BIOLOGICAL, CHEMICAL, AND PHYSICAL DRINKING WATER QUALITY FROM SHALLOW WELLS IN MALAWI; CASE STUDY OF BLANTYRE, CHIRADZULU, AND MULANJE DISTRICTS

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ABSTRACT

A study was conducted in Blantyre, Chiradzulu and Mulanje districts in Malawi to determine the biological, chemical and physical drinking water quality from shallow wells. An in-situ membrane filtration test kit (Paqualab 50) was used to determine the microbiological quality of water and a photometer was used for the chemical analyses. Water samples were collected from twenty one covered/protected and five open/unprotected shallow wells at four different times in a year to determine the change in quality with different seasons. The results of microbiological analysis show that the drinking water quality is very poor, i.e. grossly polluted with faecal matter. Total coliform (TC) and faecal coliform (FC) values in the wet season (February and April) were much higher than those in the dry season (August and October). In terms of total coliform, the results show that approximately 80% of the shallow wells tested in the dry season and 100% of the wells in the wet season did not meet the drinking water temporary guidelines, set by the Ministry of Water Development (MoWD), of a maximum of 50 TC/100ml for untreated water. Approximately 50% 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 94% of the wells failing to meet the standard in the wet season. Covered wells were not as grossly contaminated as open wells but all of the wells tested failed the MoWD standards in at least one sample. Chemical analyses results were within the drinking water guideline and variations during seasons were insignificant. pH values were within the guidelines in the dry season except for Mulanje district where on average 45% of the wells had pH values below the lower limit of 6.0. In the wet season 50% of the samples had pH values below 6.0. Turbidity values were within the guideline for all covered wells in the dry season, while about 22% had turbidity values greater than the guideline of 25 NTU in the wet season. From these results it is very clear to see that the drinking water from the shallow wells tested, in southern districts of Malawi, is grossly contaminated microbiologically, with this contamination becoming worse in the wet season.

Keywords: groundwater, Malawi, shallow well, water quality.

1. INTRODUCTION

Supply of potable water is important to the development of any country. Clean water sustains a healthy population and it contributes to the quality of life of households through the provision of basic needs of water and sanitation. It is reported that 80% of all illness in developing countries is related to water and sanitation (Tebbutt, 1998). Potable water supports public health and ensures economic growth. Water of poor quality can cause social and economic damages through water-related epidemics such as cholera which in turn increases medical treatment costs.

According to the Ministry of Health, about 80% of school going children in Malawi lack clean and safe drinking water leaving many of them infected with or dying of diarrhoea from water borne diseases (Nkawihe, 2006). It was further reported that 3,000 children were infected with diarrhoea in 2005 and 1,000 of them died. Nkawihe also reported that 43 % of the population obtains water from wells, streams and other unreliable water sources leaving them prone to water-related diseases including cholera. In Malawi, nearly 50% of all illness is related to water borne diseases (Kaluwa & Chipeta, 2005). It is estimated that only 65% of the country's population (about 12 million) has access to safe water (85% urban and 45% rural), however recent studies on the district water supplies indicate that 40% of the facilities have fallen into disrepair (Mandowa, 2005).

The vision of Malawi's new water policy is "water and sanitation for all, always" and seeks to provide every Malawian with "equitable" access to water and sanitation services for sustainable socio-economic development of the country (Anon, 2004). This is in line with the Millennium Development Goals (MDG's) and the World Summit on Sustainable Development (WSSD) targets of 2002 to strive to halve the population of people without access to water and sanitation by 2015. This is a big challenge for Malawi due to the country's economic problems where over 60% of the people live below the poverty line.

Potable water is one that is free from disease causing microorganisms (pathogens), low in concentrations of compounds that are acutely toxic or that have serious long term effects on health. Potable water should also be clear, not saline, and free from compounds that can cause colour, taste and odour. The conventional way of extracting drinking water from the ground is by drilling boreholes and shallow wells through the existing water table to form a well point. In certain regions of Southern Africa, as the water percolates through the soil, harmful physical, biological and chemical constituents (e.g. fine suspended matter, faecal coliform and fluoride) become contained in the water making it unsuitable for human consumption.

The main sources of water for rural communities are boreholes, covered/protected and open/unprotected shallow wells, gravity-fed piped systems, springs and lakes and rivers. Boreholes are small diameter (approx. 0.1 to 0.2m) mechanically drilled holes, with depths ranging from 20 to 80m. In comparison, shallow wells have larger diameter holes (≥1m), which are either hand dug or drilled, with depths not normally exceeding 15m. According to Staines (2002), 2.6 million (37%) of Malawians have access to boreholes as their main source of drinking water, 2.5 million (26%) draw their water from shallow wells, 2.1 million (21%) use either piped water or communal standpipes and the remaining 1.6 million (16%) use other water sources such as rivers, and lakes.

1.1 Aim of the study

The majority of research work undertaken on water in developing countries has focussed on surface and borehole water quality with hardly any work being undertaken on shallow wells. Shallow wells are one of the most important types of water supplies for domestic purposes for rural districts in Malawi. This research work was undertaken to develop a data-base on water quality from shallow wells. This study investigated biological, chemical and physical shallow well water quality. It compared the difference in water quality between the dry and wet season.

