MSABI Clay Filter Pots – Removal of iron and manganese from groundwater sources

Contents

1.0 Introduction

Iron and Manganese are naturally occurring metals commonly found in both surface water and groundwater.

In January 2012, MSABI determined that a review of possible methods for the removal of iron and manganese from source water should be undertaken. It is important to note that, in accordance with WHO guidelines, in most naturally occurring concentrations (including the levels measured to date in the Kilombero District), iron and manganese do not pose a health risk in terms of human consumption. In point of fact, both iron and manganese are important elements for human consumption and are dietary requirements.

However, the general Kilombero community is largely unaware of this fact, and there is (anecdotally speaking) a broad suspicion of and aversion to the presence of iron and manganese in both potable and non-potable water sources. Water with high iron and manganese content is aesthetically less desirable, as it is likely to have a metallic taste if used for potable consumption, and may cause light brown staining if used for washing or other similar purposes.

Because MSABI water points access aquifers at depths of up to 30 metres below ground level (reaching into and sometimes through rock deposits), relatively high concentrations of iron and manganese are more likely to exist in MSABI water.

In February 2012, a relevant example relating to community perceptions of safe and unsafe drinking water with respect to the presence of iron and manganese was presented to the MSABI lab.

> *A secondary school in Ifakara presented two water samples for microbiological testing.*
>
> *The first sample was from a 10 metre (third party) shallow well, and the sample was aesthetically pleasant (transparent, non-coloured and with neutral taste). The second sample was from a MSABI-installed 24 metre well, and was aesthetically less pleasant (turbid, orange-brown and with a minor metallic taste).*
>
> *The school presented the samples out of concern that MSABI well water was not safe to drink (on the basis of aesthetic appearance).*
>
> *Microbiological testing determined that the water drawn from the 10 metre **shallow well** had a **high pathogen count**, and was in fact unsafe for potable consumption without additional treatment. In contrast, the less aesthetically appealing water from the 24 metre **MSABI well** was **not found to have any microbiological contamination** in the sample tested.*

While an effort should be made to educate the community and improve awareness that groundwater containing iron and manganese is safe for human consumption, and conversely that the aesthetic appearance of water is not a reliable indication of suitability for human consumption, this study has been undertaken to determine the capacity of MSABI filter pots to remove iron and manganese and produce more appealing potable water.

1.1 Iron

The following information is taken from the World Health Organisation (WHO) factsheet on iron (1996):

- *'Iron is the second most abundant metal in the earth's crust.'*
- *'In well-water, iron concentrations below 0.3 mg/litre were characterised as unnoticeable , whereas levels of 0.3 – 3.0 mg/litre were found acceptable.'* [1]
- *'Staining of laundry…may occur at concentrations above 0.3 mg/litre.'*
- *'Iron is an essential element in human nutrition.'*
- *'Iron concentrations of 1.0 –3.0 mg/litre can be acceptable for people drinking anaerobic well-water.'*

1.2 Manganese

The following information is taken from the World Health Organisation (WHO) factsheet on manganese (2003):

- *'Manganese is one of the most abundant metals in the Earth's crust, usually occurring with iron.'*
- *'Manganese is an essential element for humans and other animals and occurs naturally in many food sources. '*
- *'Manganese is naturally occurring in many surface water and ground water sources, particularly in anaerobic or low oxidation conditions, and this is the most important source for drinking-water. The greatest exposure to manganese is usually from food.'*

Measurement	**Detail**
Guideline value	0.4 mg/litre
Occurrence Levels	Levels in fresh water typically range from 1 to 200 mg/litre, although levels as high as 10 mg/litre in acidic groundwater have been reported; higher levels in aerobic waters usually associated with industrial pollution
TDI	0.06 mg/kg of body weight, based on the upper range value of manganese intake of 11 mg/day, identified using dietary surveys, at which there are no observed adverse effects (i.e., considered a NOAEL), using an uncertainty factor of 3 to take into consideration the possible increased bioavailability of manganese from water
Limit of detection	0.01 µg/litre by AAS; 0.05 µg/litre by ICP/MS; 0.5 µg/litre by ICP/optical emission spectroscopy; 1 µg/litre by EAAS; 10 µg/litre by FAAS
Treatment achievability	0.05 mg/litre should be achievable using oxidation and filtration
Guideline derivation • Allocation of water • Weight • Consumption	 • 20% of TDI (because manganese is essential trace element) • 60-kg adult • 2 litres/day
Additional comments	The presence of manganese in drinking-water will be objectionable to consumers if it is deposited in water mains and causes water

[1] With respect to aesthetic appearance and taste

	discoloration. Concentrations below 0.05–0.1 mg/litre are usually acceptable to consumers but may sometimes still give rise to the deposition of black deposits in water mains over an extended period; this may vary with local circumstances.

