Groundwater Pollution in Shallow Wells in Southern Malawi and a Potential Indigenous Method of Water Purification

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Abstract The provision of safe drinking water is a fundamental right of basic health and an extremely high priority of the Malawi Poverty Reduction Strategy. Only 40% of the people in Malawi have access to safe drinking water at any one time. Conventional water purification systems are prohibitively expensive for developing countries. The bulk of research work carried out in developing countries has concentrated on surface and borehole water quality with barely any work on monitoring water quality from shallow wells. The extent of pollution in shallow wells together with innovative, sustainable and economical solutions for rural villagers needs to be developed.

This research work has focused on establishing data on water quality from shallow wells in southern Malawi with the view to developing a technology that uses indigenous plant extracts to purify the groundwater. An in-situ water testing kit was used to determine the water quality. The majority of the physico-chemical parameters were found to be within the recommended limits; however, microbiological water quality results showed that the water can be grossly polluted with faecal matter and the likely presence of disease causing microorganisms. Preliminary laboratory tests on a powdered extract from the common indigenous plant *Moringa oleifera* are sufficiently encouraging for microbiological purification for further more detailed work to be planned.

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1 Introduction

About 1.1 billion people in the developing world are compelled to use contaminated water for drinking/cooking (UNICEF 2004). In Africa, over half of the population is without safe drinking water and over 6 million children are believed to die every year from water-related illnesses (DeGabriele 2002; Fernando 2005). In Malawi, this equates to roughly one in five children dying before they reach the age of five (UNICEF 2003). Malawi has been ranked the worst water manager in Southern Africa Development Community (SADC) by the World Water Council (Banda 2003). A large part of the sub-region of Malawi is characterised by small towns, villages and dispersed rural settlements. As a result, access to reticulated surface water resources has been limited because of the high costs and long distances that need to be covered in order to establish infrastructure for formal water services. As a result people use untreated groundwater from borehole/shallow wells, which pose a threat to their health.

Groundwater is the main source of water for about 60% of both rural and urban residents throughout Southern Africa, (UNEP 2002). About 63% of the people in Malawi use groundwater (Staines 2002). Groundwater is mainly supplied through boreholes or shallow wells. Boreholes are mechanically drilled holes between 20 and 80 m deep, with diameters ranging from 0.1 to 0.2 m. In comparison shallow wells have larger diameter holes (>1 m), which are either hand dug or drilled, with depths <15 m. There are typically two types of shallow wells, either open (unprotected) or covered (protected) as illustrated in Fig. 1. The main forms of contamination in boreholes normally emanate from chemical elements, whilst in shallow wells stem from bacteriological and physical constituents (Chilton and Smith-Crington 1984). The detrimental impact on human health of chemical contamination normally requires many decades of exposure before it can be recognised. Where life spans are short due to high incidence of infectious diseases (e.g. cholera) emanating from bacteriological contamination, it is this form of contamination

Fig. 1 Open (unprotected) and covered (protected) shallow wells in Malawi

that needs to be addressed first in groundwater purification techniques for Southern Africa, namely Malawi. The majority of research work carried out in developing countries has concentrated on surface and borehole water quality. This research work was undertaken to obtain data on the biological, physical and chemical water quality from shallow wells. The research work also conducted preliminary testing of the effectiveness of using powder extract from *Moringa oleifera* seeds as a water purifier.

2 Water Quality from Shallow Wells

2.1 Sampling/Monitoring

The research work was undertaken in three districts (Blantyre, Chiradzulu, and Mulanje) in the southern region of Malawi; collectively containing 350 shallow wells, where a large number of water-related diseases have been reported. The water quality from the shallow wells was monitored at selected times within a typical year to represent seasonal variations i.e. twice in the dry season and twice in the wet season, with the average seasonal value reported. Monitoring was undertaken using an in-situ water testing kit, which enabled microbiological, physical and chemical water quality of the wells water to be tested in line with the World Health Organisation (WHO) standards (2006), Malawi Bureau of standards (MBS) (1990, 2005) and Ministry of Water Development standards (MoWD) (2003).

