corrosion and associated poor water quality in projects, a study was undertaken to evaluate the performance of PVC components with India MkII handpumps (Kumar Daw, 1992).

In Uganda, between 1991 and 1995 the Rural Water and Sanitation East Uganda Project (RUWASA) installed 1,938 India Mark III pumps, initially with galvanized iron riser pipes and rods. It was found that soon after installation, users began to complain about water quality, while at the same time the pipes and rods were found to be heavily corroded. To address the problem, downhole components were later switched to stainless steel (Baumann, 1998). Further corrosion problems with India MkII and India MkIII handpumps (referred to as U2 and U3 in Uganda) resulted in the development of the U3M (Uganda modified India MkIII) pump, which uses uPVC riser pipes and stainless steel connecting rods (Harvey, 2003). In western Uganda, a number of U2 and U3 pumps originally fitted with galvanized components and abandoned due to poor water quality were successfully retrofitted with corrosion-resistant U3M components (Fader, 2011). However, there appears to be limited awareness and some confusion about the U3M, its purpose, and its use among many stakeholders in Uganda.

Where iron is shown, or sometimes assumed to be naturally occurring, water treatment has been used. The use of iron-removal systems has been reported from Zambia (Karen and Anscombe, 2007; Kapulu, 2012) and trial installations in Uganda (Andersson and Johansson, 2002). It has been reported that they are difficult to maintain and may have been installed on wells in which conversion to corrosion-resistant pump components could have solved the iron problem (Fader, 2011). In such scenarios, it would be much more prudent to avoid the corrosion that caused high iron concentrations in the first place.

Despite the outputs and recommendations of the Handpumps Project, publication of standards (e.g. UNBS, 1995a, b), and implementation of various solutions, as described above, the problem still appears to be widespread. Ibe Sr et al. (2002) noted the widespread use of galvanized iron in West Africa and suggested that lessons from the Handpumps Project had not been learnt. Recent discussions (Furey, 2014) suggest that this may still be the case. Until these problems are resolved, it is likely that corrosion of handpump components will continue to be a significant problem in some places, where it will impair water quality, handpump performance, and functional sustainability.

Case study from Uganda

Introduction

WaterAid Uganda (WAU) currently operates in a number of districts in north-east Uganda working closely with District Local Governments and through two local implementing partners: Church of Uganda-Teso Diocese Planning and Development Office (CoU-TEDDO) and Wera Development Agency (WEDA). In two of these districts, Amuria and Katakwi, there had been increasing concerns over problems with poor water quality in groundwater sources due to high iron concentrations.

Revision of WAU's water quality testing protocol raised concerns about the way water quality was being tested during borehole construction. In Uganda, responsibility for sampling and testing is usually given to the drilling contractor and the authors' experience suggests that, for a number of reasons, this procedure may lead to unreliable results being reported.

In 2012, WAU began using staff from the government laboratory in Mbale to carry out on-site pH measurements at boreholes before handpump installation rather than including water quality testing in the drilling contract. An analysis of the pH measurements in Amuria and Katakwi districts from these recent tests indicated that the pH of the groundwater was much lower than was expected. Of 34 samples, 91 per cent were below pH 6.5 and 38 per cent below pH 6. This reinforced the suspicion that corrosion was likely to be contributing to the high iron concentrations reported in groundwater sources. Although pH alone is not a precise indicator of how aggressive groundwater might be, it is a relatively easy and low-cost measurement that provides a useful rule of thumb to indicate corrosion potential.

Methodology

In August 2014, WAU undertook a field testing programme on a number of recently installed boreholes where high iron concentrations had been reported by communities. The objective of the programme was to clarify the origin of high iron concentrations using the procedure described by Langenegger (1987, 1994) and to evaluate a portable iron testing kit.

The straightforward pumping test proposed by Langenegger involves purging a well that has been left unused for a short period of time and observing the change in iron concentration. The test relies on the same logic as most groundwater sampling protocols: water stored within the well is purged so that fresh groundwater can be sampled. The corrosion of pump materials will release soluble iron into the well water at a rate that will generally be greater at lower pH values. During pumping, iron released by the corrosion process will be diluted by groundwater entering the well. However, when a pump is out of use, for example overnight, concentrations will increase and the concentration of iron will be much higher in the morning (Langenegger's 'red water problem'). The test simply involves pumping a well early in the morning, before it has been used, and measuring iron concentrations at intervals until at least a volume equivalent to the column of water held in the borehole is removed. When corrosion is the main source of iron, concentrations should drop steadily until they stabilize at the natural background concentration in the aquifer (depending on how long pumping continues). If, on the other hand, iron concentrations remain high throughout continued pumping, it is likely that most of the iron originates from the aquifer.