2. METHODOLOGY

2.1 Area/timescale of the study

The study was conducted in three districts in the southern region of Malawi namely; Blantyre, Chiradzulu, and Mulanje. These districts were chosen for the study as a result of poor drinking water quality i.e. a large number of water-related diseases (e.g. cholera) have been reported (e.g. Michael-Phiri, 2003, Nkawihe, 2006). Blantyre is the largest commercial city and has a population of about 1 million people with the rural population in the region of 358,940. Chiradzulu has a total population of 282,158 while Mulanje has a population of 522,893 (Anon, 2002). These districts receive an average rainfall ranging from 700 to about 1,300 mm annually (Nkhokwe, 2005). This rainfall occurs from October or November and continues until April. The heaviest rains are experienced from December to March. To account for this seasonal variation in the rainfall pattern, water samples were obtained and analysed from the same shallow wells at four different times within a period of a year; two different batches of samples were taken in both the dry season (August and October) and wet season (February and April). This allowed a data-base of 26 shallow wells to be established on the change in water quality, in the selected districts during the changing of the seasons within a typical year. Visits to the water points were made in liaison with Water Officials from the Ministry of Irrigation and Water Development and Regional Water Boards.

2.2 Test Equipment/Sampling Method

An in-situ water quality testing kit 'Paqualab 50' was used to determine microbiological, chemical and physical contamination of the water from shallow wells. This test kit enabled water quality to be tested in line with the World Health

Organisation (WHO) standards and Malawi Bureau of Standards (MBS). Sterile conditions were obtained prior to sampling by using an autoclave steamer and during sampling by using flaming techniques around water exit points. Sample bottles were either rinsed three times with source water before collecting the sample or rinsed with 70% methanol to minimise the risk of external contamination. For covered wells, the water outlet was flame sterilised using tissue paper soaked in 70% methanol for 20–30 seconds. Water was pumped out to waste for 30-60 seconds to discharge water that had stood for a period in the service pipe if not found in use. The sample bottle was then rinsed and the sample drawn. For the open wells, the sample bottle was held by a bottle holder then plunged into the well to a depth of 0.3m below the water level to draw the sample. Microbiological analysis was carried out in-situ so that the microbiological parameters would not change with time. Water samples were collected for physico-chemical analyses in the laboratory.

2.2.1 Microbiological analyses

The numbers of total and faecal coliforms were determined using membrane filtration technique. A measured volume of water (as guided by WHO, 1993) was filtered through a membrane. Bacteria were retained on the membrane and incubated, after a recover period of one hour, at 37^{o}C and 44^{o}C for total and faecal coliforms respectively for 24 hours. If present, bacteria grew into visible colonies that were counted manually. Each test was duplicated for consistency and the results were converted to represent a count per 100ml. To ensure sterile conditions, Petri dishes, medium and forceps were autoclaved. After each sample collection, the filtration unit was flame sterilised using 70% methanol.

2.2.2 Physico-chemical analyses

Data for turbidity, pH, temperature, total dissolved solids and electrical conductivity were obtained by using the appropriate test meters from the Paqualab 50. For the chemical analyses, water samples were collected in dark sample bottles and upon return to the laboratory, reagents together with a photometer were used to determine the amount of ammonia, arsenic, nitrite, nitrate, sulphate, hardness and chlorine.

3. RESULTS

The water quality analysis parameters were compared to the WHO, MBS and MoWD temporary guidelines to ascertain if the quality of the water were in accordance with appropriate drinking water standards. The standards are given in Table 3.2 followed by the on-site microbiological analysis in Table 3.3. Prior to this in Tables 3.1a, 3.1b and 3.1c a description of the condition and status of the wells is given for the Blantyre, Chiradzu and Mulanje wells respectively. Chemical standards are given in Table 3.4 followed by tables containing the data for the wells again separated into the three districts in Tables 3.5 – 3.7. The physical data follows the same pattern with the standards in Table 3.8 followed by Tables 3.9 – 3.11. The mean of two results are shown in the data tables.

4. DISCUSSION OF RESULTS

4.1 Microbiological Water Quality

Microbiological water quality results show that the water is grossly polluted with faecal matter. In terms of total coliform, the results show that approximately 80% of the shallow wells tested in the dry season and 100% of the wells in the wet season did not meet the temporary drinking water guidelines set by the MoWD, of a maximum of 50 TC/100ml for untreated water. Approximately 50% 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 94% of the wells failing to meet the standard in the wet season. All the wells fail to meet the standard in at least one of the four samples. There was a noticeable increase in the number of coliform counts in the wet season compared to the dry season. This increase could be attributed to the fact that pollutants are easily transported to water points by rain water. There appears to be a lot of variation between the wells with some containing a very high level of faecal contamination. The open wells appear generally worse than the covered wells, but even the least polluted is clearly in excess of the MoWD temporary standard.

4.2 Physico-Chemical Water Quality

The majority of the physico-chemical parameters were found to be within the recommended limits for the WHO, MBS, and MoWD. Parameters that were found to be slightly out of the range were pH and turbidity. That is 45% of water samples from Mulanje did not meet the MoWD minimum pH standard of 6.0 in the dry season, while about 50% of water samples did not meet the minimum standard in the wet season. pH values of less than 6.0 indicate that water is acidic. This could be attributed to tea that is grown in Mulanje district. Blantyre and Chiradzulu had pH values within the recommended range. Acidic water can cause corrosion of construction materials that are used in wells e.g. casing and screens (Lakudzala and Mukhuwa, 2005).