2.0 Testing

A progressive testing procedure was planned prior to the initiation of lab work. The following variables were identified:

- Iron content of source water
- Filter pot flow rates
- Rice husk to clay ratio in filter pot units
- Accumulation of iron and manganese in filter pot membranes over time

2.1 Test 1

An initial test was undertaken to establish the potential capacity of MSABI filter pots to remove iron/manganese from source water.

2.1.1 Test 1 Method

3 test pots with varying clay to rice husk ratios were identified for initial testing (pot codes 21-14, 24-15, 23-4).

9 litres of well water was collected. The source water was taken from a MSABI well with water known to have high iron content. In addition, the identified well (adjacent to the IHI complex in Ifakara) had a minor fault and had not been used for a period of approximately 10 days. Lab testing identified an iron content of **1.605 mg/L** in the source water.

3 litres of source water were placed in each test filter pot. The filtrates were collected and tested to determine the efficiency of iron removal.

2.1.2 Test 1 Results

The following table demonstrates summary results from Test 1.

Pot Code	**Rice Content (kg)**	**Flow Rate (L/hour)**	**Source Water Iron Content (mg/L)**	**Filtered Water Iron Content (mg/L)**	**Percentage Removal (%)**
21-14	3	3.2	1.605	0.07	95.6
24-15	4.5	3.8	1.605	0.00	100.0
23-4	4	3.9	1.605	0.04	97.5

Table 2.1 – Initial filter pot iron removal efficiencies

Test 1 results demonstrated that MSABI filter pots were, at least initially, highly efficient at removing iron from source water.

2.2 Test 2

Test 2 was a more comprehensive, lab-based assessment of the potential for MSABI clay filter pots to remove iron and manganese over a period of time.

Most equivalent organisations manufacturing clay filters (operating in countries such as Nicaragua and Cambodia) recommend a useful filter pot life of between 1 and 2 years for filter pots. This limited lifespan relates primarily to uncertainty over the continued efficiency of microbiological filtration.

Following Test 1, it was unclear whether the capacity of filter pots to filter iron and manganese deteriorated over time. While extensive and lengthy testing is required to ascertain the exact capacity for iron removal over time, Test 2 was undertaken to ensure that there was not a steep deterioration in removal efficiency (i.e., over a period of weeks, with an increased volume of high-iron content water filtered).

2.2.1 Test 2 Method

Three unique test pots, different to those tested in Test 1 (and again with varying clay to rice husk ratios) were identified for Test 2.

Over a period of 6 weeks, 42 litres of high-iron content source water was filtered through each of the 3 filter pots (14 individual tests of 3 litres).

For each of the tests undertaken, the initial iron content of the source water was recorded, and compared to the iron content of the filtrates following filtration. This recording also permitted the identification of diurnal patterns of iron content in well water.

The filtrates were subsequently tested for iron content following 1 hour of filtration. The volume of water filtered over 1 hour was also recorded. This process also permitted assessment of variation in flow rate over time, in order to determine if the compounding filtration of iron had an impact on flow rate.

Following the iron content test, the remaining source water was filtered to ensure equivalent and consistent volumes of water were filtered by each filter pot.

2.2.2 Test 2 Results

Over a period of weeks, the iron content of the 42 litres of filtrates was monitored and recorded. The following figure demonstrates the efficiency of iron filtration (by percentage removal) of the three filter pots tested.

