Drinking water quality and identification of fluoritic areas in Machinga, Malawi

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ABSTRACT

There is prevalence of dental fluorosis in certain parts of Machinga District that can be attributed to elevated drinking water fluoride content in the areas. Therefore, it is important to know the actual quality of water within the district and identify specific fluoride endemic areas that may require immediate adoption of remedial measures to manage the water resource and thus protect consumers. In this study, drinking water samples were collected from boreholes and pipes at 23 sampling sites, mostly villages within the district, for fluoride and other water physicochemical parameters during dry and rainy seasons of 2004 and 2005 respectively. Fluoride endemic sites were identified from the fluoride data. A survey of school children was also done in order to examine symptoms of dental fluorosis. Levels of fluoride ranged from 0.35 to 10.30 mg/L with 70 % of the sites sampled indicating levels above the World Health Organization (WHO) guideline of 1.50 mg/L. Fluoride endemic areas were identified as those villages around Mtubwi F.P School and Liwonde L.E.A School. This finding was supported by the prevalence of a high proportion of dental fluorosis in standard 3 and 4 pupils in these two schools. Values of pH ranged from 6.70 to 9.37; electroconductivity from 1950 to 31000 µS/cm; turbidity from 0.00 to 2.41, Formazin Turbidity Units (FTU); phosphates from 0.0 to 1.88mg/L; nitrates from trace to 58 mg/L; hardness from 1.08 to 276 mg $CaCO_3$/L; sulphates from 6.09 to 109.98 mg/L; chlorides from 0.003 to 0.576 mg/L; carbonates from 2.01 to 85.30 mg/L and bicarbonates from 51.02 to 677.52 mg/L. Correlation of fluoride with other drinking water parameters was assessed using simple graphical methods. Positive correlation was observed between concentrations of fluoride with pH, total dissolved solids and carbonates, while phosphates correlated negatively with the fluorides. No correlation was observed between concentrations of fluoride with nitrates, electroconductivity, total hardness, carbonates and chlorides.

Key words: Machinga, fluoride, fluorosis, physicochemical parameters

1   INTRODUCTION

Our lives depend heavily on water that is free of toxic chemicals and pathogens but the majority of people in Malawi do not have access to safe drinking water. The National Environmental Policy (NEP) in 1996 emphasized on improvement of service delivery in the area of water supply and sanitation and the Environmental Support Programme (SEP) in 1998 added that management of water as a natural resource, pollution

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control in particular, is an essential requirement. Despite government efforts in addressing water issues in the country, very little work has been done on improving water quality, particularly in rural areas. Most of the water projects since 1995 have concentrated mainly on improvement of water delivery (NEP, 1996 and SEP, 1998). One major groundwater pollution problem is the presence of excess fluorides.

Excess fluoride intake, mainly through drinking water, can cause fluorosis that affects both teeth and bones (Karthikeyan et. al, 2000, Alarcon et. al, 2001). The World Health Organization (WHO, 2004) recommends a maximum limit of 1.5 mg/L in drinking water. Discoloured, blackened, mottled or chalky teeth as shown in Figure 1a and 1b characterize dental fluorosis. The teeth may thus become brittle and wear out.

Figure 1a: Moderate dental fluorosis

Figure 1b: Severe dental

Fluoride overdosing for a long period of time can lead to severe skeletal deformity. Paradoxically, intake of fluoride in low concentrations (0.5 to 1.5 mg/L) helps to prevent dental caries, and this is why most toothpaste contains fluorides.

The occurrence of fluorides in water is mostly of geological origin. Baseline studies in Malawi have shown that high levels of fluoride content in water are mostly found in some parts of Nkhotakota, Lilongwe, Karonga, Nsanje, Chikwawa, Mwanza, Mangochi and Machinga (Sibale et. al, 1998; Msonda, 2003, Sajidu et. al, 2004). However, the level of awareness of the dangers of fluorosis in the country is extremely low. In most villages around Liwonde in Machinga District, for example, prevalence of fluorosis in both children and adults is common but no work has been done in monitoring chemical water quality in the water sources (mostly boreholes and deep wells) of the area.

This study was, therefore, aimed at assessing the chemical water quality of water sources in Machinga District and relates the prevalence of fluorosis cases with fluoride content of the water.

1.1   The study area

The study area is located between $15^o02^/$S to $15^o07^/$S of the Equator and $35^o10^/$E to $35^o15^/$E of Greenwich. Figure 2a shows locations of the sampling sites. Population size (for those aged 18 years and over) of Liwonde Township in 2004 was 8,262 (NSO, 2004). No population figures were available for the study areas outside the township but the estimated total population for the whole study area is over 14,000. Samples were collected from several drinking water sources, which were mainly boreholes.

1.2 Physiography and Geology of the study area

The area under study lies in the Shire plain and lies at an altitude of 49 metres above mean seal level. This is a flat lying featureless area on either side of the Shire river trough covered with black sandy clay soils. From this trough, there is very gradual rise of slope on either side of the trough.

The area is among the hottest areas in Malawi with mean maximum temperature at 39° Celsius and mean minimum temperature at 7.2^o C. It is a relatively low rainfall area and the mean monthly rainfall distribution is shown in figure 2b.

The area is mainly underlain by the Precambrian basement complex metamorphic rocks and charnockitic granulalites. These are medium to high-grade metamorphic facies which are normally associated with very hard and stable rocks. The basement complex rocks are mainly composed of Pyroxene-Hornblende-Biotite Gneisses and Garnetiferous Biotite Gneisses. The basement complex rocks in the area have been blanketed by recent colluvium as result of erosion of rocks in the adjacent highlands and subsequent deposition in the Shire plain. Other major rock groups in the area include thick bands of marble, calc-silicate granulites, quartzo-feldspathic granulites and pelitic gneisses. Table 1 is a summary of the major chemical composition of the rocks.