The numbers of total and faecal coliforms were established using a membrane filtration technique carried out in-situ to ensure that the sample did not deteriorate with storage. Bacteria retained on the membranes were incubated at 37 °C and 44 °C for total and faecal coliforms respectively for a period of 24 h. Bacteria that were present produced visible colonies that were counted and converted to represent a count per 100 ml. Duplicate samples were taken for consistency during all testing stages. Test meters together with reagents were used to determine: turbidity, pH, temperature, total dissolved solids, electrical conductivity ammonia, arsenic, nitrite, nitrate, sulphate and hardness.

2.2 Results and Discussion

The water quality parameters obtained from the shallow wells were evaluated against the WHO (2006); MBS (1990, 2005); and MoWD (2003) guidelines to determine the amount and fluctuation in the level of contaminates between the dry and wet season. The standard acceptable guideline values are given at the top of Table 1 followed by the on-site microbiological and physical analyses for the three sampling districts in Malawi. In a similar format, the chemical standards are presented in Table 2 together with the chemical data for the wells. The mean of values obtained for both the dry and wet seasons are presented in the data tables.

Table 1 Microbiological and physical drinking water parameters obtained from shallow wells in Malawi

	Parameter	Microbiological: Total coliforms (per/100 ml)		Microbiological: Faecal coliforms (per/100 ml)		Physical: Turbidity (NTU)		Physical: TDS (mg/l)		Physical: Electrical (µS)		Physical: pH		Physical: Temperature (°C)	
	Season	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Standards values	WHO	0		0		5		1,000				6.5–8.5			
	MBS	0		0		5		1,000				6.5–8.5			
	MoWD	50		50		25		2,000		3,500		6.0–9.5			
Districts/Villages Blantyre	Cedric	161	545	2	164	0.47	0.00	273	229	455.0	382.0	7.08	7.02	31.2	147.5
	Chemusa	780	2,555	113	205	1.76	0.40	342	308	570.0	513.0	7.41	7.05	26.2	25.9
	Fred (1)	80	152	3	74	0.83	0.01	220	205	365.0	341.5	[b]	6.75	27.5	26.8
	Fred (2)	[a]	419	[a]	113	[a]	1.21	[a]	184	[a]	306.0	[a]	7.16	[a]	27.2
	Kumazale	[c]	1,420	[c]	320	8.45	5.14	237	218	394.5	363.0	8.81	6.83	26.0	27.1
	Kumponda	175	1,860	8	108	1.26	0.00	195	179	325.5	299.0	7.36	6.56	28.1	27.0
	Kumponda	1,4675	17,175	5,650	15,225	61.76	8.99	206	176	343.5	294.0	7.10	7.18	27.7	25.6
	Pasani	767	325	45	435	0.35	0.00	330	282	550.5	469.0	[b]	6.74	25.1	27.4
	Saili	80	1,350	10	435	0.51	0.74	203	183	339.0	305.5	[b]	7.20	25.3	26.1
Chiradzulu	Chelewani	212	[d]	37	854	0.96	3.01	114	111	190.7	184.9	6.44	6.43	24.2	23.4
	Chelewani	[a]	2,2850	[a]	818	[c]	26.36	[c]	113	[c]	188.6	[c]	6.42	[c]	22.3
	Makawa	4,350	2,165	250	373	2.13	0.00	132	125	219.5	207.5	6.65	6.47	25.3	24.6
	Mlandani	433	[d]	58	d	9.42	26.50	173	161	289.5	268.5	7.47	6.81	25.2	23.7
	Mtembo	1,970	864	30	603	2.87	14.38	172	71	286.5	117.8	7.31	6.69	24.3	25.0
	Mtembo	[a]	22,675	[a]	4,550	[a]	30.29	[a]	64	[a]	105.9	[a]	7.37	[a]	26.9
	Ng'omba	[c]	935	[c]	245	[c]	0.00	[c]	162	[c]	270.0	[c]	6.69	[c]	26.3
	Nlukla	708	5,070	237	823	2.03	19.32	112	109	188.7	181.0	6.56	6.83	24.4	24.1
	Nyasa	50	3,265	13	733	2.84	1.87	140	114	235.0	189.8	6.94	6.25	26.1	24.3