The iron-testing kit (Figure 2), manufactured by Palintest, uses a simple colour comparison method requiring the addition of a single reagent, in tablet form, to produce a colour change in the sample, the intensity of which is proportional to the

Figure 2 Palintest comparator test kit

concentration of iron. The colour of the test sample is then compared to a standard colour disc. For this study, the High Range (0 to 10 mg/l) test kit was used.

Five boreholes with India MkII pumps and GI riser pipes installed were tested at locations indicated on Figure 3. Before testing, the selected boreholes were locked overnight so that test pumping would start after the boreholes had remained unused for several hours. To enable a suitable period of pumping to be estimated and timing of sampling set, the volume of water held in the riser pipe and in the borehole was

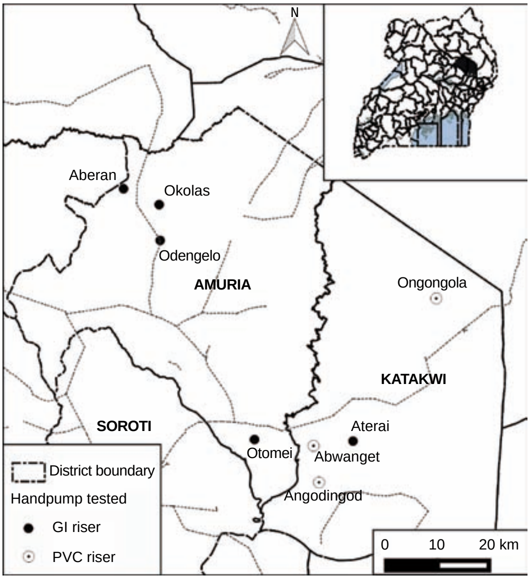


Figure 3 Location of boreholes sampled

calculated. These volumes are significant because the highest iron concentrations would be expected in water held in the riser pipe, while after the removal of at least one well volume, the iron concentrations should be approaching the natural concentration in the aquifer. For the tests, these volumes were estimated using data from borehole completion reports, assuming no changes to the borehole had been made and water levels were similar to those at the time of construction. By assuming a pumping rate, the timing of sampling could be predicted. Actual pumping rates were then measured during the test.

A steady pumping rate was maintained and samples taken at intervals so that the first was representative of water held overnight in the riser pipe, and subsequent samples represented water held in the borehole at various times. Pumping was continued for approximately two hours for these boreholes and the final samples taken after at least one well volume had been pumped. In all cases, water was pumped using the existing handpump. Samples were tested on-site for pH and electrical conductivity using calibrated probes.

The iron testing was intended to evaluate concentrations of dissolved iron in the water rather than total iron, which would inevitably include particulates such as rust particles and bacterial products. For this reason, the samples were filtered on site at 0.45 μm prior to testing. Filtration has the potential to remove any iron that has rapidly precipitated out of solution in the time between sampling and testing. However, in practice, filtration was undertaken immediately after sampling and it is considered that this would have limited the amount of iron that could have precipitated.

Duplicate filtered and unfiltered samples were also taken for subsequent analysis at the Ministry of Water and Environment's laboratory in Entebbe. All the samples were kept cool and delivered to the laboratory within one week of sampling. Samples were subsequently acidified in the laboratory prior to analysis, ensuring that any precipitated iron was re-dissolved.

Three boreholes fitted with PVC riser pipes were also visited (locations shown on Figure 3). However, as it was not possible to visit them early in the morning, they were not locked prior to the visit and the complete pumping test evaluation was not undertaken. However, a number of samples were taken for on-site and laboratory analysis.

Results for handpumps with GI risers

In the five boreholes tested, the water discharged was clear and colourless from the start of pumping, although small, solid particles, presumed to be corrosion products (rust), were often present. In several boreholes, the discharge became turbid for a short period, before clearing again. It was also found that if the boreholes were pumped vigorously, the discharge became brown and turbid. It is supposed that only when this high pumping rate is applied, do biofilm and other insoluble corrosion products become detached from the inside of the riser pipe.