Turbidity values were higher in the wet season than in the dry season for protected shallow wells. Almost 100% met the MoWD standard in the dry season. In the wet season, about 22% of the wells did not meet the MoWD standard. These results are comparable with other published data (e.g. Palamuleni, 2001), in that turbidity is always higher in the wet season than the dry season. The impact of turbidity is that the colloidal particles which cause turbidity can harbour pathogenic microorganisms thereby making disinfection ineffective. Turbidity also makes the water aesthetically unacceptable.

The recommended temperature for drinking water is 25^{o}C according to UK standards (Tebutt, 1998). There is no guideline value set by WHO, MBS and MoWD. High temperature enhances microbial activity and other chemical reactions. For the samples analysed, 90% had temperatures greater than 25^{o}C in Blantyre, 31% in Chiradzulu and 84% in Mulanje. The difference in temperature with season was not noticeable.

Although hardness values were within the set guideline values, they were higher in the wet season than in the dry season. This could be due to dissolution of chemicals in water. The impacts of hardness are scale deposition and high soap consumption.

Both the total dissolved solids (TDS) and electrical conductivity results were below the guideline values. However, TDS values were slightly higher in the dry season than in the wet season. Electrical conductivity values were also slightly higher in the dry season compared to the wet season. This could be attributed to the dilution effect of these types of pollutant in the wet season.

5. 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. However, in general the physical and chemical parameters did not change significantly with season. Certain parameters such as pH and turbidity are worse in the wet season; however other parameters such as TDS and electrical conductivity actually improve in the wet season, probably as a result of dilution. The study also highlighted the fact that a number of wells dry up during the dry season, which in turn forces people to use open water sources such as rivers. These alternative water sources are normally more grossly contaminated. Another fact highlighted in the study is that a number of the shallow wells serve more people than is required by the MoWD standard of 250 per borehole/shallow well (Mandowa, 2005). About 30% of shallow wells in Blantyre and Chiradzulu serve more than 250 people, this is worse in Mulanje where 75% of the shallow wells serve more than 250 people.

The water pollution control regulations in the Water Resources Act stipulate that water points be 100m upstream of sanitation facilities (e.g. pit latrines) (Lakudzala and Mukhuwa, 2005). Some shallow wells in the study were located less than 100m (1 in 4 were within 40m distance) from pit latrines and waste dumps. There is a need for the government to enforce standard construction procedures in order to minimise pollution of water sources. Unsewered sanitation can cause groundwater contamination by chlorides, nitrates and pathogenic microorganisms. Ndolo *et al* (2002) noted that the provision of water, sanitation and good hygiene is vital for the protection and development of human resources. The provision of water supply alone does not guarantee freedom from pollution and water-related diseases.

The present form of construction and method of water extraction for shallow wells is insufficient to yield potable water for rural communities. However, conventional water treatment technologies e.g. disinfection of water using chlorine are unaffordable/unsustainable for rural livelihoods. Therefore there is a vital need to develop sustainable cost effective technologies to treat groundwater for rural communities.

The authors of this paper are working on the development of an innovative, sustainable and economical process that utilises natural extracts from indigenous plants/crops in the form of a filter geotextile to purify the groundwater from shallow wells.

ACKNOWLEDGEMENTS

Thank you to WARFSA, Leeds Metropolitan University and the Malawi Polytechnic for their financial support.

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Table 3.1a Summary of the Condition/Status of Wells in Blantyre

	Village	Type of pump	Depth to pump (m)	Constructed/ Rehabilitated	Approx. population served	Condition of well & surrounding area
Blantyre	**Kasupe**	Open well	0.2	1997	400	Houses/toilets within 5m - Pit latrines & flush toilet systems - Dirty surrounding - Water logged area
	Saili	MADA	3.5	1994/2001	150	Surrounding with sugarcane and bananas grown within 2m, pump hard to operate (gasket problem), well constructed at an upland (hill)
	Fred(2)	MADA	8.0	2003	110	Lined with rocks, well gets dry in the dry season.
	Fred(1)	MADA	8.0	1970/2001	120	Water logged apron, animals (goats) seen loitering around.
	Kumazale	Elephant	4.0	2001/2004	200	Loose plastic outlet pipe with grass sticks for support, dirty surrounding. Has loose removable lid at the top.
	Pasani	MADA	3.3	1998	30	Surrounded by reeds and vegetables (within 3m).
	Cedric	MADA	3.3	1998	400	Close to a stream (within 5m) apron kept clean.
	Kumponda(1)	MADA	4.5	1998	120	Well runs dry in the dry season, open well within 3m, surrounded by mango, banana trees and vegetables.
	Kumponda(2)	Open well	1.5	-	-	Greyish colour, floating grass, reeds and mango leaves seen.