Mulanje	Chipoka	[c]	[c]	[c]	[c]	[c]	[c]	34	[c]	58.1	[c]	[c]	[c]	[c]	[c]
	Mulola	[e]	985	[e]	560	[e]	2.88	[e]	84	[e]	140.6	[e]	[b]	[e]	26.4
	Naluso	550	1,905	102	968	2.39	20.93	161	157	268.0	261.5	6.38	[b]	26.4	25.7
	Namaja	148	[d]	10	3,060	0.77	320.00	138	85	229.8	142.3	6.92	[b]	27.7	26.5
	Namazoma (1)	163	1,955	15	715	2.52	10.67	51	40	86.1	67.0	5.71	[b]	26.1	26.9
	Namazoma (2)	*11,590*	*12,450*	*1,630*	*350*	10.76	3.56	40	27	37.4	45.8	5.56	[b]	26.4	25.1
	Nande	[c]	[c]	[c]	[c]	[c]	[c]	40	[c]	66.1	[c]	[c]	[c]	[c]	[c]
	Nyimbiri	118	1,425	103	1,500	0.63	44.90	107	95	177.6	157.8	6.69	[b]	28.1	26.9

[a]Well was dry.
[b]Failure of equipment.
[c]Well has fallen into disrepair.
[d]Result was nullified (membrane was stuck to Petri dish).
[e]Unable to gain access to village well.
Italics indicate open/unprotected wells.
Grey shading indicates the wells which have failed to meet the MoWD (2003) standard.

Table 2 Chemical drinking water parameters obtained from shallow wells in Malawi

	Parameter	Chemical															
		Chlorine, Free (mg/l)		Chlorine, Total (mg/l)		Sulphate, SO_4 (mg/l)		Hardness $CaCO_3$ (mg/l)		Nitrate, N (mg/l)		Ammonia, N (mg/l)		Arsenic (mg/l)		Nitrite, NO_2 (mg/l)	
	Season	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Standards values	WHO			0.6–1.0		250		500		50		1.5		0.01		3	
	MBS					400		500		10				0.05			
	MoWD					800		800		100				0.05			
Districts/villages Blantyre	Cedric	0.01	0.09	0.01	0.09	1.5	4.0	115	170	0.01	0.01	0.02	0.01	≤0.003	≤0.003	0.02	0.00
	Chemusa	0.03	0.02	0.03	0.05	71.5	79.0	141	220	0.00	0.03	0.42	0.11	≤0.003	≤0.003	0.01	0.03
	Fred (1)	0.01	0.03	0.01	0.03	2.5	1.5	88	145	0.09	0.14	0.50	0.05	≤0.003	≤0.003	0.00	0.00
	Fred (2)	[a]	0.02	[a]	0.03	[a]	3.5	[a]	140	[a]	0.74	[a]	0.03	[a]	≤0.003	[a]	0.01
	Kumazale	0.03	0.01	0.03	0.02	5.5	4.0	105	143	0.00	1.92	0.19	0.02	≤0.003	≤0.003	0.00	0.01
	Kumponda	0.01	0.03	0.04	0.04	5.0	2.5	57	138	0.61	0.05	0.00	0.03	≤0.003	≤0.003	0.00	0.00
	Kumponda	0.14	0.00	0.18	0.00	8.0	0.0	75	120	0.07	0.16	0.21	0.09	≤0.003	≤0.003	0.06	0.01
	Pasani	0.01	0.02	0.01	0.02	8.5	18.5	170	210	0.00	0.06	0.00	0.20	≤0.003	≤0.003	0.00	0.01
	Saili	0.00	0.04	0.00	0.04	10.5	6.0	56	118	0.02	0.09	0.00	0.05	≤0.003	≤0.003	0.00	0.00

