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Classification and quality of groundwater supplies in the Lower Shire Valley, Malawi – Part 2: Classification of borehole water supplies in Chikhwawa, Malawi

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Abstract

This paper compares data gathered from a study of the chemical and bacteriological quality of drinking-water from 28 rural borehole supplies in Chikhwawa, Malawi, with a tiered classification scheme (Class 0 being ideal through to Class III being unsuitable for drinking without prior treatment) developed by investigators from the Institute for Water Quality Studies, Department of Water Affairs and Forestry, South Africa. In general, the majority of borehole water supplies were classified as Class 0 or Class I supplies based upon the chemical analysis and bacteriological examination. However the classification of a borehole water supply was variable and depended upon the parameter, date of sampling and whether or not it was based on the mean or individual concentration. A number of boreholes were classified as II or III as they contained elevated levels of fluoride and nitrate suggesting that consumption over short or prolonged periods of time may lead to adverse or serious health effects, such as skeletal fluorosis in adults and methaemoglobinaemia in infants. Research is required to develop practicable, affordable and sustainable methods to enable villagers to treat Class II/III water supplies and improve the quality of their drinking-water to a class suitable for human consumption.

Keywords: Classification, water, borehole, Malawi, South Africa

INTRODUCTION

Over the last decade an increasing number of studies have been undertaken on the bacteriological and chemical quality of borehole water supplies in Africa. The data accrued by investigators is more often than not compared with the health-based guideline values recommended by the World Health Organization (WHO, 2008). When studies are undertaken in conjunction with European and American investigators, the data presented is often compared with EU and USEPA drinking-water standards. However, it should be noted that these standards are based upon the quality of drinking-water supplied to the consumer's tap after the source water has undergone some degree of conventional treatment. Where national standards exist, investigators have attempted to compare their findings with those standards, but these are invariably those recommended by the WHO. Little attempt has been made to publish drinking-water standards specific to borehole water supplies in Africa.

To address this issue Kempster et al. (1997) undertook a review of South African drinking-water standards and WHO recommendations, and produced a scheme to facilitate the classification of borehole water supplies in rural areas based on single parameters. The rationale behind such a scheme was awareness that 'the boundary between the no-effect level [of constituents] and the threshold for the initial appearance of undesirable effects is not a sharp one' (Kempster et al., 1997 p. 163). In areas of the world under pressure from water resource scarcity, realistically, water quality, both source and treated, can fluctuate on a temporary basis. The scheme was designed with the thought of giving 'a clearer picture of expected effects on the domestic user'. The scheme is based on a select number of aesthetic and health-based parameters that are commonly of concern in drinking-water. On this basis, Kempster et al. produced 4 classes of water quality in terms of suitability for use, ranging from the ideal (Class 0) through to that which is deemed unsuitable for use without further treatment (Class III).

Recently, we undertook a study of the chemical quality of borehole water supplies in Chikhwawa, Malawi (Grimason et al., 2013), and compared our findings with the maximum permissible standards laid down by the Malawi Bureau of Standards for borehole water supplies (MBS, 2005), and the WHO recommended health-based guideline values for drinking-water (WHO, 2008). In this paper we present a summary of the chemical and bacteriological data accrued from that study and compare our findings with the classification scheme proposed by Kempster et al. (1997). We believe that this is the first time that the proposed scheme has been utilised for the classification of borehole supplies outside South Africa.

METHODOLOGY

Eighty-four groundwater samples were collected for chemical analyses from 28 boreholes (*n*=16 on east bank; *n*=12 on west

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bank) located in 25 remote, rural villages in the Chikhwawa District (n=3 per borehole), distributed along the east (n=15) and west (n=10) banks of the Shire River. Samples were collected every 2 months during the wet season (December, February and April) (Grimason et al., 2013). Samples for chemical analysis and bacteriological examination were processed in accordance with standard methods for the examination of water and wastewater (APHA, 1998). Bacteriological samples were collected in 500 mℓ sterile vessels after flaming the inside of the tap of the borehole pump and running off the water to waste for 30 s before obtaining a water sample. Vessels were sealed, labelled, stored in a portable ice chest (coolbox) at 4°C and transported to the Environmental Health Laboratory at the University of Malawi within 6 h. Samples were processed for faecal bacteria using a standard membrane filtration technique and subsequently with confirmatory media in accordance with APHA (1998).