Figure 2a: Map of Liwonde showing boreholes and water pipes, which were sampled.
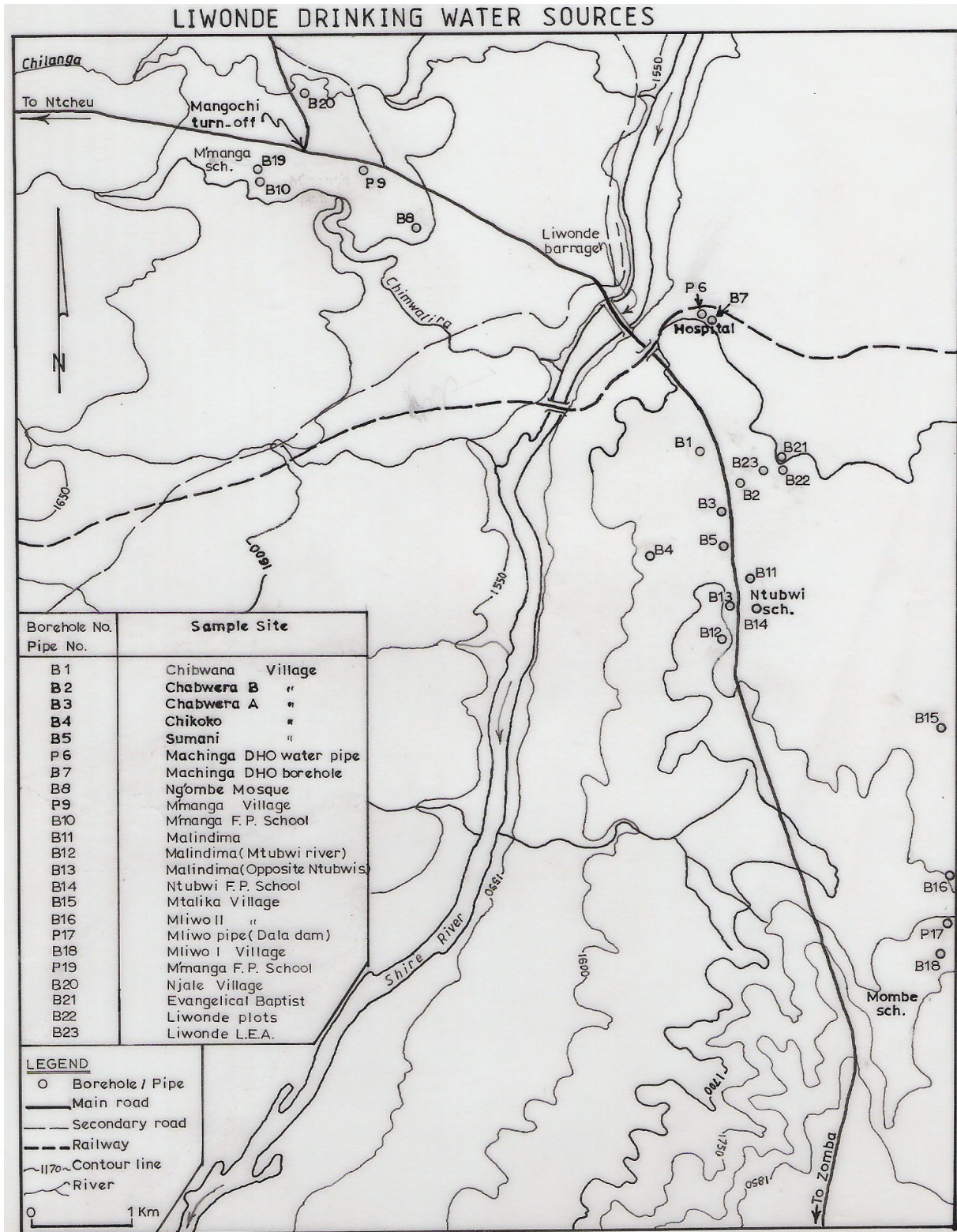

LIWONDE DRINKING WATER SOURCES

Borehole No. Pipe No.	Sample Site
B 1	Chibwana Village
B 2	**Chabwera B** "
B 3	**Chabwera A** "
B 4	**Chikoko** "
B 5	**Sumani** "
P 6	Machinga DHO water pipe
B 7	Machinga DHO borehole
B 8	Ng'ombe Mosque
P 9	M'manga Village
B 10	M'manga F. P. School
B 11	Malindima
B 12	Malindima (Mtubwi river)
B 13	Malindima (Opposite Ntubwis)
B 14	Ntubwi F. P. School
B 15	Mtalika Village
B 16	Mliwo II "
P 17	Mliwo pipe (Dala dam)
B 18	Mliwo I Village
P 19	M'manga F. P. School
B 20	Njale Village
B 21	Evangelical Baptist
B 22	Liwonde plots
B 23	Liwonde L.E.A.