Chiradzulu	Chelewani	0.02	0.00	0.02	0.00	2.5	5.0	5	57	0.00	0.00	0.00	0.01	≤0.003	≤0.003	0.54	1.23
	Chelewani	[c]	0.12	[c]	0.15	[c]	7.5	[c]	40	[c]	0.01	[c]	0.51	≤0.003	≤0.003	[c]	0.02
	Makawa	0.00	0.01	0.00	0.01	7.5	6.5	39	50	0.00	0.00	0.00	0.01	≤0.003	≤0.003	0.00	0.02
	Mlandani	0.02	0.08	0.03	0.09	3.0	8.5	65	120	0.01	0.02	0.00	0.05	≤0.003	≤0.003	0.07	0.05
	Mtembo	0.02	0.03	0.03	0.03	1.5	8.0	61	30	0.02	0.01	0.02	0.01	≤0.003	≤0.003	0.15	[b]
	Mtembo	[a]	0.03	[a]	0.08	[a]	6.5	[a]	30	[a]	0.03	[a]	0.19	[a]	≤0.003	[a]	[b]
	Ng'omba	[c]	0.05	[c]	0.05	[c]	4.0	[c]	106	[c]	0.00	[c]	0.01	[c]	≤0.003	[c]	1.76
	Nlukla	0.01	0.09	0.01	0.10	4.0	11.0	22	64	0.00	0.01	0.00	0.03	≤0.003	≤0.003	2.45	2.00
	Nyasa	0.02	0.06	0.02	0.06	0.0	6.0	32	61	0.00	0.00	0.00	0.02	≤0.003	≤0.003	0.22	0.72
Mulanje	Chipoka	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]
	Mulola	[d]	0.07	[d]	0.07	[d]	2.5	[d]	63	[d]	0.00	[d]	0.03	≤0.003	≤0.003	[d]	0.18
	Naluso	0.02	0.12	0.03	0.12	2.5	0.0	[c]	200	0.00	0.00	0.01	0.05	≤0.003	≤0.003	1.45	1.68
	Namaja	0.01	0.51	0.02	0.57	2.0	5.5	23	200	0.00	0.01	0.00	0.09	≤0.003	≤0.003	0.00	0.39
	Namazoma (1)	0.02	0.04	0.02	0.05	1.5	0.0	0	46	0.00	0.00	0.02	0.02	≤0.003	≤0.003	1.39	0.98
	Namazoma (2)	0.05	0.06	0.05	0.06	3.0	5.0	0	14	0.00	0.00	0.00	0.03	≤0.003	≤0.003	1.12	1.19
	Nande	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]
	Nyimbiri	0.03	0.165	0.04	0.17	5.0	2.5	11	148	0.00	0.00	0.01	0.10	≤0.003	≤0.003	1.13	0.55

[a]Well was dry.
[b]Failure of equipment.
[c]Well has fallen into disrepair.
[d]Unable to gain access to village well.
Italics indicate open/unprotected wells.

In terms of total coliform, all wells tested in both the dry and wet seasons did not meet the temporary drinking water guidelines set by the MoWD (2003), of a maximum of 50 TC/100ml for untreated water. Approximately 45% of the wells failed to meet the faecal coliform drinking water guideline of 50 FC/100ml in the dry season while this figure had increased to 100% of the wells failing to meet the standard in the wet season. There was a prominent rise in the number of coliforms present in the wet season compared to the dry season. Such an increase can be expected as a result of the increase in the mobility of pollutants during the rains. There is a large variation between some wells, with some containing a very high level of faecal contamination – probably a result of livestock roaming free and poor sanitation facilities in close proximity to these wells. Water quality from open wells is considerably inferior to that of covered wells, and by far exceeds guideline values.

In terms of physical and chemical pollution, shallow well water does not pose any real potential health risk i.e. the majority of the physico-chemical parameters were within the recommended guideline values. However, 12.5% of water samples did not meet the MoWD (2003) minimum pH standard of 6.0 in the dry season. About 5% of the samples did not meet the MoWD (2003) standard value for turbidity in the dry season. In the wet season this figure had increased to 21% not meeting the turbidity standard value.

3 Water Purification

The government of Malawi through the Ministry of Water Development aims at ensuring that sufficient quantities and acceptable qualities of water is equitably accessible to every individual on a sustainable basis (Government of Malawi 2003). Attempts to overcome water quality problems have been undertaken but at an unaffordable cost by rural livelihoods. There is a vital need to develop sustainable cost effective technologies to remove biological contamination from shallow well water for rural people who live below the poverty line.