CLASSIFICATION SYSTEM

The classification scheme proposed by Kempster et al. (1997 p. 163) was used to classify rural borehole water supplies examined in this study (Table 1):

- **Class 0**
  'This is ideal water quality, suitable for lifetime use, with no adverse health effects on the user. This class is essentially the same as the target water quality range in the 2nd edition of the *South African Water Quality Guidelines for Domestic Use* (DWAF, 1996).'
- **Class I**
  'Water in this class is safe for lifetime use, but falls short of the ideal water quality in that there may be instances of adverse health effects, but these are usually mild, and overt health effects are almost sub-clinical and difficult to demonstrate. Water in Class I does not cause health effects under normal circumstances. Aesthetic effects may, however, be apparent.'
- **Class II**
  'Water in this class is defined as that where adverse health effects are unusual for limited short-term use. Adverse health effects may become more common particularly with prolonged use over many years, or with lifetime use. This class represents water suitable for short-term or emergency use only, but not necessarily suitable for continuous use over a lifetime.'
- **Class III**
  'This water has constituents in a concentration range where serious health effects might be anticipated, particularly in infants or elderly people with short-term use, and even more so with longer term use. The water in this class is not suitable for use as drinking water without adequate treatment to shift the water into a lower and safer class.'

RESULTS AND DISCUSSION

A summary of the data gathered by Grimason et al. (2013) on a range of chemical constituents and bacteriological analysis of 28 borehole water supplies in Chikhwawa, Malawi, is presented in Table 2. Based upon this data, each borehole water supply was classified according to the criteria proposed by Kempster et al. (1997) (Table 3). Tables 4 to 7 present a summary of the water classes determined for each borehole water supply based on the results of 3 samples. The physico-chemical and bacteriological data gathered highlight the variable nature of classifying borehole water supplies, demonstrating the need for a tailored classification scheme proposed by these investigators. For example, for the borehole supply at Matumula on the east bank the class for the iron parameter was Class 0 on 2 sampling occasions and Class II on a separate sampling occasion (Table 4). Despite this variation in quality, based on the mean concentration of the three samples taken, the borehole supply would be classified as Class II (Table 3).

Electrical conductivity and pH

Based on the electrical conductivity (EC) data, 11 borehole water supplies of 16 tested on the east bank fell within Class 0, and 5 boreholes fell within Class I. On the west bank 4 boreholes were classified as Class 1, 5 boreholes as Class II and 3 boreholes as Class III, respectively. All pH values were within Class 0 (pH 6–9).

TABLE 1
Parameters, values and classification of drinking-water quality proposed by Kempster et al. (1997)

Constituent	Class 0	Class I	Class II	Class III
Total dissolved solids (mg/ℓ)	0 – 450	450 – 1 000	1 000 – 2 450	>2 450
Electrical conductivity (µS/cm)	0 - 700	700 – 1 500	1 500 – 3 700	>3 700
Nitrate plus nitrite as N (mg/ℓ)	0 – 6	6 – 10	10 – 20	>20
Fluoride (mg/ℓ)	0 – 1.0	1.0 – 1.5	1.5 – 3.5	>3.5
Sulphate (mg/ℓ)	0 – 200	200 – 400	400 – 600	>600
Magnesium (mg/ℓ)	0 – 30	30 – 70	70 – 100	>100
Sodium (mg/ℓ)	0 – 100	100 – 200	200 – 400	>400
Chloride (mg/ℓ)	0 – 100	100 – 200	200 – 600	>600
pH	6.0 – 9.0	5 – 6 or 9 – 9.5	4 – 5 or 9.5 – 10	<4 or >10
Iron (mg/ℓ)	0 – 0.1	0.1 – 0.2	0.2 – 2.0	>2.0
Manganese (mg/ℓ)	0 – 0.05	0.05 – 0.1	0.1 – 1.0	>1.0
Zinc (mg/ℓ)	0 – 3.0	3.0 – 5.0	5.0 – 10.0	>10.0
Arsenic (mg/ℓ)	0 – 0.01	0.01 – 0.05	0.05 – 0.2	>0.2
Cadmium (mg/ℓ)	0 – 0.005	0.005 – 0.01	0.01 – 0.02	>0.02
Faecal coliforms (cfu/100 mℓ)	0	0 - 1	1 – 10	>10
Ammonia (as N) (mg/ℓ)	0 – 1	1 - 2	2 – 10	>10

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TABLE 2
Mean physico-chemical and bacteriological results of 28 borehole water samples collected and analysed from the east (BH 1–16) and west (BH 17–28) bank of the Shire River (*n*=3) (summarised from Grimason et al. (2013)