LEGEND
O Borehole / Pipe
── Main road
── Secondary road
▬ ▬ Railway
～1170～ Contour line
River
0   1 Km

Figure 2b: Monthly average rainfall profile for Liwonde
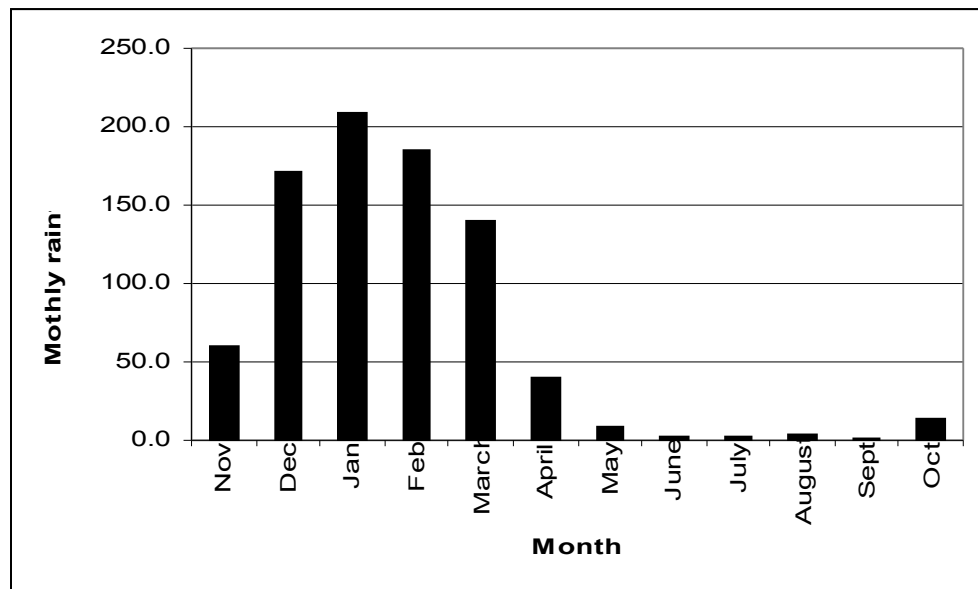

Table 1: Main rock groups and the geochemical composition of the study area

Rock name	Main minerals	Major Geochemical composition	Type of mineral
Pyroxene-Hornblende-Biotite-Gneisses	Pyroxene	Fe, Mg, Si, O, Ca, Na, Al	Silicate
	Hornblende	Ca, Na, Mg, Al, Fe, Si, O, OH	Silicate
	Biotite	Al, K, Fe, Si, O, Mg, OH	Silicate
	Feldspar	Na, Ca, Al, K, Si, O	Silicate
	Quartz	Si, O	Silicate
Garnetiferous-Biotite-Gneisses	Garnet	Fe, Mg, Mn, Al, Si, O, Ca, Cr	Silicate
	Feldspar	Na, Ca, Al, K, Si, O	Silicate
	Quartz	Si, O	Silicate
Marble	Calcite	Ca, C, O	Carbonate
	Dolomite	Ca, Mg, C, O	Silicate
Granulites	Feldspar	Na, Ca, Al, K, Si, O	Silicate
	Quartz,	Si, O	Silicate
	Garnet.	Fe, Mg, Mn, Al, Si, O, Ca, Cr	Silicate

3   MATERIALS AND METHODS

3.1   Sample Collection

Three water samples were collected at each sampling site (borehole or water tap) into one-litre polythene bottles that had been rinsed with deionised water followed by the water to be collected.

3.2   Analysis of physicochemical properties

The samples were tested for fluoride using an ion-selective electrode. An electrical conductivity meter and pH meter were used to determine electro conductivity and pH, respectively. Nitrate concentration was determined by ultraviolet spectrophotometric method (Yang et. al, 1998) while phosphate and sulphate levels were determined by vanadomolybdophosphate acid colourimetric and turbidimetric methods, respectively. Chlorides were tested by using argentometric method while a titrimetric method was used to analyse carbonate and bicarbonate levels in the samples as described in the standard methods of the Association of Official Analytical Chemists (AOAC). The fluoride data were correlated with those of other drinking water parameters by plotting graphs of fluoride data and those of the other parameter in order to come up with the general trend.

3.3   Prevalence of dental fluorisis

A survey was conducted among standard 3 and 4 primary school pupils in the area of study (Mombe, Mtubwi, Liwonde L.E.A. and Mmanga F.P. schools) to determine the prevalence of dental fluorosis. This was done by identifying those pupils in standard 3 and 4 who were born or had stayed in the area for over two years and counting the number of pupils with dental fluorosis from the identified group. Standard 3 and 4 pupils are at the age of developing permanent teeth and seem to be affected most. Boys and girls were counted separately. The results were subjected to statistical analysis.

4   RESULTS AND DISCUSSION

Tables 2a, 2b, 2c and 2d give physicochemical characteristics of water sampled at the 23 sites indicated in the study area. The results show that ground water quality in some villages within the study area is very poor due to high fluoride contents. Fluoride concentrations at sites such as Chibwana, Chabwera A and B, Chikoko, Sumani, Malindima (close to Mtubwi river), Malindima/Mkalawire, Malindima (opposite Mtubwi school), Mtalika, Mliwo I village boreholes, Mtubwi F. P School, Evangelical Baptist Church, Liwonde plots, Liwonde L.E.A, N'gombe mosque and Machinga D.H.O were much higher than the maximum concentration of 1.5 mg/L allowed for drinking water. The main potential source of the fluoride ground water pollution in these places could be the geological set up of the aquifer. The aquifer could be composed of fluoritic rocks such as carbonate fluoroapatite (isolated in these areas) whose slow dissolution infiltrate into the groundwater. However, the major rock mineral composition as shown in Table 1 does not indicate any existence of fluoritic rocks. Further research is therefore needed in these places to determine the actual sources of the high

fluoride levels in the water. Concentrations of selected parameters such as pH, electroconductivity (EC), phosphates (PO_4^{3-}), nitrates (NO_3^-), hardness ($CaCO_3$), turbidity, sulphates (SO_4^{2-}), chlorides (Cl^-). total dissolved solids (TDS), carbonates (CO_3^-) and bicarbonates (HCO_3^-) were determined and are shown in the Tables 2a and 2b together with the corresponding values of the WHO standards for drinking water. Water pH of Mtubwi F.P school, Malindima and Mtalika village boreholes were much higher than the acceptable limit of 8.5 and, therefore, the water may tend to have a bitter or soda-

like taste. All other parameter concentrations are within the acceptable WHO standards except for nitrates at Chibwana village (58 mg/L), which was slightly higher than the allowable limit of 50 mg/L and the same was true of phosphates at Mliwo village pipe (1.88 mg/L). The differences in the parameter values between dry and rainy season water samples were not significant in most cases. However, for most fluoride values, the trend showed a slight increase from rainy