Results from the field analysis using the Palintest kit show a distinct colour change from deep red (sampled from riser pipe) to light orange at the end of the test, indicating a decline in iron concentration. An example from the test at the

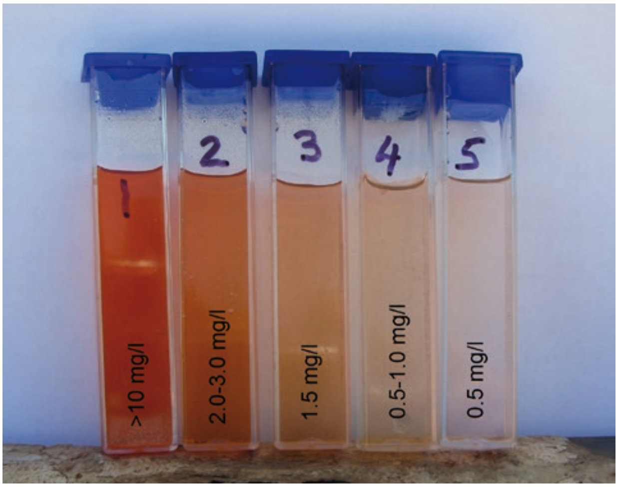


Figure 4 Results of Palintest analysis at Odengelo handpump

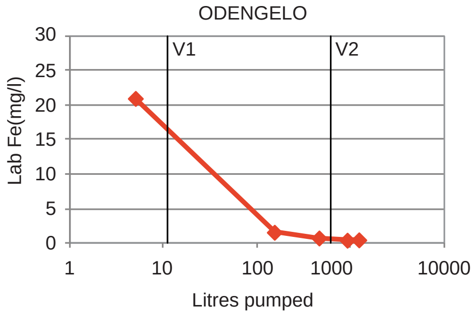
Odengelo borehole is shown on Figure 4, annotated with the iron concentrations interpreted from the comparator disc.

The results from the field tests and laboratory analysis are compared on Figure 5, with the laboratory results also presented graphically. The laboratory results for filtered samples confirm the results from field tests and show a clear fall in iron concentrations during pumping, indicating that the elevated concentrations are due to corrosion of the handpump components. The field results tend to be higher, possibly indicating iron that precipitated out during transport was not recovered by acidification at the laboratory. More comparable results may have been obtained if it had been possible to preserve the samples with nitric acid in the field.

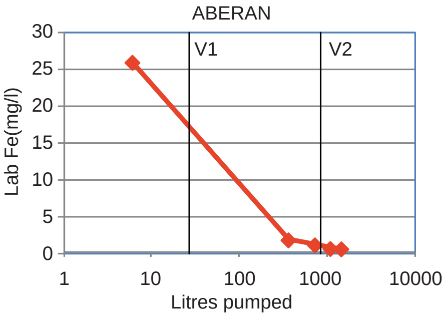
Concentrations in unfiltered samples are often much higher, as might be expected due to the presence of solid corrosion particles. Results from unfiltered samples can also be much more variable, as illustrated in the results from the Okolas handpump. These show a sudden increase in iron concentration after about 1,000 litres had been pumped, corresponding to an observed increase in turbidity during pumping. This illustrates how concentrations can be anomalously large if solid corrosion products are included in the analysis.

pH values in the samples recorded at the end of the test ranged from 6.38 to 6.97, indicating (from Table 1) that GI pipes would not be recommended in four of the boreholes and have limited suitability in the fifth. In three of the boreholes, the initial filtered iron concentrations, which varied from 21 to 26 mg/l, had reduced to between 0.5 and 0.17 mg/l by the end of the test. In the remaining two boreholes, the initial iron concentrations were lower at 4.5 and 1.17 mg/l and these had reduced to 0.86 and 0.48 mg/l respectively by the end of the test.

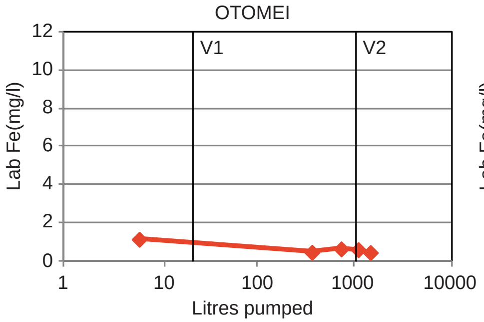
Iron concentrations recorded from the original pre-pump installation water quality testing show that for four of these boreholes, the iron concentrations were between 0.08 and 0.68 mg/l. At the fifth borehole, Aterai, a concentration of 13.5 mg/l was



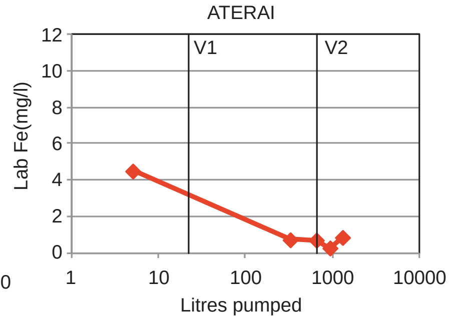
litres	5	153	459	918	1,224
Palintest	>10	2.0-3.0	1.5	0.5-1.0	0.5
Lab (F)	21	1.6	0.77	0.45	0.5
Lab (T)	nt	nt	nt	nt	nt