Village/Area.	BH No.	TDS (mg/ℓ)	EC (µS/cm)	NO_3 (mg/ℓ)	F (mg/ℓ)	SO_4 (mg/ℓ)	Mg (mg/ℓ)	Na (mg/ℓ)	Cl (mg/ℓ)	pH	Fe (mg/ℓ)	Mn (mg/ℓ)	Zn (mg/ℓ)	As (Mg/ℓ)	Cd (Mg/ℓ)	FC cfu/100 mℓ	NH3 (mg/ℓ)
Mkhwicho	1	nd	591.0	3.3	1.1	37.8	35.5	50.5	21	7.3	0.4	0.0	0.0	< 15	< 1.5	0	nd
Matumula	2	nd	602.3	29.1	0.1	18.1	19.8	17.3	8.1	7.4	0.3	0.0	0.3	< 15	< 1.5	0	nd
Mpokonyola	3	nd	346.3	9.6	0.3	6.5	23.1	15.0	31.9	7.5	0.4	0.2	0.1	< 15	< 1.5	0	nd
Mfela School	4	nd	660.7	42.3	0.4	15.9	24.9	15.6	33.7	7.4	0.4	0.3	0.0	< 15	< 1.5	59	nd
Kapufeni	5	nd	325.3	0.1	4.8	5.9	13.7	16.0	8.9	7.4	0.6	0.4	0.3	< 15	< 1.5	0	nd
Khumbulani	6	nd	634.7	24.7	0.4	7.9	35.8	63.5	12.7	7.3	0.6	0.0	0.8	< 15	< 1.5	0	nd
Chinkole	7	nd	959.3	27.8	0.5	17.2	32.5	85.4	60.2	7.4	0.4	0.0	0.1	< 15	< 1.5	53	nd
Khumbulani	8	nd	431.0	47.3	1.9	14.8	30.8	50.6	16.7	7.4	0.4	0.1	0.3	< 15	< 1.5	0	nd
Zimphutsi	9	nd	865.3	0.0	0.6	45.9	25.6	43.7	71.2	7.2	0.2	0.0	0.0	< 15	< 1.5	0	nd
Samu	10	nd	860.7	19.9	0.4	14.6	40.9	24.1	16.3	6.9	0.4	0.0	0.1	< 15	< 1.5	27	nd
Ad. Market	11	nd	887.3	8.5	0.4	12.1	32.7	52.5	29.5	7.2	0.6	0.0	0.1	< 15	< 1.5	41	nd
Mpangeni	12	nd	893.0	3.7	0.9	6.6	48.7	97.2	22.1	7.4	1.1	0.2	0.0	< 15	< 1.5	35	nd
Bello	13	nd	486.0	0.0	0.2	9.4	15.9	30.4	46.4	7.6	0.5	0.5	0.0	< 15	< 1.5	0	nd
Chadula I	14	nd	220.7	1.1	0.2	4.5	12.8	18.8	8.4	7.5	1.6	0.2	0.1	< 15	< 1.5	0	nd
Chadula II	15	nd	364.7	0.0	0.6	10.3	13.5	29.2	15.8	7.6	1.0	0.5	0.0	< 15	< 1.5	0	nd
Mtuwawa	16	nd	320.0	20.4	0.3	11.2	12.8	31.6	39.2	7.5	1.3	0.6	0.0	< 15	< 1.5	2	nd
Wiliyamu I	17	nd	1206	47	1	16.3	36	45.3	38	7.1	0.8	0	0.1	< 15	< 1.5	0	nd
Wiliyamu II	18	nd	1341.3	5.5	1.4	59.6	17.8	329.7	68.9	7.4	0.8	0	0	< 15	< 1.5	1	nd
Nedi	19	nd	2164.0	37	2.2	75.4	54	401.9	386	7.3	0.4	0	0	< 15	< 1.5	7	nd
Kanthema	20	nd	1823.7	7.3	2.1	781.7	42.9	366	145.9	7.3	0.4	0	0	< 15	< 1.5	50	nd
Kabudula I	21	nd	1367.7	29.9	1.6	84.4	21.6	474.8	142.3	7.6	0.5	0	0	< 15	< 1.5	15	nd
Kabudula II	22	nd	1967.0	0	3.2	62.8	16.8	519.1	103.8	7.6	0.6	0	0	< 15	< 1.5	0	nd
Lawyi 2	23	nd	1826.3	0	2	87.6	18.1	574.1	90.9	7.7	1.0	0	0	< 15	< 1.5	0	nd
Dyelatu Sch.	24	nd	2454.3	0	2.8	240.5	23	531.7	176.7	7.5	1.5	0.1	0	< 15	< 1.5	0	nd
Lakiuji	25	nd	4307.7	15.4	3.9	181.3	32.7	613.6	156.6	7.4	1.6	0.1	0.1	< 15	< 1.5	113	nd
Migano	26	nd	4055.0	177.6	3	294.4	54.3	1177.6	330.3	7.3	3.9	0.2	0.1	< 15	< 1.5	0	nd
Sisev	27	nd	1053.3	28.7	2.8	24.9	27.6	154.6	34.5	7.6	0.5	0	0	< 15	< 1.5	0	nd
Mtondeza	28	nd	6574.3	3	2.9	154.3	13.8	697.2	426	7.5	0.9	0.4	0	< 15	< 1.5	2	nd

nd = not determined

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TABLE 3
Classification of borehole water quality in Chikhwawa based upon mean physical and biological results of borehole water samples collected from the east and west bank of the Shire River according to the Kempster et al. (1997) classification system