Table 2a: Average concentrations of selected water parameters ± standard deviations

Borehole (B) or Pipe (P) #	Sample site	Water parameters					
		Turbidity (FTU)		SO$_4^{2-}$ (mg/L)		F$^-$ (mg/L)	
		Dry season	Rainy season	Dry season	Rainy season	Dry season	Rainy season
B1	Chibwana village	Trace	Trace	17.30±0.53	13.26±0.02	**3.20±0.06**	**2.32±0.02**
B2	Chabwera B village	Trace	Trace	15.64±1.13	17.72±0.29	**4.08±0.05**	**2.70±0.05**
B3	Chabwera A village	Trace	Trace	23.47±0.68	24.40±0.86	**5.86±0.03**	**3.98±0.06**
B4	Chikoko village	0.38±0.00	1.71± 0.23	17.90±0.53	33.65±0.76	**10.30± 0.02**	**8.19±0.08**
B5	Sumani village	Trace	Trace	31.15±1.58	45.10±0.38	**8.88±0.41**	**7.35±0.06**
P6	Machinga DHO water board	Trace	Trace	4.81±0.08	18.01±0.57	1.15±0.12	0.66±0.06
B7	Machinga DHO borehole	Trace	Trace	55.54±2.18	62.92±0.57	**7.59±0.03**	**7.05±0.07**
B8	N'gombe mosque	Trace	ND	59.76±1.13	ND	**1.77±0.06**	ND
P9	Mmanga village tap	Trace	Trace	3.83±0.15	6.18±0.19	0.71±0.01	0.45±0.02
B10	Mmanga F.P School	Trace	Trace	40.56±0.30	64.47±0.48	1.48±0.02	**2.77±0.01**
B11	Malindima	1.14±0.25	Trace	34.61±0.08	54.17±0.67	**6.92±0.08**	**6.83±0.01**
B12	Malindima (along Mtubwi river	Trace	Trace	29.50±1.58	39.19±0.95	**8.22±0.11**	**8.23±0.03**
B13	Malindima (opp. Mtubwi sch)	1.14±0.25	Trace	35.97±1.88	48.63±2.58	**7.28±0.12**	**7.46±0.07**
B14	Mtubwi F.P School	0.38±0.00	Trace	30.78±0.15	54.83±0.57	**7.50±0.02**	**7.72±0.02**
B15	Mtalika village	Trace	Trace	43.27±.2.26	51.88±0.48	**6.54±0.16**	**6.17±0.06**
B16	Mliwo (II) village	Trace	Trace	5.86±0.23	109.98±0.76	1.39±0.07	1.050.04
P17	Mliwo pipe	2.41±0.00	4.00± 0.25	87.08±1.05	106.93±7.63	0.46±0.02	0.35±0.03
B18	Mliwo (I) village	Trace	Trace	30.78±0.60	44.72±0.38	**4.32±0.13**	**3.83±0.06**
P19	Mmanga F.P school pipe	0.38±0.00	Trace	2.85±0.08	7.70±0.19	0.78±0.08	0.53±0.06
B20	Njale village	Trace	Trace	6.09±0.15	11.99±0.48	1.08±0.06	0.68±0.00
B21	Evangelical Baptist Church	Trace	Trace	35.74±0.15	36.99±0.67	**6.25±0.10**	**6.29±0.10**
B22	Liwonde plots	Trace	Trace	33.18±1.35	35.56±0.57	**6.44±0.01**	**6.23±0.07**
B23	Liwonde L.E.A School	Trace	Trace	27.69±0.98	34.61±0.19	**5.42±0.04**	**5.46±0.05**
WHO water standards		<5 FTU (acceptable but not std)		250 (acceptable but not std)		1.5	

Note: Bold figures indicate fluoride concentrations above the WHO limit of 1.5 mg/L
N/A = Not available
ND = Not detected