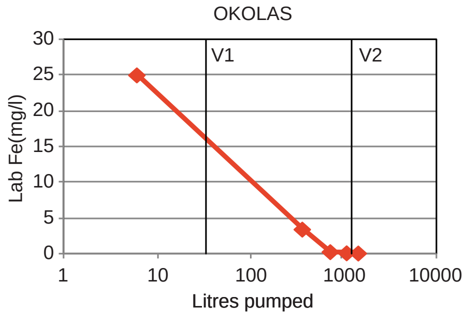
6	360	720	1080	1440
>10	7.5	1.5	0.5-1.0	0.5-1.0
26	1.91	1.23	0.74	0.69
38	nt	nt	nt	nt



litres	6	360	720	1080	1440
Palintest	5	1.5	1.0-1.5	0.5-1.0	0.5-1.0
Lab (F)	1.17	0.49	0.67	0.45	0.48
Lab (T)	2.98	72	0.4	nt	nt



5	324	648	929	1296
>10	1.0-1.5	0.5-1.0	0.5-1.0	1
4.5	0.73	0.71	0.28	0.86
nt	0.67	nt	nt	0.75



litres	6	360	720	1080	1440
Palintest	>10	4	1	0.5-1.0	
Lab (F)	25	3.5	0.36	0.2	0.17
Lab (T)	83	7.7	5.9	144	11

Palintest	Iron (filtered) mg/l
Lab (F)	Iron (filtered) mg/l
Lab (T)	Iron (Total) mg/l
EC	µS/cm
V1	Water volume in rising main
V2	Water volume in borehole
nt	Not tested

Figure 5 Results of laboratory tests on samples from pumps with GI risers

Figure 6 Threads on riser pipe at Odengelo, one year after installation

measured. This is certainly anomalous when compared to all other samples taken in the district over a two-year period, but the cause of this is unclear.

Following the tests, the riser pipes on some of the handpumps were withdrawn to allow inspection for signs of corrosion. Evidence of corrosion products was seen at all the sites and in particular at Odengelo village where the riser pipe was found to be leaking. The threads on several pipe joints at this handpump were severely damaged (Figure 6) and also indicated the use of sub-standard material. This borehole was only completed in October 2013 and the pump installed in December 2013, indicating how rapidly corrosion can affect a handpump in aggressive groundwater conditions. It is clear that this process would lead to more leakage and possibly to joint failure.

Results for handpumps with PVC risers

Although these handpumps were not tested in the same way as the India MkII handpumps, inspection of the pumps and the water quality results are revealing. Two boreholes fitted with U3M pumps (PVC riser and stainless steel pump rods) recorded exceptionally low pH values, between 6.00 and 5.68. The borehole at Amaratoit recorded iron concentrations (filtered) of between 1.0 and 1.5 mg/l from the Palintest kit and 1.56 and 2.22 mg/l from laboratory analysis. The second borehole at Abwanget recorded concentrations (filtered) of 0.5 mg/l from the Palintest kit and 0.06 mg/l from laboratory analysis.

The third borehole at Angodingod (Figure 7) was a U2 fitted with 1¼” PVC riser pipe (supplied by Davies and Shirtliff, Kampala) and GI pump rods. The Palintest results from two samples indicated iron concentrations less than 0.5 mg/l, confirmed by laboratory results of 0.06 mg/l. A pH of 6.2 was measured in the sample. Overall experience of this installation has been positive to date. The community has reported an acceptable yield and an absence of coloured water in the early morning, as was the case with pumps with galvanized iron riser pipes.

Figure 7 PVC riser pipe fitted to an India MkII pump at Angodingod

The high iron concentrations recorded in the Amaratoit borehole (noted above) appear to be natural, given that the pump components are corrosion-resistant. This well had a severe turbidity problem, possibly as a result of a completion which included an inappropriate screened section in weathered deposits. Although the turbidity was not related to corrosion, unfiltered samples tested at the laboratory had iron concentrations of between 3.85 and 4.6 mg/l and one sample a concentration of 45 mg/l.