Village/Area.	TDS (mg/ℓ)	EC (µS/cm)	NO_3 (mg/ℓ)	F (mg/ℓ)	SO_4 (mg/ℓ)	Mg (mg/ℓ)	Na (mg/ℓ)	Cl (mg/ℓ)	pH	Fe (mg/ℓ)	Mn (mg/ℓ)	Zn (mg/ℓ)	As (Mg /ℓ)	Cd (Mg /ℓ)	FC cfu/100 mℓ	NH3 (mg/ℓ)
Mkhwicho	nd	0	0	I	0	I	0	0	0	II	0	0	0	0	0	nd
Matumula	nd	0	III	0	0	0	0	0	0	II	0	0	0	0	0	nd
Mpokonyola	nd	0	I	0	0	0	0	0	0	II	II	0	0	0	0	nd
Mfela School	nd	0	III	0	0	0	0	0	0	II	II	0	0	0	III	nd
Kapufeni	nd	0	0	III	0	0	0	0	0	II	II	0	0	0	0	nd
Khumbulani	nd	0	III	0	0	I	0	0	0	II	0	0	0	0	0	nd
Chinkole	nd	I	III	0	0	I	0	0	0	II	0	0	0	0	III	nd
Khumbulani	nd	0	III	II	0	I	0	0	0	II	I	0	0	0	0	nd
Zimphutsi	nd	I	0	0	0	0	0	0	0	I	0	0	0	0	0	nd
Samu	nd	I	II	0	0	I	0	0	0	I	0	0	0	0	0	nd
Ad. Market	nd	I	I	0	0	I	0	0	0	II	0	0	0	0	III	nd
Mpangeni	nd	I	0	0	0	I	0	0	0	II	II	0	0	0	III	nd
Bello	nd	0	0	0	0	0	0	0	0	II	II	0	0	0	0	nd
Chadula I	nd	0	0	0	0	0	0	0	0	II	II	0	0	0	0	nd
Chadula II	nd	0	0	0	0	0	0	0	0	II	II	0	0	0	0	nd
Mtuwawa	nd	0	III	0	0	0	0	0	0	II	II	0	0	0	II	nd
Wiliyamu I	nd	I	III	I	0	I	0	0	0	II	0	0	0	0	0	nd
Wiliyamu II	nd	I	0	I	0	0	II	0	0	II	0	0	0	0	I	nd
Nedi	nd	II	III	II	0	I	III	II	0	II	0	0	0	0	II	nd
Kanthema	nd	II	I	II	III	I	II	I	0	II	0	0	0	0	III	nd
Kabudula I	nd	I	III	II	0	0	III	I	0	II	0	0	0	0	III	nd
Kabudula II	nd	II	0	II	0	0	III	I	0	II	0	0	0	0	0	nd
Lawyi 2	nd	II	0	II	0	0	III	0	0	II	0	0	0	0	0	nd
Dyelatu Sch.	nd	II	0	II	I	0	III	I	0	II	I	0	0	0	0	nd
Lakiuji	nd	III	II	III	0	I	III	I	0	II	I	0	0	0	III	nd
Migano	nd	III	III	II	I	I	III	II	0	III	II	0	0	0	0	nd
Sisev	nd	I	III	II	0	0	I	0	0	II	0	0	0	0	0	nd
Mtondeza	nd	III	0	II	0	0	III	0	0	II	II	0	0	0	I	nd