Table 2b: Average concentrations of selected water parameters ± standard

Borehole (B) or Pipe (P) #	Sample site	Water Parameters					
		Cl⁻ (mg/L)		TDS (mg/L)		CO₃⁻ (mg/L)	
		Dry season	Rainy season	Dry season	Rainy season	Dry season	Rainy season
B1	Chibwana village	0.034±0.000	0.031±0.000	550±2	640±6	56.72±2.62	41.40±1.66
B2	Chabwera B village	0.027±0.001	0.020±0.000	422±10	538±34	50.61±1.75	51.33±1.66
B3	Chabwera A village	0.029±0.001	0.028±0.000	444±20	577±6	69.81±5.24	47.19±0.83
B4	Chikoko village	0.032±0.000	0.034±0.002	528±16	581±26	63.70±4.36	53.81±4.14
B5	Sumani village	0.035±0.000	0.037±0.000	489±37	556±14	45.38±1.75	54.97±1.99
P6	Machinga DHO water board	0.007±0.001	0.007±0.000	104±4	106±3	1.75±0.00	3.86±0.78
B7	Machinga DHO borehole	0.036±0.001	0.036±0.000	872±20	1012±25	136.13±6.98	126.67±9.11
B8	N'gombe mosque	0.054±0.000	ND	545±10	ND	47.99±7.85	ND
P9	Mmanga village tap	0.029±0.000	0.003±0.000	50±2	43±2	3.49±0.00	0.00±0.00
B10	Mmanga F.P School	0.033±0.001	0.036±0.000	374±6	660±12	33.16±1.75	44.71±0.00
B11	Malindima	0.035±0.000	0.036±0.000	316±4	368±6	19.78±1.65	33.94±0.83
B12	Malindima (along Mtubwi river	0.034±0.000	0.035±0.000	304±8	358±15	15.71±3.49	29.47±1.99
B13	Malindima (opp. Mtubwi sch)	0.035±0.001	0.036±0.000	374±6	352±14	16.58±0.87	22.35±0.83
B14	Mtubwi F.P School	0.036±0.000	0.036±0.000	370±6	393±14	19.20±0.00	22.35±0.83
B15	Mtalika village	0.034±0.000	0.034±0.000	380±8	394±10	29.67±1.75	24.84±1.66
B16	Mliwo (II) village	0.010±0.000	0.010±0.000	290±6	547±14	2.62±0.87	5.13±0.17
P17	Mliwo pipe	0.004±0.001	0.004±0.000	64±4	54±4	0.00±0.00	0.00±0.00
B18	Mliwo (I) village	0.030±0.000	0.027±0.001	532±16	648±12	39.62±2.97	40.57±4.14
P19	Mmanga F.P school pipe	0.003±0.000	0.003±0.000	112±4	82±2	3.49±0.00	0.00±0.00
B20	Njale village	0.576±0.001	0.590±0.001	1556±8	1772±22	74.17±0.87	119.22±0.00
B21	Evangelical Baptist Church	0.032±0.001	0.034±0.000	368±8	382±10	19.20±0.00	17.39±2.48
B22	Liwonde plots	0.032±0.000	0.032±0.000	282±2	382±14	22.22±1.74	17.55±0.99
B23	Liwonde L.E.A School	0.029±0.000	0.030±0.000	430±26		29.67±1.75	32.29±0.83
WHO water standards		250 (not std but above which may give rise to taste)		1200(not std but above which may objectionable)		NA	

Note: Bold figures indicate fluoride concentrations above the WHO limit of 1.5 mg/L
         N/A = Not available
         ND = Not detected

Table 2c: Average concentrations of selected water parameters ± standard deviations

Borehole (B) or Pipe (P) #	Sample site	Water Parameters					
		HCO$_3^-$ (mg/L)		PH		EC (µS/cm)	
		Dry season	Rainy season	Dry season	Rainy season	Dry season	Rainy season
B1	Chibwana village	307.88±7.63	318.94±6.00	6.70±0.05	6.92±0.01	14000±3000	14000±0
B2	Chabwera B village	317.64±5.32	289.70±3.25	6.97±0.04	7.21±0.05	12000±0	12000±0
B3	Chabwera A village	322.08±6.21	351.88±5.05	7.15±0.01	7.22±0.02	14400±100	14700±0
B4	Chikoko village	362.89±13.31	347.67±10.94	7.19±0.03	7.09±0.02	9200±200	16000±0
B5	Sumani village	379.75±3.55	345.31±4.21	7.74±0.05	7.56±0.19	8800±0	17270±205
P6	Machinga DHO water board	158.82±0.89	109.43±1.68	7.51±0.06	7.45±0.03	3500±0	2700±0
B7	Machinga DHO borehole	589.14±10.65	547.17±18.52	7.25±0.00	7.23±0.08	21267±896	17270±350
B8	N'gombe mosque	330.06±14.20	ND	6.99±0.01	ND	18500±500	
P9	Mmanga village tap	130.43±0.89	76.60±2.53	7.45±0.01	7.22±0.04	6900±0	1500±0
B10	Mmanga F.P School	277.71±4.44	235.71±0.00	7.10±0.02	6.91±0.10	20000±0	10700±450
B11	Malindima	228.32±6.53	202.20±4.88	9.23±0.01	9.37±0.05	13750±250	8930±50
B12	Malindima (along Mtubwi river	208.51±0.89	182.50±6.93	8.15±0.01	8.23±0.02	14000±0	8070±90
B13	Malindima (opp. Mtubwi sch)	225.37±3.55	203.72±1.68	9.26±0.01	9.37±0.02	13250±250	8870±130
B14	Mtubwi F.P School	228.03±0.87	203.72±1.68	9.25±0.02	9.37±0.02	12250±250	8900±0
B15	Mtalika village	207.62±5.32	211.97±3.54	9.19±0.01	9.25±0.03	5050±150	8470±370
B16	Mliwo (II) village	155.27±13.31	129.45±1.53	7.05±0.01	6.92±0.07	8050±50	4730±40
P17	Mliwo pipe	44.36±5.32	79.30±1.85	7.71±0.02	7.76±0.15	7600±100	1050±50
B18	Mliwo (I) village	361.12±2.66	311.58±11.87	7.41±0.02	7.28±0.15	11000±100	14000±0
P19	Mmanga F.P school pipe	130.43±2.66	78.29±0.84	7.42±0.01	7.35±0.04	1950±50	1450±30
B20	Njale village	496.87±1.77	373.76±6.73	6.87±0.01	6.84±0.04	31000±1000	38670±470
B21	Evangelical Baptist Church	217.38±2.66	212.14±1.68	8.05±0.05	8.11±0.08	5250±150	6830±90
B22	Liwonde plots	228.03±0.89	203.38±1.68	8.04±0.01	8.14±0.02	5050±50	6470±50
B23	Liwonde L.E.A School	262.63±0.00	241.60±0.84	7.77±0.01	7.63±0.17	5900±0	7450±40
WHO Water Standards		NA		6.5 – 8.5		N/A	