Summary of results

The following observations can be made from the field testing:

- The Palintest comparator kit performed well at identifying the decline in iron concentration as the well was pumped.
- Iron concentrations from the comparator were slightly higher than those measured at the laboratory, possibly a consequence of the lack of on-site preservation with nitric acid.
- All the samples from boreholes with GI components showed a sharp decline in iron concentration when pumped continuously for two hours. In the final samples, iron concentrations in filtered samples were between 0.17 and 0.86 mg/l.
- The unfiltered samples often showed very high iron concentrations, 144 mg/l in one case, indicating that solid corrosion particles are likely to be present and incorporated in the analysis result.
- The filters used (Cronus syringe filter with 1 µm prefilter 25 mm, 0.45 µm) were highly effective and did not block. Only in one of the U3M installations

(Amaratoit) did turbidity (non-iron related) cause the filters to rapidly block. However, the use of on-site filtration needs to be treated with some caution. Filtering may distort the results if there is a rapid alteration of Fe^{+2} to Fe^{+3} in the time between taking the sample and filtration. In this case the measured iron concentration may be lower than is actually the case. Selecting a larger filter size may compensate for this.
- PVC riser pipes appear to be working effectively on one U2 installation where the pH of the groundwater suggests that corrosion and poor water quality would be a risk if GI pipes were fitted.
- Naturally high iron concentrations were recorded in one of the boreholes fitted with a U3M pump.

Discussion and conclusions

It has been known, and documented, for over 30 years that installation of galvanized iron components in aggressive groundwater leads to corrosion, causing premature failure of pump components and unacceptable water quality. Despite this, there appears to have been a lack of awareness of the problem and its causes, leading to the continued installation of susceptible India Mark II handpumps with GI rods and riser pipes in aggressive groundwater. This also suggests that there is little or no feedback from the user communities to the implementers, or that feedback is not being listened to or followed up. At the time of this study, there was little evidence that any implementers were taking steps to avoid the installation of GI components in aggressive groundwater. Although this paper features a case study from Uganda, previous studies and the recent RWSN 2014 synthesis of handpump discussions indicate that the problem is not unique to Uganda.

Four topics are discussed below where it is felt that changes to the current methods of operation could be made to prevent the problem of high iron concentrations which has persisted for so long. These are:

- changes to project planning and implementation of new waterpoints;
- revision of the handpump rehabilitation process;
- improvement of the water quality testing process;
- use of corrosion-resistant pump components.

Project planning and implementation

When installing new handpumps, there are two opportunities to identify if aggressive groundwater is likely to be a problem:

- at the planning stage before the specifications and bill of quantities (BoQ) are finalized;
- during project implementation and following water quality testing.

Given the ongoing problem with corrosion, it seems that assessment of the aggressivity of groundwater at the planning stage is either neglected completely, or if the issue is highlighted, the implications are ignored because of lack of understanding by the implementers. A lack of coordination and cooperation between different stakeholders may also mean that information is not shared and acted on.

At the project implementation stage, it is common that the drilling contractor is responsible for all aspects of the contract, subcontracting specific areas when necessary. Contracts are often on a ‘no water, no pay’ basis and there may be an emphasis by the implementing organization on accepting the lowest bidder. These conditions place additional financial pressure on the contractor, which may lead them to cut corners and costs, resulting in, for example, the use of sub-standard pump components, or questionable practices when dealing with water quality sampling and analysis. Experience of the easy availability of poor quality handpump components in Zambia (Anscombe, 2014) suggests that more robust procedures for procurement are required by implementing organizations and governments. If the specifications are too lax, or supervision is insufficient, the contractor may be able to purchase and install poor quality components. In addition, technical specifications may stipulate the use of galvanized iron, regardless of groundwater conditions and in disregard of published standards.

During construction, water quality sampling may not be undertaken to the appropriate standards, or the results not considered in handpump selection. In the author’s experience, samples may not be analysed for weeks after sampling and some results, pH in particular, may no longer be representative of the true groundwater conditions. Even if aggressive groundwater is identified, the lack of flexibility in specifications and cost constraints may mean that GI materials are installed by default.

Where aggressive groundwaters have been identified, switching from corrosion-prone galvanized iron to corrosion-resistant stainless steel or plastic is not always straightforward. Several constraints make selection of alternative materials difficult in some areas, including limited supply chains, lack of local knowledge and competence in different installation and maintenance techniques, and availability of appropriate tools to work with these materials.

Revision of handpump rehabilitation process

Where high iron concentrations are present in an existing water source, the source of the iron needs to be established so that appropriate action can be taken. The test described above allows field technicians to easily distinguish between dissolved iron originating from the corrosion of pump materials and that originating from the aquifer. The test offers an easy method for NGOs, district governments, and other implementers to be confident of the origins of high iron in water supplies so that appropriate action can be taken. In this study, iron concentrations were measured using a Palintest Comparator, which proved reliable and easy to use. Brett (2015) reported the results of similar tests in northern Uganda using a test-strip method for estimating iron concentrations (SenSafe™ Iron Check).