nd = not determined

Sulphate, nitrate, faecal coliform and fluoride parameters

With the exception of the borehole supply at Kanthema (Class III) on the west bank, every other supply fell within Class 0 (*n*=25; 89%) or I (*n*=2; 7%) for the sulphate parameter. Elevated levels of sulphate in water (400–600 mg/ℓ) may be associated with diarrhoea in sensitive, transient and non-adapted consumers, and can impart a bitter taste to the water (Kempster et al., 1997; WHO, 2008). Consumers of borehole water at Dyelatu School and Miagno on the west bank complained of a bitter taste associated with the water. Interestingly, these two supplies were the only ones to fall within Class I, with mean sulphate concentrations ranging from 219–252.3 mg/ℓ and 285.8–305.9 mg/ℓ, respectively. At levels > 600 mg/ℓ in water, such as the case with Kanthema (mean concentration 781.7 mg/ℓ), Kempster et al. (1997) state such water should not be used for drinking, especially by infants, due to the possibility of life-threatening diarrhoea in this sensitive, non-adapted group of individuals. No health-based guideline value has been established by the WHO, as the existing data do not identify a level of sulphate in drinking water that is likely to cause adverse health effects in humans. However, because of the gastro-intestinal effects that can result from drinking water with elevated sulphate levels, the WHO recommend that health authorities be notified of sources of drinking-water containing levels greater than 500 mg/ℓ (WHO, 2008). In Malawi, the Malawi Bureau of Standards (MBS) derived maximum permissible level for sulphate in borehole water supplies is 800 mg/ℓ, although the grounds upon which this standard is based is not known.

Of concern is the alarmingly high number of borehole supplies that were classified as Class II (*n*=2; 7%) / III (*n*=11; 39%) for the nitrate parameter, given its known association with methaemoglobinaemia (blue baby syndrome) in bottle-fed infants (Kempster et al., 1997). The risk of methaemoglobinaemia in infants significantly increases with simultaneous exposure to nitrates and microbial contaminants in water and is rarely associated with nitrate in the absence of faecal contamination of drinking-water (WHO, 2008). This is of particular concern as 5 of the 13 borehole water supplies that were categorised as Class II (*n*=1) / III (*n*=4) for the nitrate parameter (Mfela School, Chinkole, Nedi, Kabudula I and Lukiuji), contained faecal coliforms at levels which placed them in Classes II (*n*=1) and III (*n*=4), respectively, for the faecal coliform bacteria parameter. Most supplies were classified as 0 / I (*n*=19; 68%) with respect to the presence of faecal coliform bacteria. Interestingly, the Malawi Bureau of Standards maximum

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TABLE 4
Classification of Mkhwicho, Matumula, Mpokonyola, Mfela School, Kapufeni, Khumvlani and Chinkole borehole water supplies on the east bank of the Shire River according to the Kempster et al. (2007) classification system

	Mkhwicho				Matumula				Mpokonyola				Mfela School				Kapufeni				Khumbulani				Chinkole			
Class	**0**	**I**	**II**	**III**	**0**	**I**	**II**	**III**	**0**	**I**	**II**	**III**	**0**	**I**	**II**	**III**	**0**	**I**	**II**	**III**	**0**	**I**	**II**	**III**	**0**	**I**	**II**	**III**
E.C.	***				***				***				***				***				***					***		
NO	***							***		**	*					***	***							***				***
F		***			***				**	*				***						***	***				**	*		
SO	***				***				***				***				***				***				***			
Mg	**	*			***				***				**	*			***					***				***		
Na	***				***				***				***				***				**	*			***			
Cl	***				***				***				***				***				***				***			
pH	***				***				***				***				***				***				***			
Fe	*		**		**		*			*	**			*	**			*	**			*	**			*	**	
Mn	***				***					*	**				***				***		***				***			
Zn	***				***				***				***				***				***				***			
As	***				***				***				***				***				***				***			
Cd	***				***				***				***				***				***				***			
FC	***				***				**	*					*	**	***				***				*			**

** Classification based on the concentration of the parameter detected in each of 3 samples; nd = not determined*

TABLE 5
Classification of Khumbulani, Zimphutsi, Samu, Admarc Market, Mpangeni, Bello and Chadula I borehole water supplies on the east bank of the Shire River according to the Kempster et al. (1997) classification system

	Khumbulani				Zimphutsi				Samu				Admarc Market				Mpangeni				Bello				Chadula I			
Class	**0**	**I**	**II**	**III**	**0**	**I**	**II**	**III**	**0**	**I**	**II**	**III**	**0**	**I**	**II**	**III**	**0**	**I**	**II**	**III**	**0**	**I**	**II**	**III**	**0**	**I**	**II**	**III**
E.C.	***					***				***				***				***			***				***			
NO				***	***					*		**		***			***				***				***			
F				***	***				***				***				***				***				***			
SO	***				***				***				***								***				***			
Mg	**	*			***				*	**				***							***				***			
Na	***				***				***				***								***				***			
Cl	***				***				***				***								***				***			
pH	***				***				***				***								***				***			
Fe			***			*	**			*	**				***							*	**				***	
Mn	*	**			***				***				***										***				***	
Zn	***				***				***				***								***				***			
As	***				***				***				***				***				***				***			
Cd	***				***				***				***				***				***				***			
FC	***				***				**			*	**			*	*			**	***				***			