Table 3.1b Summary of the Condition/Status of Wells in Chiradzulu

	Village	Type of pump	Depth to pump (m)	Constructed/ Rehabilitated	Approx. population served	Condition of well & surrounding area
Chiradzulu	**Mlandani**	Elephant	9.0	2005	200	Dirty surrounding (with sugarcane wastes). Loose lid at the top which is opened sometimes for maintenance.
	Nlukla	Elephant	6.0	2004	700	Surrounding swept daily. Houses within 30-40m. Sugarcane, mangoes within 2m.
	Chelewani(1)	MADA	4.0	1998/2003	100	Dirty surrounding, houses within 90m upstream, surrounded by gardens (maize, peas, etc). Open well 3-4m downstream.
	Chelewani(2)	Open well	1.0	-	0	Water for gardening only. Well covered with green seed-like plants in the wet season. Well gets dry in the dry season.
	Nyasa	Afridev	7.5	2004	300	Water logged apron with moulds, surrounding very dirty with grass and other solid waste. Houses/shops within 10m.
	Makawa	Afridev	7.0	1970/2004	200	Cracks around pump, surrounded by banana plants and vegetables.
	Ng'omba	MADA	6.0	1999	500	Near a stream (5m) with reeds, bananas, and mango trees in the vicinity. Cracks on the slab. Houses about 100m upstream.
	Mtembo	Elephant	8.0	2004	100	Water with tiny black spots. Water dries up in the dry season. Open well within 5m.
	Mtembo	Open well	4.0	-	0	Water used for washing and gardening.

Table 3.1c Summary of the Condition/Status of Wells in Mulanje

	Village	Type of pump	Depth to pump (m)	Constructed/ Rehabilitated	Approx. population served	Condition of well & surrounding area
Mulanje	**Namaja**	Afridev	5.9	2004	550	Close to a sugarcane garden (from 3m). houses within 75m upstream.
	Naluso	Afridev	6.0	2003	660	Houses/toilets within 50m upstream. Surrounding was dirty.
	Nande	Afridev	4.0	2003	300	Surrounding with banana leaves, sugarcane and tree leaves (dirty). Surrounding stones with moulds. House and pit latrine built within 7m.
	Nyimbiri	Afridev	6.0	2003	500	Dirty surrounding. Near a stream (within 10-15m).
	Namazoma(1)	Afridev	4.6	2003	300	Clean surrounding (swept daily). Near a stream (about 20m).
	Namazoma(2)	Open well	1.0	1950	200	For all domestic uses. Never runs dry. Houses 100m upstream.
	Chipoka	Afridev	6.0	2003	250	Dirty surrounding. Surrounded by cassava, mango and banana plantations.
	Mulola	Afridev	6.5	2003	300	Near a gmelina tree. Well fenced with wooden poles.

Table 3.2 Standard Microbiological Drinking Water Values

Parameters	Total Coliforms per 100ml	Faecal Coliforms per 100ml
WHO	0	0
MBS	0	0
MoWD	50	50

Table 3.3 Microbiological Drinking Water Data for Districts/Villages in Malawi

Districts/Villages	Parameter	Total Coliforms per 100ml				Faecal Coliforms per 100ml			
	Season	Dry		Wet		Dry		Wet	
	Month	Aug	Oct	Feb	Apr	Aug	Oct	Feb	Apr
Blantyre	**Cedric**	80	241	299	790	2	2	94	233
	Chemusa	*170*	*1390*	*4240*	*870*	*170*	*55*	*310*	*100*
	Fred (1)	16	143	85	218	0	5	58	90
	Fred (2)	0	-	233	605	0	-	128	98
	Kumazale	2	5625*	2340	500	290	4775*	610	30
	Kumponda	20	330	1900	1820	10	5	95	120
	Kumponda	*3350*	*26000*	*23950*	*10400*	*2600*	*8700*	*28450*	*2000*
	Pasani	120	1413	400	250	4	85	40	830
	Saili	36	124	1600	1100	4	16	800	70
Chiradzulu	**Chelewani**	10	413	#	1685	0	73	1218	490
	Chelewani*	-	*#*	*20900*	*24800*	-	*29600*	*435*	*1200*
	Makawa	820	7880	2180	2150	40	460	435	310
	Mlandani	165	700	#	3660	15	100	#	470
	Mtembo	1000	2940	852	875	0	60	820	385
	Mtembo	-	-	*38800*	*6550*	-	-	*7350*	*1750*
	Ng'omba	60	*	870	1000	190	*	330	160
	Nlukla	65	1350	4320	5820	35	438	1015	630
	Nyasa	0	100	2040	4490	0	25	1120	345
Mulanje	**Chipoka**	1940	*	*	*	0	*	*	*
	Mulola	--	275	1435	535	--	0	1025	95
	Naluso	50	1050	2720	1090	70	133	1920	15
	Namaja	95	200	#	6850	15	5	4020	2100
	Namazoma (1)	225	100	3050	860	20	10	1190	240
	Namazoma (2)	*19280*	*3900*	*22000*	*2900*	*160*	*3100*	*300*	*400*
	Nande	5700	*	*	*	200	*	*	*
	Nyimbiri	5	230	2210	640	0	206	2580	420

- well was dry
--unable to gain access to village well
* well has fallen into disrepair
# result was nullified (membrane was stuck to Petri dish)
Italics indicate open/unprotected wells - all other wells are covered/protected