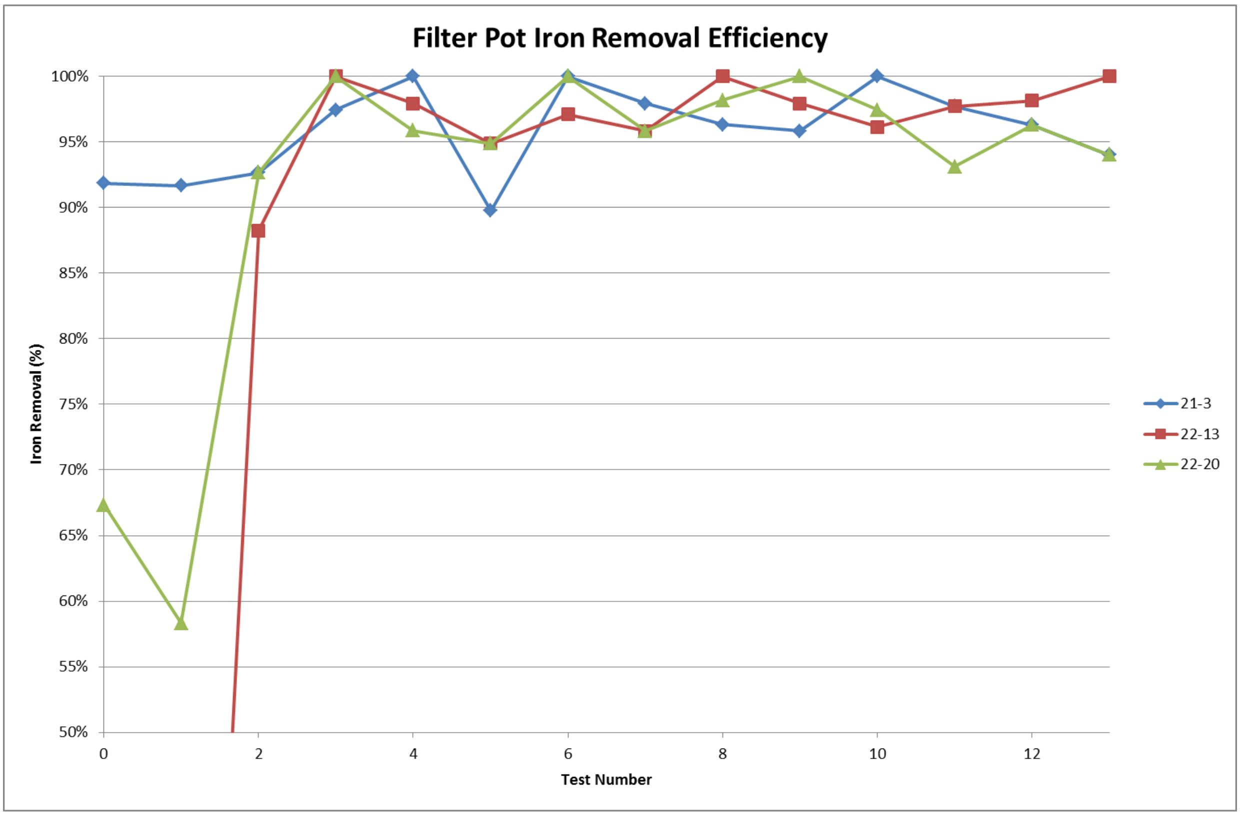

Figure 1: Efficiency of filter pots in the filtration of iron over time (total of 14 tests)

The first two filtration tests undertaken on pots 22-13 and 22-20 demonstrated inconsistent results, as shown in the above figure. These anomalies are likely due to excess iron content on the outside of the clay filter pot, and which was subsequently washed away during filtration, and can subsequently be discarded.

Initial anomaly results aside, the filter pots demonstrated highly consistent filtration efficiencies over the course of the test.

- A minimum of 88% iron removal was achieved, with
- Removal efficiency consistently above 95%.

Within the limits of the test procedure and span, these results present promising evidence that MSABI filter pots can effectively filter iron and manganese from source water over a period of time.

A secondary consideration was to determine if there is a relationship between the iron content of the source water, and the efficiency of iron removal. Conceivably, relatively high iron content in the source water could translate to a higher content of iron in the filtrate.

The following figure demonstrates the relationship between the iron content in the source water, and the efficiency of filter pot iron removal.