** Classification based on the concentration of the parameter detected in each of 3 samples; nd = not determined*

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TABLE 6
Classification of Chadula II and Mtuwawa borehole water supplies on East Side & Wiliyamu I, Wiliyamu II, Nedi, Kanthema and Kabudula I borehole water supplies on the west bank of the Shire River according to the Kempster et al. (1997) classification system

	Chadula II				Mtuwawa				Wiliyamu I (WS)				Wiliyamu II (WS)				Nedi (WS)				Kanthema (WS)				Kabudula I (WS)			
Class	0	I	II	III	0	I	II	III	0	I	II	III	0	I	II	III	0	I	II	III	0	I	II	III	0	I	II	III
E.C.	***				***					***				***					***				***			***		
NO	***					**	*					***	***							***		***						***
F	***				***				*	*	*			***					***				***				***	
SO	***				***				***				***				***							***	***			
Mg	***				***					***			***					***				***			***			
Na	***				***				***						***				**	*			***					***
Cl	***				***				***				**	*				*	**			***			*	**		
pH	***				***				***				***				***				***				***			
Fe		*	**				***			*	**				***			*	**			*	**				***	
Mn			***				***		***				***				***				***				***			
Zn	***				***				***				***				***				***				***			
As	***				***				***				***				***				***				***			
Cd	***				***				***				***				***				***				***			
FC	***						*	**	***				**		*		**			*	**			*	***			

** Classification based on the concentration of the parameter detected in each of 3 samples; nd = not determined*

TABLE 7
Classification of Kabudula II, Lawyi 2, Dyelatu School, Lakiuji, Migano, Sisev and Mtondeza borehole supplies on the west bank of the Shire River according to the Kempster et al. (1997) classification system

	Kabudula II				Lawyi 2				Dyelatu School				Lakiuji				Migano				Sisev				Mtondeza			
Class	0	I	II	III	0	I	II	III	0	I	II	III	0	I	II	III	0	I	II	III	0	I	II	III	0	I	II	III
E.C.			***				***				***					***				***		***						***
NO	***				***				***				*			**				***	*			**	***			
F			***				***				***				*	**			*	**			***				***	
SO	***				***					***			**		*				***		***				*	**		
Mg	**	*			***				**	*			**	*				***			***				***			
Na				***				***				***			*	**				***		***						***
Cl		***			***					***					**	*			***				***				***	
pH	***				***				***				***				***				***				***			
Fe			***			*	**				**	*			***					***		*	**				***	
Mn	***				***						***		*		**		***				***						***	
Zn	***				***				***				***				***				***				***			
As	***				***				***				***				***				***				***			
Cd	***				***				***				***				***				***				***			
FC	*			**	***				***				**			*	***				***				**		*	

** Classification based on the concentration of the parameter detected in each of 3 samples; nd = not determined*

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permissible level for the faecal coliform parameter in borehole water is 50 cfu/100 mℓ (Grimason et al., 2013), whilst most national standards set a standard of 0 cfu/100 mℓ in drinking water in accordance with the World Health Organization guideline value (WHO, 2011). The basis for the MBS MPL for faecal coliforms is unclear and clarification could not be provided by the MBS when consulted.

With the exception of samples collected from boreholes located at Khumbulani (> 40 mg/ℓ), Wiliyamu I (> 40 mg/ℓ) and Migano (> 170 mg/ℓ), all other borehole samples complied with the maximum permitted level of 45 mg/ℓ nitrate set by the Malawi Bureau of Standards and the WHO health-based guideline value (50 mg/ℓ). Although no faecal coliform bacteria were detected in samples examined from these three borehole supplies, the reasons for the significantly high nitrate concentrations detected warrant further investigation by the health authorities. As a short-term measure, the WHO recommend that water should not be used for bottle-fed infants when nitrate levels are above 100 mg/ℓ; however, it may be used if medical authorities are increasingly vigilant when the nitrate concentration is between 50 and 100 mg/ℓ, provided that the water is known and is confirmed to be microbially safe (WHO, 2008).

Of equal concern is the number of borehole water supplies which were classed as II (n=10) and III (n= 10) with respect to the fluoride parameter, along with the known association of high fluoride levels with dental and skeletal fluorosis (Kempster et al., 1997; WHO, 2008). Fluoride in water is considered to be an essential element for the development and protection of teeth and bones. The current WHO health-based GV (1.5 mg/ℓ), which is 4 times lower than the Malawi maximum permitted level, is considered to be a threshold where the benefit of resistance to tooth decay is weighed against the risk of developing dental fluorosis. In this study evidence of dental fluorosis was clearly visible in consumers of Class II and III borehole water supplies, especially supplies located on the west bank of the Shire River. Consumption of borehole water containing levels greater than 3.5 mg/ℓ over a prolonged period of time may cause skeletal problems (Kempster et al., 1997). Therefore additional studies need to be undertaken to determine the skeletal health effects in people consuming water from Class III supplies such as those located at Kapufeni, Kabudula II and Lakiuji.