Note: Bold figures indicate fluoride concentrations above the WHO limit of 1.5 mg/L
N/A = Not available
ND = Not detected

Table 2d: Average concentrations of selected water parameters ± standard deviations

Borehole (B) or Pipe (P) #	Sample site	Water Parameters					
		PO₄³⁻(mg/L)		N0₃⁻(mg/L)		Hardness (mg CaCO3/L)	
		Dry season	Rainy season	Dry season	Rainy season	Dry season	Rainy season
B1	Chibwana village	0.09±0.02	0.44±0.05	58.29±2.33	46.25±1.16	175.49±3.49	198.45±2.45
B2	Chabwera B village	0.09±0.00	0.44±0.05	8.19±0.03	8.470.01	114.49±0.54	132.304.90
B3	Chabwera A village	0.12±0.03	0.15±0.05	1.90±0.13	1.57±0.18	114.49±0.54	117.60±2.00
B4	Chikoko village	0.12±0.03	0.34±0.04	0.09±0.00	Trace	83.87±0.52	75.95±2.45
B5	Sumani village	0.09±0.02	0.14±0.05	5.55±0.53	3.91±0.35	35.65±0.67	46.55±0.00
P6	Machinga DHO water board	0.35±0.05	0.19±0.00	1.46±0.06	0.18±0.01	47.84±0.44	72.28±1.23
B7	Machinga DHO borehole	0.22±0.03	0.24±0.03	29.30±0.16	19.76±1.70	101.95±1.27	132.30±4.90
B8	N'gombe mosque	0.28±0.03	ND	0.00±0.00	ND	151.89±1.84	
P9	Mmanga village tap	0.38±0.03	0.14±0.05	0.76±0.00	1.16±0.10	52.68±0.54	56.35±0.00
B10	Mmanga F.P School	0.35±0.05	0.49±0.00	7.84±0.16	5.17±0.29	98.09±0.27	126.18±3.68
B11	Malindima	0.20±0.00	0.29±0.09	Trace	Trace	4.80±0.04	41.65±1.30
B12	Malindima (along Mtubwi river	0.06±0.03	0.14±0.05	Trace	Trace	14.51±0.54	46.55±2.45
B13	Malindima (opp. Mtubwi sch)	0.12±0.03	0.14±0.05	Trace	Trace	3.49±0.27	29.40±0.00
B14	Mtubwi F.P School	0.14±0.00	0.09±0.00	Trace	Trace	1.08±0.00	9.80±0.00
B15	Mtalika village	0.14±0.00	0.19±0.00	Trace	Trace	1.08±0.00	34.30±0.00
B16	Mliwo (II) village	0.20±0.00	0.34±0.05	2.06±0.00	0.13±0.01	158.56±1.32	51.04±0.00
P17	Mliwo pipe	0.41±0.05	1.88±0.10	0.22±0.00	0.16±0.01	4.57±0.27	4.90±0.00
B18	Mliwo (I) village	0.09±0.00	0.34±0.02	1.30±0.19	1.90±0.20	56.76±0.56	44.10±0.00
P19	Mmanga F.P school pipe	0.14±0.00	0.14±0.05	0.12±0.01	1.60±0.23	51.42±0.67	49.82±1.15
B20	Njale village	0.12±0.03	0.34±0.05	Trace	Trace	276.69±2.58	293.35±6.60
B21	Evangelical Baptist Church	0.00±0.00	0.09±0.00	Trace	Trace	7.88±0.51	12.74±0.00
B22	Liwonde plots	0.00±0.00	0.09±0.00	Trace	Trace	9.68±0.88	39.20±0.00
B23	Liwonde L.E.A School	0.04±0.00	0.19±0.00	Trace	Trace	33.68±0.51	71.05±3.46
WHO Water Standards		0.5 mg/L		50 mg/L		N/A	

Note: Bold figures indicate fluoride concentrations above the WHO limit of 1.5 mg/L
N/A = Not available
ND = Not detected

season to dry season. This could be attributed to high dilution effects during the rainy season. Some of the parameters such as sulphates were generally higher in rainy season than in dry season. This could be due to agricultural chemicals such as fertilizers infiltrating the aquifer during rainy season.

Graphs showing the correlation of fluoride content with other water parameters were determined and are presented in Figures 3A to 3H. In general, the graphs show positive correlation between the concentrations of fluoride with pH, total dissolved solids and carbonates. However, phosphates correlated negatively with the fluoride concentration and no obvious correlation was graphically depicted in the case of fluoride concentration and electroconductivity, nitrates, total

hardness and carbonates. Further work on multiple regression is needed in order to correlate the behaviour of fluoride on other water parameters.

Table 3 gives results of the survey of school pupils (Std 3 and 4) who had symptoms of moderate to severe dental fluorosis and the corresponding fluoride levels in water sources around the schools. The results show that there was a higher proportion of pupils with moderate to severe dental fluorosis at Mtubwi F.P. school than in the other three schools. This observation agreed with the finding of very high fluoride levels (above 5.86 mg/L) in boreholes in villages around the school. However, Liwonde L.E.A School, which is also surrounded by boreholes of high fluoride contents, showed low proportions (both girls and boys) of dental fluorosis. This could be attributed to the fact that most households around Liwonde L.E.A. School drink water provided by the Southern Region Water Board while almost all households around Mtubwi drink water from boreholes.