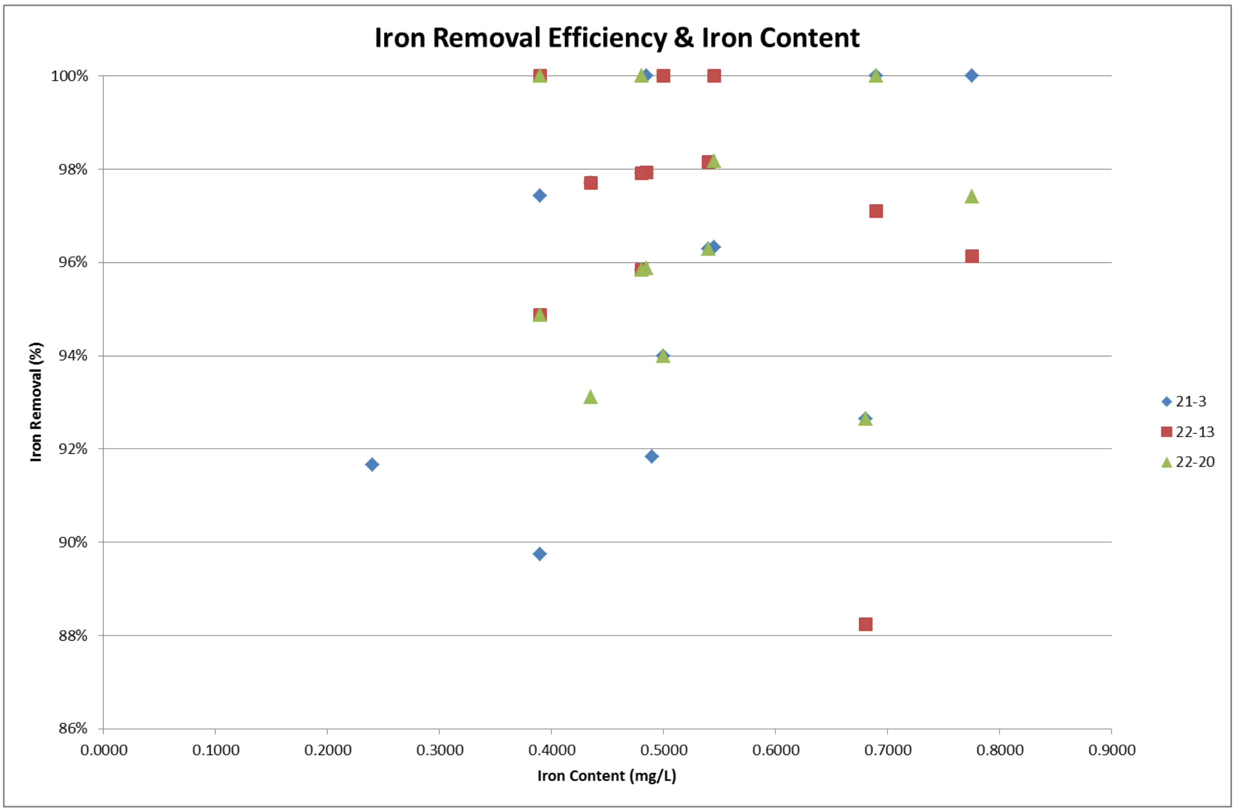

Figure 2: Iron removal efficiency graphed against the iron content of the source water

The results demonstrate a neutral relationship between the iron content in the source water (ranging from 0.240 mg/L to 0.775 mg/L) and the efficiency of removal (ranging from 88% to 100%). Table 2.2 demonstrates the removal efficiencies of filter pot 21-3.

Iron Content	**Iron Removal Efficiency**
0.240 mg/L	92 %
0.775 mg/L	100 %

Table 2.2 – Filter pot 21-3 – iron removal efficiencies

In sum, on the basis of recorded iron levels, the efficiency of iron removal achieved by the MSABI filter pots is non-dependent on the degree of iron content.

As flow rates were recorded for each of the iron removal tests undertaken, these have been recorded against removal efficiencies in order to determine if there is a relationship between the rice husk content (rate of flow) and capacity to filter iron. While the filter pots were always saturated prior to each test, it should be noted that the flow rates recorded are for an inflow volume of 3 litres, and therefore not a true representation of the filter pot flow rates (which would be significantly higher if the filter pot was full).