Magnesium, sodium and chloride parameters

All borehole water supplies fell within either Class 0 (n=16; 57%) or I (n=12; 43%) for the magnesium parameter. At levels below 70 mg/ℓ (Class 0 and I supplies) no undesirable health or aesthetic effects are discernible; however problems associated with soap lathering may be noticeable with Class I supplies. Elevated levels of magnesium in water (> 70 mg/ℓ) can impart a bitter taste to water supplies (Kempster et al., 1997). The highest magnesium levels recorded in this study were detected in samples from the borehole supply located at Migano (54.3 mg/ℓ), which consumers complained as having a bitter taste to it.

With respect to the sodium and chloride parameters, all samples on the east bank were classified as Class 0. In contrast, the majority of borehole supplies on the west bank were classified as II (n=2) or III (n=8) with respect to the sodium parameter, and two supplies were classified as II for the chloride parameter. Both Class II chloride supplies (Nedi and Migano) were associated with supplies classified as III for the sodium parameter. Health-based guidelines for magnesium, sodium and chloride in drinking water have not been established by the WHO as they are deemed to be naturally occurring chemicals which are usually found at concentrations which are not toxic to health (WHO, 2008). However, it is acknowledged that concentrations of chloride above 250 mg/ℓ can give rise to a detectable 'salty' taste in water. In this study, 3 villages had borehole water supplies that contained chloride values greater than 250 mg/ℓ (Nedi, Migano & Mtondeza); interestingly water consumers from all three villages complained of there being a distinct and mildly unpleasant salty taste to the water. The maximum permitted levels for magnesium, sodium and chloride recommended by the Malawi Bureau of Standards for borehole supplies are 200 mg/ℓ, 500 mg/ℓ and 750 mg/ℓ, respectively.

Iron, manganese and zinc parameters

The majority of borehole water supplies on both sides of the river fell within Class II (n=25; 89%) for the iron parameter. Two supplies on the east bank were classified as Class I and one supply on the west bank as Class III (Migano). In general, no health effects are associated with the levels of iron in Class 0, I and II supplies (Kempster et al., 1997), except in sensitive individuals. However, Kempster et al. (1997) do state that negative health effects can occur in infants who consume water from Class III supplies. With regards to the manganese parameter two-thirds of borehole supplies were classed as 0 (n=15; 54%) or I (n=3), well below the WHO health-based guideline value (0.4 mg/ℓ). Eight supplies on the east bank and 2 supplies on the west bank were classified as Class II; however, the concentrations detected were usually below the WHO guideline value, with slight exceedances detected at Bello, Chadula II and Mtuwawa (≤ 0.6 mg/ℓ).

All borehole supplies were classed as 0 with respect to the zinc parameter as they contained concentrations generally < 0.8 mg/ℓ, significantly lower than the upper limit for Class 0 supplies (3 mg/ℓ). At levels > 5 mg/ℓ zinc can impart a bitter taste to water and at levels > 10 mg/ℓ may be toxic (Kempster et al., 1997). However, the WHO reports that the concentrations of zinc found in groundwater are usually < 0.05 mg/ℓ (WHO, 2008), marginally lower than the levels detected in this study. Nevertheless, all borehole supplies complied with the Malawi Bureau of Standards maximum permitted levels for iron (3 mg/ℓ), manganese (1.5 mg/ℓ) and zinc (15 mg/ℓ), with the exception of the elevated iron levels detected at Migano (> 3.5 mg/ℓ). No WHO guideline values have been established for iron and zinc.

The main problems associated with iron and manganese in borehole water supplies tends to be aesthetic rather than health-related. Problems associated with unsightly floating 'black/brown bits (particles)' and 'brown staining of white clothes (linen)' during washing were reported by women from different villages. This problem is probably brought about by the oxidation of soluble iron, manganese and/or copper to form insoluble precipitates brought about by the mechanical agitation processes involved during hand-washing of clothes (Grimason et al., 2013). Some women stated that they often used a dishcloth to remove (filter out) unsightly particles before storing water in clay pots to cool. Similar observations have been noted by Taulo et al. (2008) in villages located around the lakeshore in Malawi. In that study significantly high concentrations of faecal coliform (*Escherichia coli*) and *Staphylococcus aureus* bacteria were detected in rinsed water from dishcloths. Therefore, the action taken to remove an aesthetic non-health related parameter could inadvertently result in the contamination of the water with a health-related contaminant. The appearance of unsightly discoloured borehole water resulted in some women reverting back to unprotected sources (Grimason et al., 2013).