3.1 Plant Extracts

Natural plant extracts have been used for water purification for many centuries. For example, *Strychnos potatorum* was noted as being used as a clarifier between the 14th and 15th centuries BC; *Zea mays* was used as a settling agent by sailors in the 16th and 17th centuries. *Tigonella foenum; Cyamopsis psoraloides; Hibiscus sabdariffa; Lens esculenta*, have also been used, in history, to aid water purification (Schulz and Okun 1984). However, the science and civil engineering application of the use of plant extracts have not, really, been developed beyond its embryonic stage. This is largely due to the fact that money has been spent in developed countries, on more technologically advanced water purification processes.

One of the most promising plant extracts identified to date is the powder obtained from the seeds of the *Moringa oleifera* tree. In Sudan, rural women use dry *Moringa oleifera* seeds powder to treat highly turbid Nile water (Muyibi and Evison 1995). The University of Leicester in the UK has used the *Moringa oleifera* seeds within a contact flocculation filtration process for the treatment of low turbidity water. Sutherland et al. (1994) reported that the seeds have been effective in the removal of suspended solids in the order of 80–99.5% from surface waters containing medium to high initial turbidities.

3.2 *Moringa oleifera* as a Water Purifier – Preliminary Laboratory Trial

To assess the coagulant potential of the *Moringa oleifera* powder as a purifier for water from shallow wells to be used on a local level, a jar test was undertaken using different amounts of the powder, ranging from 0.1 to 20 g/l. A series of 11 beakers containing the contaminated water was first placed on the flocculator; the mixing paddles were inserted and at a slow speed (20 revs/min) the selected amount of the powder was added to the beaker. The samples were then stirred at 250 revs/min (high speed) for 1 min to ensure complete dispersion after which the speed of the mixing paddles was reduced to 20 revs/min for 15 min as recommended by Peavy et al. (1985) to aid in the formation of flocs. The flocculator was then switched off and samples were allowed to settle for 15 min to simulate the settling time at a treatment plant. This was undertaken to allow optimum conditions to be established. Each sample was then filtered through double 'Whatman #4' filter papers and the remaining 'purified' water was sent to a commercial testing laboratory for analysis.

It can be seen from Table 3 that approximately a 50–100% improvement was obtained in terms of the elimination of total coliforms. A 100% improvement was obtained in terms of E. coli at all concentrations. Colour appears to be readily removed and to some extent turbidity. The optimum dose appears relatively low – in the region of 1 g/l. Although the situation is not entirely clear there is certainly sufficient data for further more detailed work to establish the optimum dose and any link with factors such as pH.

4 Conclusions and Recommendations

The study showed that shallow wells yield water of unacceptable microbiological quality and that the situation is significantly worse in the wet season; almost certainly due to the mobility of this type of pollutant increasing. The physical and chemical parameters were, in general, within standard values and did not fluctuate significantly with season.

Table 3 Raw water quality and the change in quality with *Moringa oleifera* powder

Sample reference	Total coliforms per 100 ml	*E.Coli* per 100 ml	Colonies 2 days 37 °C No/ml	Colonies 3 days 22 °C No/ml	pH	Conductivity 20 °C (μS/cm)	Turbidity (FTU)	Colour (Hazen)
Raw water	9	9	28	40	5.9	79	5.84	130
Moringa oleifera 1.0 g/l	0	0	3	4	5	95	2.25	17.2
Moringa oleifera 2.5 g/l	1	0	1	3	4.5	168	4.61	12.8
Moringa oleifera 5.0 g/l	5	0	15	16	4.3	219	16.6	11.4
Moringa oleifera 10.0 g/l	4	0	2	3	4.1	369	46.8	14.1
Moringa oleifera 15.0 g/l	5	0	6	2	3.9	463	75.2	17
Moringa oleifera 20.0 g/l	4	0	7	6	3.8	557	167	18.6

The study also showed that *Moringa oleifera* powder can significantly reduce the number of both total and faecal coliforms, turbidity and colour for certain contaminated waters. As coliforms are indicators of faecal contamination and hence disease causing bacteria, such as *Vibrio choleri* which causes cholera; any capability for their removal from drinking water should significantly contribute to an improvement in public health.

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