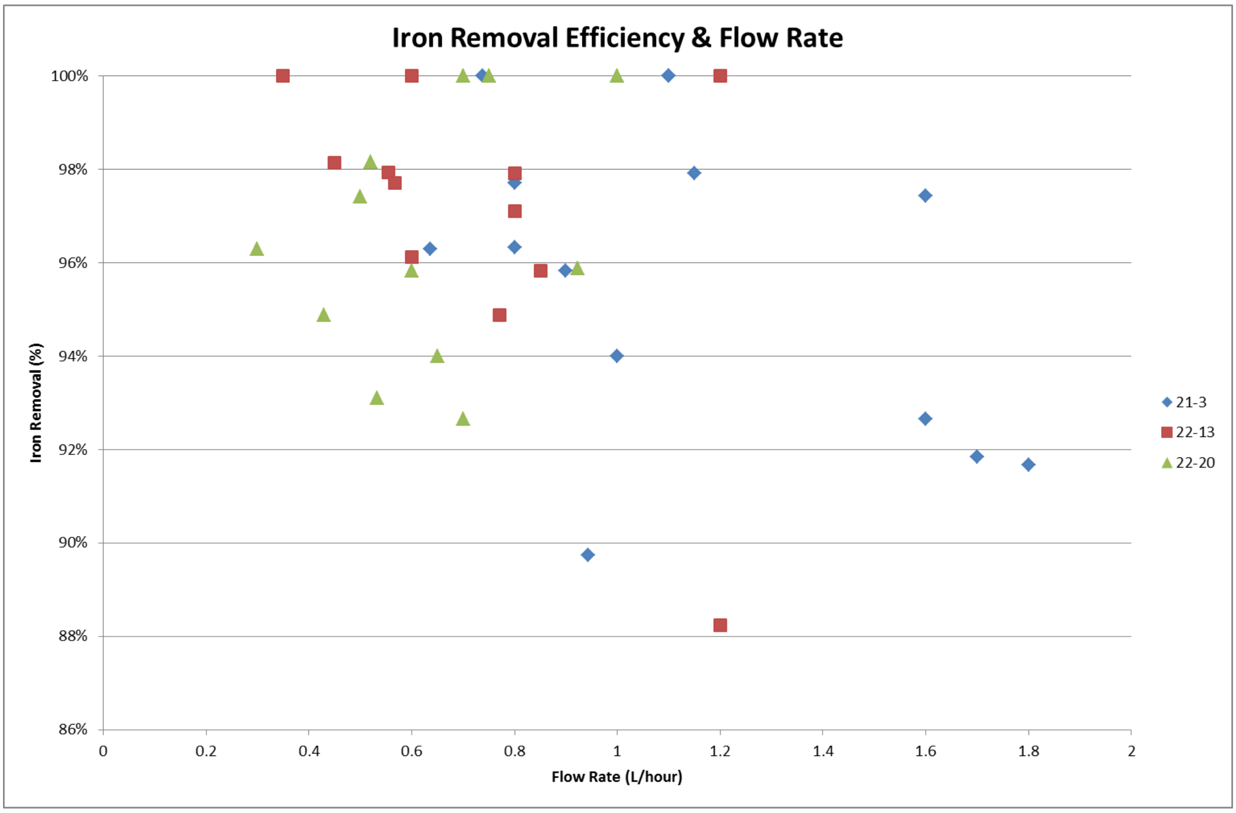

Figure 3: Iron removal efficiency against recorded flow rate

The graph demonstrates clearly that the iron removal efficiency is non-dependent on the rate of flow. Table 2.3 demonstrates filter pot 21-3, which achieved the following flow rates and corresponding removal efficiencies.

Flow Rate	Iron Removal Efficiency
0.64 L/hour	96 %
1.60 L/hour	97 %

Table 2.3 – Filter pot 21-3 – iron removal efficiencies

The data collected in Test 2 also serves the purpose of demonstrating the iron content of source water in a high-use well throughout the day. This data is presented below, and demonstrates the iron content of well water at various times during the days the tests were undertaken.