Table 3.4 Standard Chemical Drinking Water Values

	Parameter	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)
Standards	WHO	˜	0.6-1.0	250	1.5	50	1.5	0.01	3
	MBS	˜	˜	400	2	10	˜	0.05	˜
	MoWD	˜	˜	800	3	100	˜	0.05	˜

~ no guideline value set

Table 3.5a Chemical Drinking Water Data for Wells in Blantyre

	Parameter	Chlorine (Free) (mg/l)				Chlorine (Total) (mg/l)				Sulphate SO_4 (mg/l)				Hardness $CaCO_3$ (mg/l)			
	Season	Dry		Wet		Dry		Wet		Dry		Wet		Dry		Wet	
	Month	Aug	Oct	Feb	Apr	Aug	Oct	Feb	Apr	Aug	Oct	Feb	Apr	Aug	Oct	Feb	Apr
Villages	Cedric	0.00	0.02	0.16	0.01	0.00	0.02	0.16	0.01	3	0	3	5	122	108	145	195
	Chemusa	*0.02*	*0.04*	*0.02*	*0.02*	*0.02*	*0.04*	*0.04*	*0.05*	*83*	*60*	*81*	*77*	*145*	*137*	*115*	*325*
	Fred(1)	0.00	0.01	0.01	0.05	0.00	0.01	0.01	0.05	5	0	3	0	85	90	95	195
	Fred(2)	0.00	-	0.01	0.02	0.00	-	0.01	0.04	10	-	0	7	47	-	115	165
	Kumazale	0.00	0.05	0.00	0.02	0.00	0.05	0.01	0.02	3	8	5	3	115	95	90	195
	Kumponda(1)	0.00	0.02	0.00	0.06	0.01	0.06	0.01	0.07	5	5	5	0	75	38	80	195
	Kumponda(2)	*0.22*	*0.06*	*0.00*	*0.00*	*0.24*	*0.11*	*0.00*	*0.00*	*8*	*8*	*0*	*0*	*85*	*65*	*85*	*155*
	Pasani	0.00	0.02	0.00	0.04	0.00	0.02	0.00	0.04	17	0	37	0	130	210	235	185
	Saili	0.00	0.00	0.01	0.06	0.00	0.00	0.01	0.06	8	13	12	0	56	56	70	165

Table 3.5b Chemical Drinking Water Data for Wells in Blantyre

	Parameter	Nitrate N (mg/l)				Ammonia N (mg/l)				Arsenic (µg/l)				Nitrite NO_2 (mg/l)			
	Season	Dry		Wet		Dry		Wet		Dry		Wet		Dry		Wet	
	Month	Aug	Oct	Feb	Apr	Aug	Oct	Feb	Apr	Aug	Oct	Feb	Apr	Aug	Oct	Feb	Apr
Villages	Cedric	0.000	0.012	0.003	0.021	0.03	0.00	0.00	0.02	≤3	≤3	≤3	≤3	0.001	0.032	0.004	0.000
	Chemusa	*0.000*	*0.000*	*0.000*	*0.055*	*0.83*	*0.00*	*0.10*	*0.12*	*≤3*	*≤3*	*≤3*	*≤3*	*0.012*	*0.000*	*0.004*	*0.055*
	Fred(1)	0.070	0.100	0.140	0.140	1.00	0.00	0.00	0.10	≤3	≤3	≤3	≤3	0.000	0.000	0.000	0.007
	Fred(2)	0.430	-	0.580	0.900	0.00	-	0.00	0.05	≤3	-	≤3	≤3	0.006	-	0.004	0.007
	Kumazale	0.000	0.000	3.200	0.640	0.00	0.38	0.00	0.04	≤3	≤3	≤3	≤3	0.004	0.000	0.011	0.007
	Kumponda(1)	0.900	0.310	0.072	0.036	0.00	0.00	0.00	0.05	≤3	≤3	≤3	≤3	0.000	0.006	0.001	0.001
	Kumponda(2)	*0.000*	*0.130*	*0.320*	*0.006*	*0.08*	*0.33*	*0.16*	*0.02*	*≤3*	*≤3*	*≤3*	*≤3*	*0.004*	*0.108*	*0.012*	*0.003*
	Pasani	0.000	0.009	0.059	0.063	0.00	0.00	0.37	0.02	≤3	≤3	≤3	≤3	0.000	0.000	0.012	0.000
	Saili	0.040	0.000	0.059	0.120	0.00	0.00	0.00	0.10	≤3	≤3	≤3	≤3	0.003	0.000	0.001	0.004