Arsenic, cadmium and ammonia parameters

Arsenic (MDL 15 µg/ℓ) and cadmium (MDL 1.5 µg/ℓ) were not detected in borehole samples above their minimum detection limits and therefore all borehole supplies fell into Class 0. An analysis of borehole water supplies for ammoniacal nitrogen was not undertaken as part of this study.

CONCLUSION

A review of the literature suggests that this is the first time that any investigators outside South Africa have utilised the guideline criteria set out by Kempster et al. (1997) to classify rural borehole supplies in Africa. This may be due to the fact that most studies do not entail a comprehensive analysis of water samples for chemical constituents in order to facilitate such classifications. We found the criteria and range of classifications proposed by these investigators extremely useful to classify borehole water supplies as compared with the single guideline values recommended by the WHO for drinking-water (WHO, 2008; WHO, 2011) and maximum permitted levels imposed by the Malawi Bureau of Standards for borehole supplies (MBS, 2005). In addition, Kempster et al. (1997) also include a range of standards for parameters for which no WHO guideline values are currently proposed (e.g., iron, zinc, magnesium, electrical conductivity, total dissolved solids) which enabled the data accrued in this study to be compared and classified.

In general, borehole water supplies fell mainly within Class 0 and I for the vast majority of water parameters. Borehole supplies which were classified as II or II were primarily located on the west bank of the Shire River, mainly as a result of elevated levels of both health-related (e.g. nitrate, fluoride, faecal coliforms) and non-health related parameters (e.g. iron, manganese and electrical conductivity).

The levels detected indicate that consumption over a short or prolonged period of time (depending upon the parameter) could have an adverse (Class II) or serious (Class III) health effect on the consumer, e.g., skeletal fluorosis in adults and methaemoglobinaemia in infants. Of particular concern is the borehole located at Migano as it currently provides Class II water to consumers with respect to the levels of fluoride, chloride and manganese detected and Class III water with respect to the significantly higher nitrate, sodium, iron and electrical conductivity levels detected. Kempster et al. (1997) recommend that Class II borehole water supplies are only 'suitable for short-term or emergency use only (and) not (for consumption) over a lifetime' and Class III supplies should not be consumed by sensitive groups (e.g., infants, elderly), even over a short-period of time, without adequate treatment. However, in reality most villagers will be unaware of the quality of their borehole water supply and will probably consume such water from the cradle to the grave. For many people who reside in rural areas in Malawi a borehole water supply is deemed to be safe if it is clear, odourless and palatable.

In Malawi, the Ministry of Irrigation and Water Development (MIWD) recommend that upon construction of a borehole, and before maintenance and control is officially handed over to the community, a small number of water quality tests are undertaken (i.e. pH, total dissolved solids, sulphates, nitrates, fluoride, chloride, electrical conductivity and iron) (MIWD, 2002). In light of the findings of this study we suggest that the MIWD consider revising their recommendation and require Government and non-Government providers of borehole water supplies to undertake an analysis of the parameters identified by Kempster et al. (1997). This would enable the quality of the water to be classified and determine whether any additional treatment is required to ensure that the water is both wholesome and fit for human consumption. On too many occasions boreholes are sunk in Malawi without any consideration of the chemical and bacteriological quality of the supply. The recipient community, grateful for the provision of a borehole, may unknowingly consume water that is unfit for human consumption. Nevertheless, it is recognised that water derived from borehole sources in rural Malawi is undoubtedly superior in quality to other protected (e.g. capped wells) and unprotected (shallow wells, rivers) drinking-water sources (Palamuleni, 2002; Pritchard et al., 2007; Mkandawire and Banda, 2010).

We recommend that the criteria for the classification scheme developed by Kempster et al. (1997) should be updated in light of recent amendments to the South African Water Quality Guidelines for Domestic Use (DWAF, 1996) and WHO recommendations (WHO 2008). It is recommended that any new classification scheme should be a default-based system whereby the overall class of a borehole defaults to the poorest class based on the health-related parameters. This would provide an incentive for the providers of boreholes to ensure that the water provided is wholesome, fit for human consumption and does not constitute a significant medical risk to the consumer. Research is required to develop practicable, affordable and sustainable methods to enable villagers to treat Class II/III water supplies and improve the quality of their drinking-water to a class suitable for human consumption.

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