Table 4 shows p-values when proportions of fluorosis cases are compared between schools. Mtubwi F.P. School is significantly different from the other three schools at the 95% level of confidence. This confirms that fluorosis cases among school pupils at Mtubwi F.P. School are really higher than at Liwonde L.E.A, Mombe and Mmanga F.P. Schools. No significant differences were observed in proportions of fluorosis cases between girls and boys in all schools sampled (p>0.05).

5   CONCLUSION

The results have shown that the ground water of villages around Mtubwi F.P School in Liwonde contains very high fluoride concentrations, which is the main cause of dental fluorosis among the school going children in the area. This is a serious health issue requiring Government's intervention to provide alternate safe drinking water supply or consider use of available water defluoridation technologies in order to protect the people in the area.

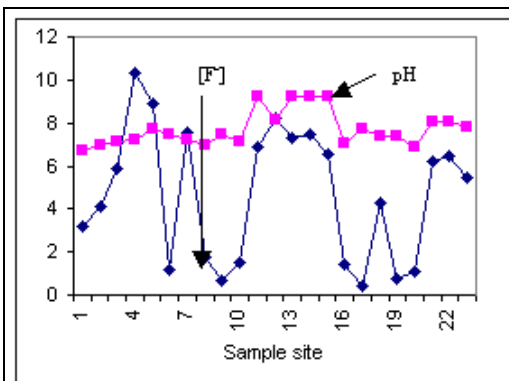**Figures 3A to 3H**: Graphs of fluoride levels compared to levels of other (indicated) parameters for dry season analysis
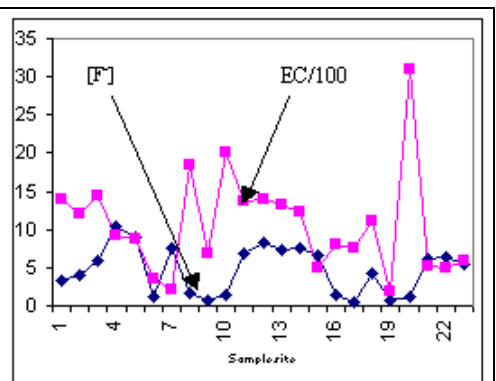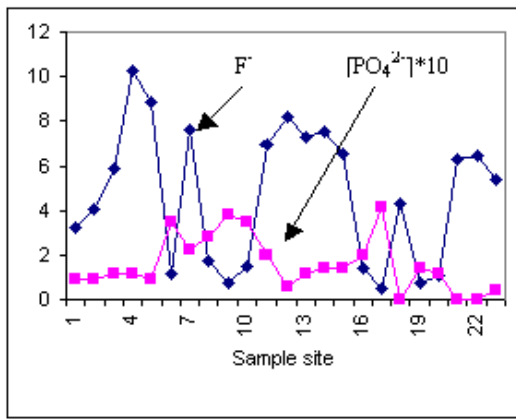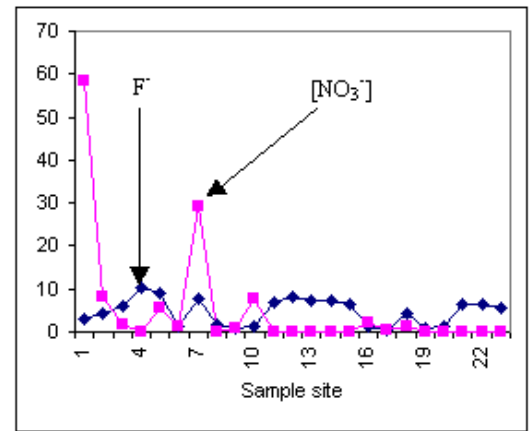