Table 3.6a Chemical Drinking Water Data for Wells in Chiradzulu

	Parameter	Chlorine (Free) (mg/l)				Chlorine (Total) (mg/l)				Sulphate SO_4 (mg/l)				Hardness $CaCO_3$ (mg/l)			
	Season	Dry		Wet		Dry		Wet		Dry		Wet		Dry		Wet	
	Month	Aug	Oct	Feb	Apr	Aug	Oct	Feb	Apr	Aug	Oct	Feb	Apr	Aug	Oct	Feb	Apr
Villages	Chelewani(1)	0.00	0.04	0.00	0.00	0.00	0.04	0.00	0.00	0	5	5	5	6	3	34	80
	Chelewani(2)	*	*0.14*	*0.05*	*0.18*	*	*0.15*	*0.12*	*0.18*	*	*113*	*15*	*0*	*	*65*	*14*	*65*
	Makawa	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	7	8	5	8	52	26	10	90
	Mlandani	0.02	0.02	0.11	0.04	0.04	0.02	0.14	0.04	3	3	17	0	60	70	75	165
	Mtembo	0.00	0.04	0.02	0.04	0.01	0.05	0.02	0.04	0	3	9	7	65	56	3	56
	Mtembo	-	-	*0.06*	*0.00*	-	-	*0.15*	*0.00*	-	-	*8*	*5*	-	-	*3*	*56*
	Ng'omba	0.00	*	0.10	0.00	0.05	*	0.10	0.00	9	*	5	3	34	*	56	155
	Nlukla	0.01	0.00	0.14	0.04	0.01	0.00	0.14	0.05	3	5	19	3	22	22	42	85
	Nyasa	0.01	0.02	0.05	0.06	0.01	0.02	0.05	0.06	0	0	7	5	42	22	14	108

Table 3.6b Chemical Drinking Water Data for Wells in Chiradzulu

	Parameter	Nitrite N (mg/l)				Ammonia N (mg/l)				Arsenic (µg/l)				Nitrate NO_2 (mg/l)			
	Season	Dry		Wet		Dry		Wet		Dry		Wet		Dry		Wet	
	Month	Aug	Oct	Feb	Apr	Aug	Oct	Feb	Apr	Aug	Oct	Feb	Apr	Aug	Oct	Feb	Apr
Villages	Chelewani(1)	0.000	0.001	0.003	0.001	0.00	0.00	0.00	0.02	≤3	≤3	≤3	≤3	0.94	0.13	1.36	1.10
	Chelewani(2)	*	*0.155*	*0.018*	*0.004*	*	*1.00*	*0.34*	*0.68*	*	*≤3*	*≤3*	*≤3*	*	*0.85*	*0.00*	*0.04*
	Makawa	0.003	0.000	0.000	0.000	0.00	0.00	0.00	0.02	≤3	≤3	≤3	≤3	0.00	0.00	0.00	0.04
	Mlandani	0.010	0.019	0.027	0.004	0.00	0.00	0.01	0.08	≤3	≤3	≤3	≤3	0.03	0.11	0.07	0.03
	Mtembo	0.030	0.003	0.004	0.006	0.03	0.00	0.00	0.01	≤3	≤3	≤3	≤3	0.13	0.16	3.80	+
	Mtembo	-	-	*0.069*	*0.000*	-	-	*0.34*	*0.03*	-	-	*≤3*	*≤3*	-	-	*1.38*	+
	Ng'omba	0.000	*	0.004	0.001	0.00	*	0.00	0.02	≤3	*	≤3	≤3	1.18	*	2.00	1.52
	Nlukla	0.000	0.006	0.021	0.003	0.00	0.00	0.00	0.05	≤3	≤3	≤3	≤3	4.00	0.90	2.00	2.00
	Nyasa	0.000	0.000	0.004	0.003	0.00	0.00	0.00	0.03	≤3	≤3	≤3	≤3	0.26	0.18	0.64	0.80

Table 3.7a Chemical Drinking Water Data for Wells in Mulanje

	Parameter	Chlorine (Free) (mg/l)				Chlorine (Total) (mg/l)				Sulphate SO_4 (mg/l)				Hardness $CaCO_3$ (mg/l)			
	Season	Dry		Wet		Dry		Wet		Dry		Wet		Dry		Wet	
	Month	Aug	Oct	Feb	Apr	Aug	Oct	Feb	Apr	Aug	Oct	Feb	Apr	Aug	Oct	Feb	Apr
Villages	Chipoka	0.02	*	*	*	0.02	*	*	*	5	*	*	*	0	*	*	*
	Mulola	--	0.00	0.07	0.06	--	0.00	0.07	0.06	--	3	0	5	--	56	60	65
	Naluso	0.02	0.02	0.21	0.02	0.03	0.02	0.21	0.02	5	0	0	0	47	*	235	165
	Namaja	0.01	0.00	0.96	0.05	0.02	0.01	1.00	0.14	4	0	8	3	42	3	325	75
	Namazoma	0.03	0.00	0.05	0.02	0.04	0.00	0.07	0.02	3	0	0	0	0	0	70	22
	Namazoma	*0.04*	*0.05*	*0.06*	*0.05*	*0.04*	*0.05*	*0.06*	*0.05*	*6*	*0*	*5*	*5*	*0*	*0*	*14*	*14*
	Nande	0.04	*	*	*	0.05	*	*	*	4	*	*	*	0	*	*	*
	Nyimbiri	0.04	0.02	0.32	0.01	0.05	0.02	0.33	0.01	7	3	5	0	16	6	210	85