Where corrosion is identified as the origin of the iron, remedial action may comprise retrofitting corrosion-resistant materials to existing pump heads, or replacing the pumps with corrosion-resistant alternatives (Afridev, Blue Pump, U3M), where these are appropriate. Each solution, however, comes with its own set of constraints that must be considered.

Improvement of water quality testing process

As has been discussed, pH provides a relatively easy to measure and low-cost indicator of the corrosion potential of groundwater. pH on its own is not always indicative of aggressive groundwater conditions, but it can highlight the need for caution. Experience suggests that, unless tight control on water quality sampling and testing can be enforced, the accuracy of pH measurements cannot be guaranteed. Existing data may not always be suitable to accurately define areas of potentially aggressive groundwater if the sample handling was poor. The best option is to measure the pH of borehole water on-site. There are, however, practical difficulties associated with this. For accurate readings, even the most basic pH meters require careful handling and calibration using buffer solutions that are not easy for implementers to obtain and properly use.

There are simple alternatives to pH meters for on-site pH testing, such as pH test strips, though accuracy may be a concern. Brett (2015) compared results from three types of pH test strips to a calibrated Hanna digital pH meter at 16 handpump boreholes in northern Uganda and concluded that two of the three brands tested gave sufficiently accurate results. Additional research may be needed to determine the applicability of low-cost pH test strips for field determinations of pH.

The difficulty of measuring pH accurately on-site can be overcome where it is possible to deploy a trained laboratory technician to take on-site readings for a long enough period to establish the general groundwater conditions in a district. Confidence in overall water quality results can also be increased where the local implementing organization can be given the responsibility for collecting and transporting the samples to a reliable laboratory. For example, in Katakwi and Amuria, WaterAid undertook an intensive period of on-site pH testing with the Ministry of Water and Environment. The lesson was that implementers should not view mobilization of trained water quality assessment technicians to the field as ‘expensive’ as it could save their entire investment in a borehole. However, where it is not possible to deploy a trained technician and there is some risk of aggressive groundwater it would seem prudent to avoid use of galvanized iron rods and riser pipes completely. In many cases, this trade-off would mean slightly elevated installation costs to the implementer in exchange for increased acceptance and significantly lower maintenance costs for the users, which is a better recipe for a sustainable improved water service.

Use of corrosion-resistant materials

A switch to corrosion-resistant materials is not necessarily simple to undertake. Experience from Uganda has shown that supply chains for corrosion-resistant materials are generally weak and there may be uncertainties about quality. There is little demand for alternatives, so galvanized iron rods and riser pipes dominate the market. Stainless steel and plastic materials are theoretically available, appearing in product catalogues but visits to several suppliers in Kampala revealed that very low stock levels are generally held. It appears that suppliers have been reluctant to carry large stocks because they do not sell as fast as GI.

Even where stainless steel is available, it cannot be assumed that a simple retrofit will be without complications. Most handpump mechanics do not carry sufficient tools to work with stainless steel components. WaterAid found that stainless steel riser pipes from a large supplier in Kampala had slightly larger diameter welded couplings, requiring special tools and making it very difficult to fit to pump water tanks or cylinders without substantial modification. Subsequent use of stainless steel by Amuria district has however not yielded any reported problems.

Similarly, a switch over to the U3M Handpump, which makes use of 2½" (nominal) corrosion-resistant plastic riser pipes and stainless steel rods, is not without problems. Despite being a national standard pump in Uganda, some contractors are unfamiliar with the pump's installation and maintenance. Many handpump mechanics are not familiar with the nuances of the U3M and few have the special tools the pump requires. In addition, there seems to be little awareness about the 'open-top' design of the pump; one of the authors has been told by many key stakeholders that the entire string of riser pipes is often removed to make repairs that could be made *in situ* if the specialized maintenance methods of the 'open-top' design were utilized. The result of these issues can often be unnecessary damage to the pump during installation and maintenance, as well as increased costs. In addition, the U3M is only effective up to depths of 35 m, beyond which yields are greatly reduced and the likelihood of failure is increased. Greater pumping depths are common in parts of Uganda.

The retrofitting of 1¼" PVC pipes to U2 pumps has been trialled on a few pumps with positive results. However, low supplier stock levels of the pipe have inhibited trials on other pumps. There are also concerns with possible weaknesses associated with the reduced strength of threaded PVC joints. The promising performance of the Davis and Shirtliff pipe should be monitored and trials expanded to a greater sample of pumps at various installation depths. WaterAid is yet to test the maximum depth at which the pipe can operate without impaired performance. Further engagement with others that have researched the use of 1¼" PVC pipes will also be useful, as there is little published material on the topic.