Figure 3A
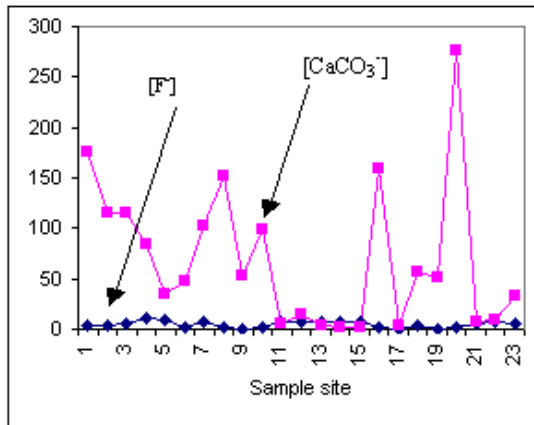

Figure 3B

Figure 3C

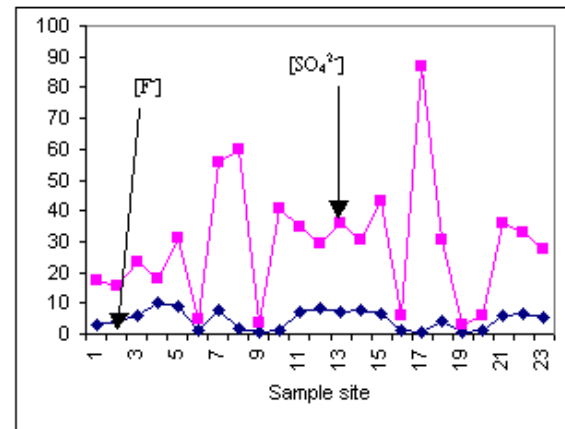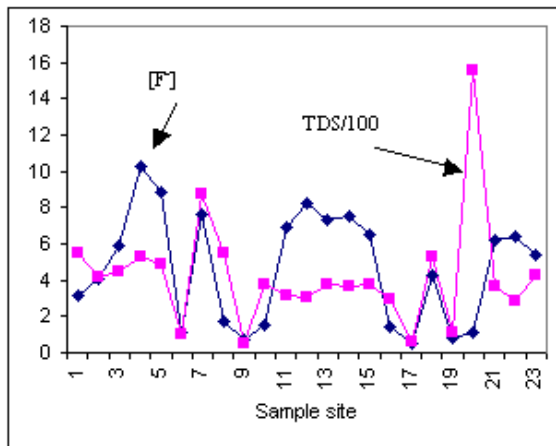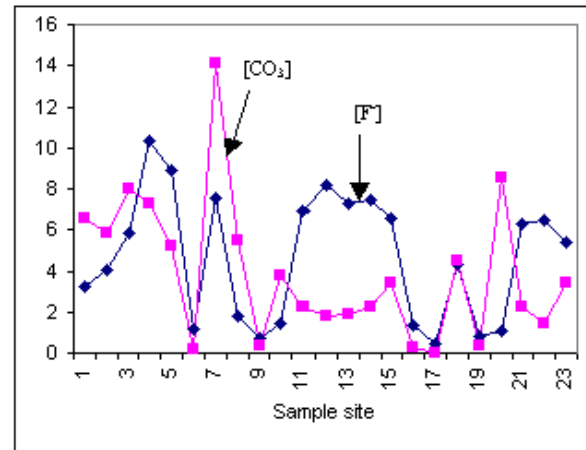Figure 3D

Figure 3E

Figure 3F

Figure 3G

Figure 3H

Table 3: Dental fluorosis cases in std 3 and 4 pupils in schools around Liwonde and corresponding fluoride levels in water sources surrounding the schools

School Name	Boreholes around the school	Fluoride levels (rainy season) of the respective boreholes (mg/L)	Class total[a]	Pupils with fluorosis cases	Proportion of fluorosis cases
Mombe F.P. School	B16, P17, B18	1.39, 0.46, **4.32**	Std3: 21 boys 20 girls	7 boys 3 girls	0.33 0.15
			Std4: 17 boys 14 girls	5 boys 2 girls	0.29 0.14
Mtubwi F.P School	B3, B4, B5, B11, B12, B13, B14,	**5.86, 10.30, 8.88, 6.92, 8.22, 7.28, 7.50**	Std3: 34 boys 32 girls	17 boys 18 girls	0.50 0.56
			Std4: 16 boys 32 girls	13 boys 12 girls	0.81 0.38
Liwonde L.E.A. School	B1, B2, B21, B22, B23	**3.20, 4.08, 6.25 6.44, 5.42**	Std3: 36 boys 42 girls	8 boys 10 girls	0.22 0.24
			Std4: 36 boys 23 girls	14 boys 5 girls	0.34 0.22
Mmanga F.P. School	B8, P9, B10, P19, B20	**1.77**, 0.71, 1.48 0.78, 1.08	Std3: 53 boys 54 girls	4 boys 6 girls	0.08 0.11
			Std4: 19 boys 17 girls	6 boys 3 girls	0.32 0.18

[a] total number of pupils born (or stayed over two years) in the area
Bold values are above WHO maximum allowable limit of 1.5 mg/L

Table 4: p-values of proportions of fluorosis cases between schools

(I) School	(J) School	p-value (between I and J)
Mombe	Mtubwi Liwonde Mmanga	0.003 0.684 0.504
Mtubwi	Mombe Liwonde Mmanga	0.003 0.005 0.001
Liwonde L.E.A	Mombe Mtubwi Mmanga	0.684 0.005 0.290
Mmanga	Mombe Mtubwi Liwonde L.E.A	0.504 0.001 0.290

Acknowledgements

References

Alarcon-Herrera, M.T., Martin-Dominguez, I.R., Trejo-Vazquez, R., Rodriguez-Dozal, S. (2001). Well water fluoride, dental fluorosis, and bone fractures in the Guadian Valley of Mexico, *Fluoride*, 34 (2), 139

Karthikeyan, G., Shunmugasundarraj, A. (2000). Isopleth mapping and in situ fluoride dependence on water quality in the Krishnagiri block of Tamil Nadu in South India, *Fluoride*, 33 (3), 121

Msonda, W. K. (2003). *A study of ground water quality, water defluoridation and impact of dental fluorosis in Nathenje, Lilongwe, Malawi.* MSc Thesis, University of Malawi.

Government of Malawi (1996). *National Environmental Policy (NEP)*, Ministry of Natural Resources and Environmental Affairs, Lilongwe, Malawi

Government of Malawi (1998). *Environmental Support Programme (ESP)*, Ministry of Natural Resources and Environmental Affairs, Lilongwe, Malawi

Government of Malawi (2004). *Population aged 18 years and over,* National Statistical Office, Zomba, Malawi, (unpublished)

Official Methods of Analysis of the Association of Official Analytical Chemists (AOAC). (1990), 15th Edn. Association of Official Analytical Chemists Inc., Virginia, USA

Sajidu S.M., Makhumula P., Masamba W.R.L., Mwatseteza J.F. (2004). Fluoride Content and Chemical Water Quality in Borehole Water in Selected Rural Areas of Southern Malawi*,* Unpublished.

Sibale, E. K., Chidothe, C., Tsakala, M. (1998). Oral health status among the 12 and 15 year old school pupils in Machinga district, Ministry of Health, Government of Malawi, Lilongwe, Malawi.

Yang, J.E., Skogley, E.O., Schaff, B.E., Kim, J.J. (1998). A simple spectrophotometric determination of nitrate in water, resin and soil extract, *Soil Sci. Soc. Am. J.*, 62, 1108

WHO Guidelines for drinking water quality. (2004), Third Edition, Vol.1, *Recommendations*. Geneva: World Health Organization