Table 3.7b Chemical Drinking Water Data for Wells in Mulanje

	Parameter	Nitrite N (mg/l)				Ammonia N (mg/l)				Arsenic (µg/l)				Nitrate NO_2 (mg/l)			
	Season	Dry		Wet		Dry		Wet		Dry		Wet		Dry		Wet	
	Month	Aug	Oct	Feb	Apr	Aug	Oct	Feb	Apr	Aug	Oct	Feb	Apr	Aug	Oct	Feb	Apr
Villages	Chipoka	0.000	*	*	*	0.07	*	*	*	≤3	*	*	*	0.59	*	*	*
	Mulola	--	0.000	0.000	0.001	--	0.00	0.01	0.05	--	≤3	≤3	≤3	--	1.60	0.12	0.24
	Naluso	0.003	0.000	0.003	0.003	0.01	0.00	0.06	0.04	≤3	≤3	≤3	≤3	1.14	1.76	2.00	1.36
	Namaja	0.000	0.000	0.012	0.004	0.00	0.00	0.08	0.10	≤3	≤3	≤3	≤3	0.00	0.00	0.55	0.23
	Namazoma	0.001	0.000	0.000	0.000	0.04	0.00	0.02	0.02	≤3	≤3	≤3	≤3	1.18	1.60	0.86	1.10
	Namazoma	*0.000*	*0.004*	*0.001*	*0.003*	*0.00*	*0.00*	*0.01*	*0.04*	*≤3*	*≤3*	*≤3*	*≤3*	*0.83*	*1.40*	*1.02*	*1.36*
	Nande	0.004	*	*	*	0.00	*	*	*	≤3	*	*	*	1.60	*	*	*
	Nyimbiri	0.003	0.000	0.006	0.003	0.02	0.00	0.09	0.11	≤3	≤3	≤3	≤3	0.76	1.50	0.85	0.24

- well was dry
-- unable to gain access to village well
* well has fallen into disrepair
# result was nullified (membrane was stuck to Petri dish)
+ failure of test equipment

Italics indicate open/unprotected wells - all other wells are covered/protected

Table 3.8 Standard Physical Drinking Water Values

	Parameter	Turbidity (NTU)	TDS (mg/l)	Electrical Conductivity (µS)	pH
Standards	WHO	5	1000	-	6.5-8.5
	MBS	5	1000	-	6.5-8.5
	MoWD	25	2000	3500	6.0-9.5

Table 3.9a Physical Drinking Water Data for Wells in Blantyre

	Parameter	Turbidity (NTU)				TDS (mg/l)				Electrical Conductivity (µS)			
	Season	Dry		Wet		Dry		Wet		Dry		Wet	
	Month	Aug	Oct	Feb	Apr	Aug	Oct	Feb	Apr	Aug	Oct	Feb	Apr
Villages	Cedric	0.52	0.41	0.00	0.00	268.0	278.0	253.0	205.0	447	463	422	342
	Chemusa	*2.50*	*1.01*	*0.49*	*0.31*	*346.0*	*338.0*	*324.0*	*291.0*	*577*	*563*	*541*	*485*
	Fred(1)	0.19	1.46	0.02	0.00	239.0	200.0	207.0	203.0	397	333	345	338
	Fred(2)	2.13	-	0.00	2.41	180.3	-	190.0	177.2	300	-	317	295
	Kumazale	1.58	15.32	10.27	0.00	243.0	231.0	230.0	205.0	404	385	384	342
	Kumponda(1)	1.77	0.75	0.00	0.00	195.6	194.6	177.7	181.0	327	324	296	302
	Kumponda(2)	*86.00*	*37.51*	*9.13*	*8.85*	*213.0*	*198.9*	*184.2*	*168.5*	*356*	*331*	*307*	*281*
	Pasani	0.54	0.16	0.00	0.00	330.0	330.0	325.0	238.0	551	550	542	396
	Saili	0.80	0.22	1.47	0.00	207.0	198.6	194.2	172.3	346	332	324	287

Table 3.9b Physical Drinking Water Data for Wells in Blantyre

	Parameter	pH				Temperature (^{o}C)			
	Season	Dry		Wet		Dry		Wet	
	Month	Aug	Oct	Feb	Apr	Aug	Oct	Feb	Apr
Villages	Cedric	7.01	7.14	6.69	7.34	28.3	34.1	28	267
	Chemusa	*7.43*	*7.38*	*7.10*	*6.99*	*27*	*25.4*	*26.3*	*25.4*
	Fred(1)	6.80	+	6.81	6.69	26.6	28.3	27.1	26.4
	Fred(2)	7.56	-	6.91	7.40	27.7	-	27.9	26.5
	Kumazale	7.31	10.31	7.01	6.64	24.8	27.2	28	26.2
	Kumponda(1)	7.32	7.40	6.64	6.47	25.8	30.45	27.8	26.2
	Kumponda(2)	*7.10*	*7.10*	*7.00*	*7.36*	*28.7*	*26.7*	*26.9*	*24.2*
	Pasani	7.17	+	7.05	6.42	24.7	25.5	28.5	26.3
	Saili	6.68	+	6.68	7.71	24.8	25.7	26.5	25.6