Recommendations

Addressing existing handpumps with corrosion problems should be a priority for stakeholders, while avoiding the creation of future corrosion problems should be vital. At existing handpumps where iron-related water quality problems have been identified, boreholes should be tested to determine if the source of iron is natural or from corrosion. The choice of rehabilitation methods can then be determined.

The main recommendation for preventing the corrosion-induced water quality problems is considered to be improvement to the planning stage of water supply projects:

- Pre-implementation planning for projects must include serious consideration of relevant tests to indicate the potential for groundwater to cause corrosion of susceptible pump components, using on-site testing if required. Reference should also be made to government databases and water quality mapping, if available, and treated with the appropriate caution. Communication and coordination with local government and other NGOs working in the area can also reveal concerns about aggressive groundwater. A full assessment should be undertaken to identify problems that may be already known within the project area, such as water quality and handpump sustainability, which can have major implications for new boreholes.

- Based on appropriate planning, properly formulated contracts and BoQs with sufficient flexibility are needed. Contracts and budgets should include sufficient contingency to allow alternative handpump components to be installed if proven necessary by on-site experience.
- Consideration should be given to separation of the various tasks involved so that the drilling contractor is not responsible for handpump installation or water quality testing. For example, water quality sampling could come under the responsibility of the project supervisor.

Improvements to the implementation stage include:

- the provision of competent supervision so that specifications are followed and appropriate handpumps are installed;
- ensuring that water quality testing is undertaken correctly and critical parameters are measured on-site, where possible.

Where aggressive groundwaters are known to be present, there should be a focus on communication, data sharing, collaboration, and advocacy among government, private sector, NGOs, and communities on the issue of corrosion-resistant handpump options. Sector coordination bodies, such as UWASNET (Uganda Water and Sanitation Network) and NETWAS (Network for Water and Sanitation) in Uganda, could be an appropriate focus for such discussions.

Finally, in the larger context, where the selection of approved corrosion-resistant pumps is limited, stakeholders should advocate for revision of the relevant government standards.

References

Andersson, H. and Johansson, J. (2002) *Iron Removal from Groundwater in Rakai District, Uganda* [pdf], MSc thesis, Department of Environmental Engineering, Sweden: Lulea University of Technology <http://epubl.luth.se/1402-1617/2002/292/LTU-EX-02292-SE.pdf> [accessed 21 September 2015].

Anscombe, J. (2014) 'Sustainable Groundwater Development: The failure of handpumps and why a call to action is needed' [online], RWSN DGroups discussion <https://dgroups.org/RWSN/groundwater_rwsn/discussions/ae169411>.

Arlosoroff, S., Tschannerl, G., Grey, D., Journey, W. and Roche, R. (1987) *Community Water Supply: The Handpump Option* [online], Washington, DC: World Bank <www.rural-water-supply.net/en/resources/details/409> [accessed 21 September 2015].

Baumann, E. (1998) *Handpump Technology Input to the Joint Review of the Rural Water Supply and Sanitation Eastern Uganda Project: RUWASA Phase IIA* [online], St Gallen, Switzerland: SKAT/RWSN <www.rural-water-supply.net/en/resources/details/418> [accessed 21 September 2015].

Baumann, E. and Furey, S. (2013) *How Three Handpumps Revolutionised Rural Water Supplies: A Brief History of the India Mark II/III, Afridev, and the Zimbabwe Bush Pump* [online], Rural Water Supply Network. Field Note 2013-1, St Gallen, Switzerland: SKAT/RWSN <www.rural-water-supply.net/en/resources/details/475> [accessed 21 September 2015].

Brett, M.E. (2015) *Field Study Investigating the Potential of Water Quality Testing to Predict Corrosion in Boreholes in Northern Uganda*, MSc thesis, Macon, GA: Mercer University School of Engineering.

Chilton, P.J. and Smith-Carington, A.K. (1984) 'Characteristics of the weathered basement aquifer in Malawi in relation to rural water supplies', in *Challenges in African Hydrology and Water Resources: Proceedings of the Harare Symposium*, p. 70 [pdf], IAHS Press <http://hydrologie.org/redbooks/a144/iahs_144_0057.pdf> [accessed 21 September 2015].

Fader, C.T. (2011) *Retrofitting Boreholes Contaminated With Iron in Rural Uganda* [pdf], MSc thesis, Houghton, MI: Michigan Technological University <www.geo.mtu.edu/~jsgierke/student_theses/FaderC_MSCEReport_RetrofittingWellsContaminatedWithIRB.pdf> [accessed 21 September 2015].

Furey, S. (2014) *Handpumps: Where Now? A Synthesis of Online Discussions (2012–2014)* [online], St Gallen, Switzerland: Rural Water Supply Network/SKAT Foundation <www.rural-water-supply.net/en/resources/details/614> [accessed 21 September 2015].