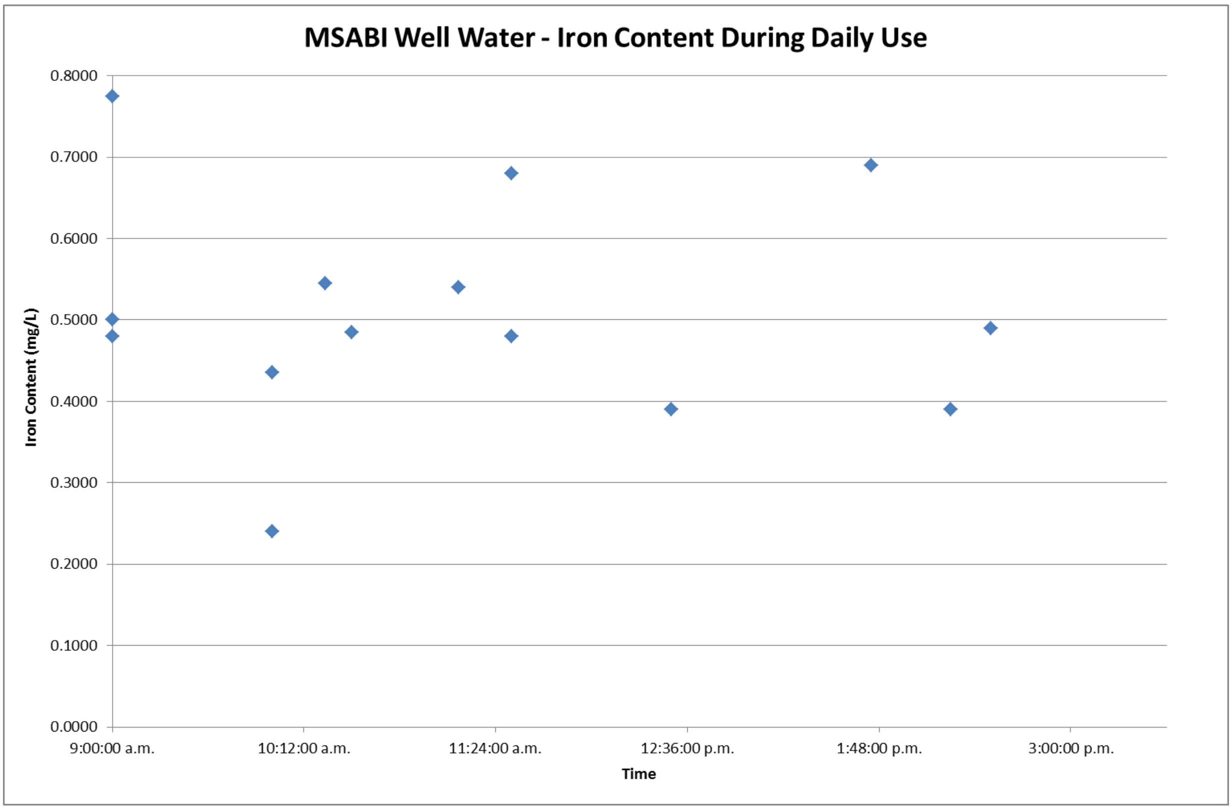

Figure 4: Diurnal pattern of iron content in MSABI well – Ifakara Township

2.3 Test 3

Test 3 was undertaken parallel to Test 2, and involved a field test to determine the potential for MSABI clay filter pots to remove iron and manganese over a period of time.

Three MSABI clay filter pots, with varying rice husk to clay ratios, were delivered to the owner of the semi-private MSABI well that was demonstrating high iron content, and acted as the source for all other testing. The intended purpose was to submit MSABI filter pots to constant use and filtration of source water with high iron content.

2.3.1 Test 3 Method

Each of the three filter pots was tested to determine their iron removal efficiencies prior to delivery for the field experiment. Three filter pots were delivered to the MSABI client who had originally noted the iron content and consequent discoloration of the well water at his property.

During the test, MSABI requested the well owner was requested to use the filter pots consistently over the next 21 days (3 weeks), and make a note each time he filled each filter pot. This recording process would allow MSABI to determine the total volume of well water filtered by each pot, in conjunction with the record of daily iron content in the source water.

A secondary lab test following the three week trial period was used to identify any deterioration of the iron removal efficiency of each filter pot.

2.3.2 Test 3 Results

The owner was requested to use the filter pots consistently over 21 days (3 weeks), and make a note each time he filled each filter pot. A secondary lab test following the three week trial period would identify any deterioration of the iron removal efficiency of each filter pot.