Table 3.10a Physical Drinking Water Data for Wells in Chiradzulu

	Parameter	Turbidity (NTU)				TDS (mg/l)				Electrical Conductivity (µS)			
	Season	Dry		Wet		Dry		Wet		Dry		Wet	
	Month	Aug	Oct	Feb	Apr	Aug	Oct	Feb	Apr	Aug	Oct	Feb	Apr
Villages	Chelewani(1)	1.08	0.84	4.82	1.19	114.2	114.2	112.3	109.4	190.5	190.9	187.4	182.3
	Chelewani(2)	*	*812.00*	*28.07*	*24.65*	*	*143.7*	*113.5*	*113.0*	*	*240.0*	*188.9*	*188.2*
	Makawa	3.55	0.70	0.00	0.00	132.0	131.4	126.8	122.6	220.0	219.0	211.0	204.0
	Mlandani	1.37	17.46	53.00	0.00	167.0	179.2	149.2	173.0	280.0	299.0	249.0	288.0
	Mtembo	2.00	3.74	14.22	14.53	176.1	168.2	73.5	67.9	294.0	279.0	122.5	113.1
	Mtembo	-	-	*45.38*	*15.19*	-	-	*71.2*	*55.8*	-	-	*118.6*	*93.1*
	Ng'omba	0.63	*	0.00	0.00	172.8	*	160.7	163.4	288.0	*	268.0	272.0
	Nlukla	1.80	2.25	32.42	6.21	113.6	111.2	112.8	104.5	189.4	188.0	188.0	174.0
	Nyasa	2.28	3.40	3.74	0.00	132.4	147.8	114.1	113.6	221.0	249.0	190.3	189.3

Table 3.10b Physical Drinking Water Data for Wells in Chiradzulu

	Parameter	pH				Temperature (^oC)			
	Season	Dry		Wet		Dry		Wet	
	Month	Aug	Oct	Feb	Apr	Aug	Oct	Feb	Apr
Villages	**Chelewani(1)**	6.54	6.34	6.37	6.48	23.7	24.6	24.5	22.2
	Chelewani(2)	*	*7.14*	*6.26*	*6.58*	*	*28.1*	*23.5*	*21.0*
	Makawa	6.72	6.58	6.56	6.38	27.0	23.6	25.6	23.6
	Mlandani	7.97	6.97	6.74	6.88	27.2	23.1	24.8	22.6
	Mtembo	7	7.61	6.89	6.49	24.6	24.0	26.3	23.7
	Mtembo	-	-	*6.83*	*7.91*	-	-	*29.6*	*24.2*
	Ng'omba	6.14	*	7.24	6.13	30.3	*	27.6	25.0
	Nlukla	6.58	6.53	6.28	7.37	24.4	24.3	24.7	23.5
	Nyasa	7.18	6.69	6.27	6.23	26.8	25.3	24.7	23.9

Table 3.11a Physical Drinking Water Data for Wells in Mulanje

	Parameter	Turbidity (NTU)				TDS (mg/l)				Electrical Conductivity (µS)			
	Season	Dry		Wet		Dry		Wet		Dry		Wet	
	Month	Aug	Oct	Feb	Apr	Aug	Oct	Feb	Apr	Aug	Oct	Feb	Apr
Villages	**Namaja**	0.50	1.03	502.00	138.00	138.7	137.1	73.0	97.7	231.0	228.5	121.7	162.9
	Naluso	2.04	2.73	36.06	5.80	161.1	161.7	153.9	160.3	268.0	268.0	256.0	267.0
	Nande	1.63	*	*	*	39.6	39.6	*	*	66.1	66.1	*	*
	Nyimbiri	0.32	0.94	67.00	22.80	108.3	104.9	94.6	94.6	180.6	174.5	157.8	157.7
	Namazoma	2.50	2.54	16.53	4.80	56.0	46.8	41.1	39.2	93.3	78.9	68.5	65.4
	Namazoma	*5.66*	*15.86*	*4.72*	*2.40*	*27.9*	*52.9*	*27.5*	*27.4*	*46.3*	*28.4*	*45.9*	*45.7*
	Chipoka	1.96	*	*	*	35.5	33.4	*	*	59.6	56.6	*	*
	Mulola	--	1.67	4.64	1.12	--	83.7	89.0	79.8	--	139.6	148.2	133.0

Table 3.11b Physical Drinking Water Data for Wells in Mulanje

	Parameter	pH				Temperature (^oC)			
	Season	Dry		Wet		Dry		Wet	
	Month	Aug	Oct	Feb	Apr	Aug	Oct	Feb	Apr
Villages	**Namaja**	6.91	6.93	5.88	+	27.2	28.2	26.8	26.2
	Naluso	6.35	6.4	6.21	+	26.6	26.1	25.9	25.5
	Nande	5.33	*	*	*	23.4	*	*	*
	Nyimbiri	6.67	6.71	6.29	+	29.8	26.4	27.7	26.1
	Namazoma	5.64	5.78	5.22	+	25.0	27.2	27.2	26.6
	Namazoma	*5.42*	*5.7*	*5.22*	+	*24.7*	*28.0*	*25.5*	*24.6*
	Chipoka	5.66	*	*	*	26.0	*	*	*
	Mulola	--	6.15	6.03	+	--	27.1	26.4	26.4

- well was dry
-- unable to gain access to village well
* well has fallen into disrepair
# result was nullified (membrane was stuck to Petri dish)
+ failure of test equipment
Italics indicate open/unprotected wells - all other wells are covered/protected