Harvey, P.A. (2003) *Sustainable Handpump Projects in Africa: Report on Fieldwork in Uganda* [pdf], Leicestershire, UK: Water, Engineering and Development Centre, Loughborough University <http://wedc.lboro.ac.uk/docs/research/WEJW2/Report_-_Uganda.pdf> [accessed 21 September 2015].

Harvey, P.A. and Skinner, B.H. (2002) *Sustainable Handpump Projects in Africa: Report on Fieldwork in Zambia* [pdf] Leicestershire, UK: Water, Engineering and Development Centre, Loughborough University <http://wedc.lboro.ac.uk/docs/research/WEJW2/Report_-_Zambia.pdf> [accessed 1 September 2015].

Harvey, P.A., Jawara, D. and Reed, R.A. (2002) *Sustainable Handpump Projects in Africa: Report on Fieldwork in Ghana* [pdf], Leicestershire, UK: Water, Engineering and Development Centre, Loughborough University <http://wedc.lboro.ac.uk/docs/research/WEJW2/Report_-_Ghana.pdf> [accessed 21 September 2015].

Ibe Sr, K.M., Egereonu, U.U. and Sowa, A.H.O. (2002) 'The impact of corrosion on water quality of West African sub-region', *Environmental Monitoring and Assessment* 78: 31–43 <http://dx.doi.org/10.1023/A:1016128404928>.

Kapulu, M. (2012) *Iron Removal in Borehole Water: A Case Study of Luapula Province*, MSc thesis, Lusaka: University of Zambia.

Karen, M. and Anscombe, J. (2007) *Bad Tasting Groundwater Tackled* [pdf], The Water Wheel, March/April 2007 <www.wrc.org.za/Knowledge%20Hub%20Documents/Water%20Wheel/

Articles/2007/02/WaterWheel_2007_02_groundwater%20p16-17.pdf> [accessed 21 September 2015].

Kumar Daw, R. (1992) *Performance of PVC Riser Pipes with India Mark II Hand Pumps: Results from Field Trials February 1988 to March 1992* [pdf], Danida Project Directorate, Bhubaneshwar, Orissa, India <www.rural-water-supply.net/_ressources/documents/default/1-609-2-1408964093.pdf> [accessed 13 September 2014].

Langenegger, O. (1987) *Groundwater Quality: An Important Factor for Selecting Handpumps* [online], Washington, DC: World Bank <www.ircwash.org/resources/groundwater-quality-important-factor-selecting-handpumps> [accessed 21 September 2015].

Langenegger, O. (1994) *Groundwater Quality and Handpump Corrosion in Africa* [online], UNDP-World Bank Water and Sanitation Program, Water and Sanitation Report 8 <www.rural-water-supply.net/en/resources/details/604> [accessed 21 September 2015].

Lewis, W.J. and Chilton, P.J. (1989) 'The impact of plastic materials on iron levels in village groundwater supplies in Malawi', *Water and Environment Journal* 3(1): 82–8 <http://dx.doi.org/10.1111/j.1747-6593.1989.tb01369.x>.

Parker, A. (2011) *WASHtech: Africa Wide Water, Sanitation and Hygiene Technology Review: WASHTech Deliverable 2.1*, p. 17 [online], RWSN <www.rural-water-supply.net/en/taf/taf-selection-tool/details/520> [accessed 21 September 2015].

Uganda National Bureau of Standards (UNBS) (1995a) *US 405 (1995): Shallow Well Handpump (Model U2/U3)* [pdf], Uganda Standard 405 <https://ia601604.us.archive.org/1/items/us.405.1995/us.405.1995.pdf> [accessed 18 January 2015].

UNBS (1995b) *US 404 (1995): Extra Deepwell CBMS Handpump* [pdf], Uganda Standard 404 <https://ia601609.us.archive.org/28/items/us.404.1995/us.404.1995.pdf> [accessed 18 January 2015].

UNBS (2008) *Uganda Standard: Drinking (Potable) Water – Specification*, US 201:2008 <https://law.resource.org/pub/ug/ibr/us.201.2008.html> [accessed 21 September 2015].

World Bank (1986) *Draft Sample Bidding Documents for the Procurement of Handpumps* [online], Rural Water Supply Handpumps Project, Nairobi: UNDP <www.ircwash.org/resources/draft-sample-bidding-documents-procurement-handpumps> [accessed 21 September 2015].

World Health Organization (WHO) (2011) *Guidelines for Drinking-water Quality*, 4th edn [online], Geneva: World Health Organization <www.who.int/water_sanitation_health/publications/2011/dwq_guidelines/en/> [accessed 21 September 2015].