Table 3.1 demonstrates the approximate test details recorded by the MSABI well owner. Records of water filtered allow for the calculation of the total weight of iron filtered by each filter pot over the 3 week period. (The iron content was calculated using the average iron content derived from lab tests undertaken during the same period.)

Days	Average Daily Filtrates	Total Filtrates	Average Iron Content	Total Iron Filtered
21	25 litres / day	525 litres	0.52 mg/L	273 mg

Table 3.1 – Field records of filter pot use and total iron filtration

Table 3.2 demonstrates the iron removal test results before and after the3 week field trial.

Date	Test	Iron Content	MSABI Filter Pot			Average Efficiency
			22-1	24-4	21-2	
14-02-2012	Initial test	0.48 mg/L	0.01 mg/L	0.01 mg/L	0.01 mg/L	98%
10-03-2012	Post-field test	0.43 mg/L	0.01 mg/L	0.03 mg/L	0.02 mg/L	95%

Table 3.2 – Filter pot efficiency before and after field testing

3.0 Test Conclusions

The filter pot iron removal efficiencies following field testing are within the range recorded prior to the field tests. There was no tangible deterioration of the filter pot iron removal efficiency recorded following the 3 week field tests.

As such, the combination of lab and field tests undertaken is sufficient to establish that:

- MSABI clay filter pots have the capacity to effectively remove almost all trace of iron and manganese from source water.
- The capacity of MSABI clay filter pots to filter iron and manganese from source water does not observably deteriorate in the short to mid-term.

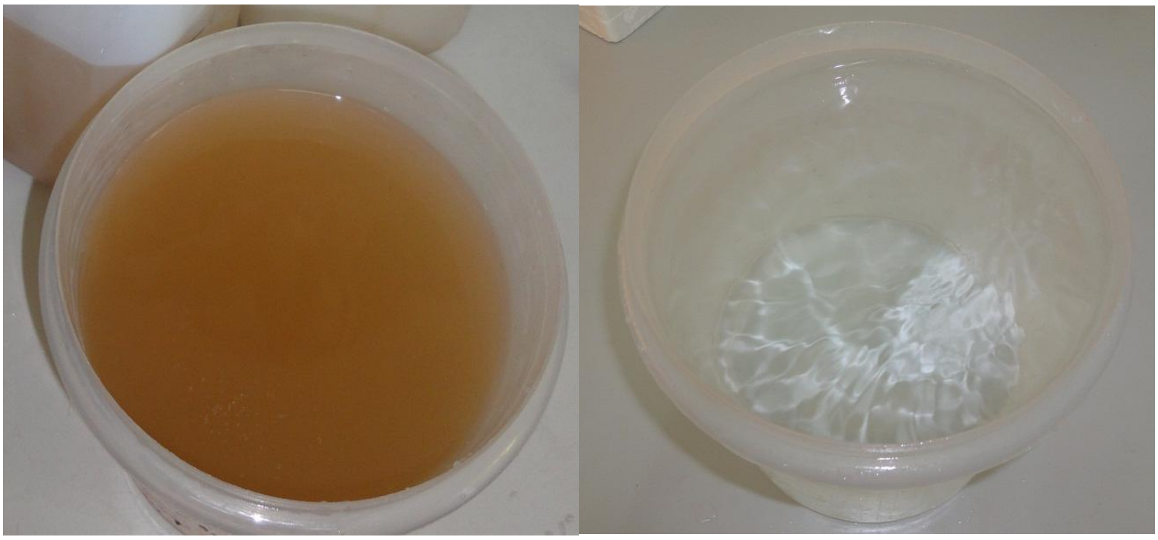

Image 1: Water sourced from a MSABI well - high in iron content - before and after filtration using a MSABI filter pot

It is recommended that the on-going capacity of MSABI filter pots to filter iron and manganese from source water be monitored.

4.0 Sand Filter Testing

In contrast to MSABI clay filter pot testing, a series of parallel tests were undertaken on a concept sand filter. Once it was established that the MSABI clay filter pots had the capacity to remove iron from source water, the sand filter tests were conducted in order to test if an equivalent percentage of iron could be removed at an increased flow rate

4.1.1 Sand Filter - Description

A simple model sand filter was developed using a 10 litre plastic receptacle.

Approximately 4 litres of fine sand was placed at the base of the receptacle, and a plastic tap was attached at the base, with gauze used to ensure only water would flow out. A plastic lid was placed over the top of the receptacle, with a number of holes punctured in it to ensure the source water, once poured in, would be exposed to oxygen.

4.1.2 Sand Filter – Method

A total of 18.5 litres of source water, high in iron content, was flushed through the content sand filter. Between 1 and 1.5 litres was passed through at a time. The iron content of the source water before filtration was recorded, and the iron content of the filtrate following filtration was also recorded.

4.1.3 Sand Filter – Test Results

The following figure demonstrates the effectiveness of the sand filter at progressively filtering iron from the source water.

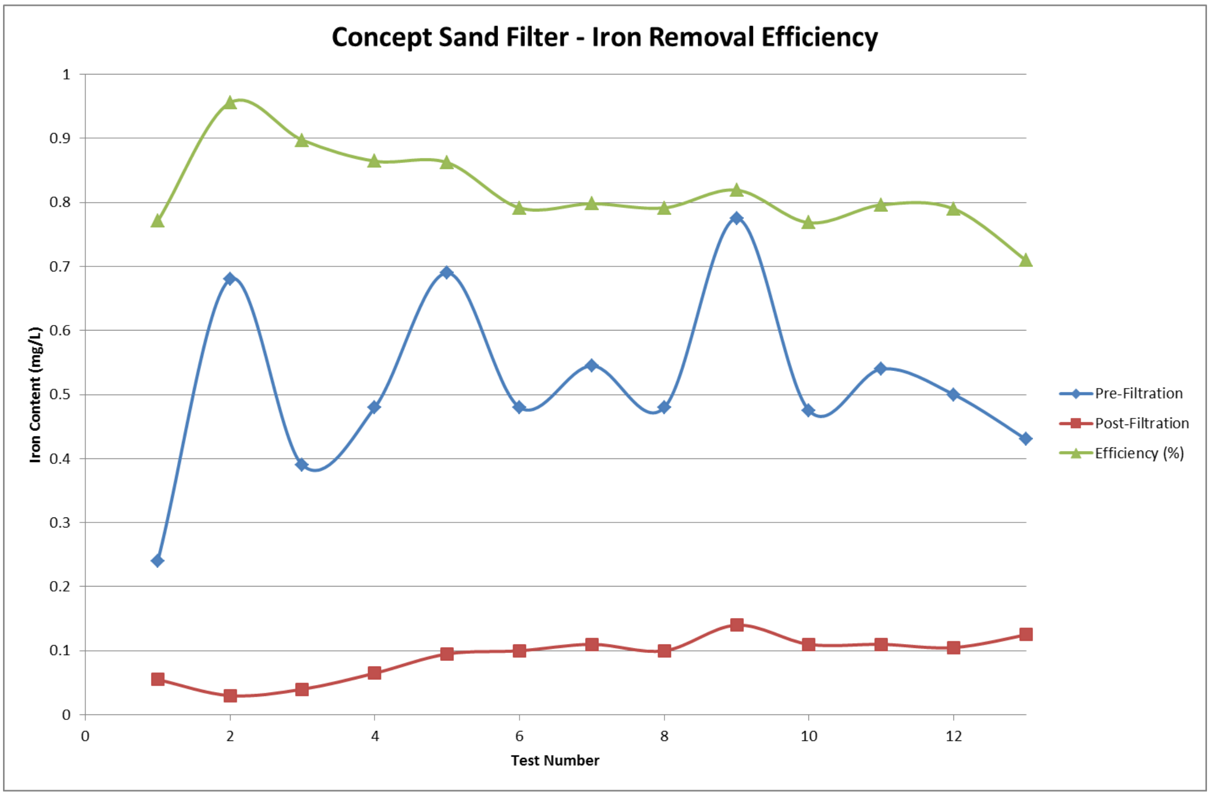

Figure 5: Sand filter iron removal efficiency

The results of the sand filter testing demonstrate that, over only a minimal test period, the capacity of the concept sand filter to effectively filter iron from the source water deteriorates over time.

Further testing is required to determine the exact extent and reason for the functional deterioration, but this initial research suggests that sand filters and equivalent basic technologies would be suitable only for the treatment of high iron content water only to a general water quality, and not to potable water quality.