ASSESSMENT OF GROUNDWATER QUALITY IN WELLS WITHIN THE BOMBALI DISTRICT, SIERRA LEONE

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ABSTRACT

This study assessed the quality of 60 groundwater wells within the Bombali District of Sierra Leone. Water samples from the wells were analysed for physical (temperature, turbidity, conductivity, total dissolved solids and salinity), chemical (pH, nitrate-nitrogen, sulphate, calcium, ammonia, fluoride, aluminium, iron, copper and manganese) parameters using potable water testing kit; and bacteriological (faecal and non-faecal coliforms) qualities. Results show that 73% of the samples had turbidity values below the WHO, ICMR and United USPHS standards of 5 NTU. The electrical conductivity (µS/cm) of 5% of the whole samples exceeded the WHO guideline value, 8% of the entire samples had values higher than the WHO, ICMR and USPHS recommended concentration. In terms of iron, 25% of all the samples had values in excess of WHO, ICMR and USPHS recommended value of 0.3mg/l. For manganese, 12% of the entire samples had values more than the WHO and ICMR standards. On the other hand, more water samples (22%) had manganese values above USPHS guideline value. For bacteriological quality, 28% of the wells were polluted by faecal and non-faecal coliforms. 60% and 40% of the entire samples had faecal and non-faecal coliforms respectively above the WHO standard. Remedial measures recommended include regular monitoring of the physico-chemical and bacteriological quality of water yield from these wells as well as teaching of the communities' basic sanitation and hygiene practices.

Keywords: Groundwater quality, Well waters, Physical, chemical and biological characteristics, Sierra Leone

INTRODUCTION

Water is an important natural resource that requires proper management to ensure its quality, quantity and sustainability. Water, the liquid earth, is the most familiar substance on earth. Life evolved in water and living things are 70 – 90% water (Mader, 1993). From hydrological statistics, the volume of water world wide amounts to some 1.4 x 10^9 Km^3 (Hassan *et al.*, 2008). Water covers nearly 71% of the earth's surface, it accounts for 66% of the mass of an adult human body, and it is needed by all living things (McMurry and Castellion, 2003). Therefore water is life. Needless to say that water is an indispensable resource needed for socio-economic development of any country (Chima *et al.*, 2007). The availability of wholesome and reliable water resource is a pivot upon which man's choice of siting residential areas revolves. Kolo and Tukura (2007) indicated that the development of many urban towns and cities warrants construction of small lakes and reservoirs across small rivers and streams to supply these towns and cities with pipe borne water. This is because man needs water for several purposes such as farming, production, transport, recreation and sports, as well as domestic activities including cooking, laundry, bathing and drinking.

The history of socio-economic development, whether in the hydraulic civilization of the Fertile Crescent or in the developed world today, may be looked at essentially from the extent to which we manage water and make water regularly available. This explains why a recent publication on freshwater calls it the "human imperative" (NEST, 1991). Thus adequate water management is the right key to unlock economic development and societal well being. The modern world is aware of the relationship between water and water-borne diseases as vital public health issue (Asonye *et al*., 2007). In Africa, there is inadequate availability of potable water. This is echoed by Mason (1996) who stated that about half of the inhabitants of developing countries do not have access to safe drinking water and 75% have no sanitation, some of their wastes eventually contaminating their drinking water supply. About 1.3 billion people in developing world are compelled to use contaminated water for drinking and cooking and over six million children are believed to die every year from water related illnesses (Fernando, 2005; Mkandawire, 2008). Globally, 1.1 billion people do not have access to safe water and 2.4 billion people are without adequate sanitation (Lucas and Gilles, 2003; Garba *et al*., 2008). An estimated 3.43 million Sierra Leonean do not have access to adequate sanitation facilities (MEWR, 2010). Contaminated water, poor hygiene and sanitation adversely affect human health. Throughout the world about 2.3 billion people suffer from diseases that are linked to water related problems (WHO, 1997; Asonye *et al*., 2007) such as diarrhoea, cholera, dysentery, typhoid fever and infectious hepatitis. About 80% of all illness and over one-third of the deaths in the developing countries are related to water (Mkandawire, 2008). Yearly, about 4 million children under the age of five die in developing countries due to water related problems (USAID, 1990). In Sierra Leone, over 50% of child mortality is associated with the prevailing poor water and sanitation services (MEWR, 2010). Also in Sierra Leone, it is estimated that 47% urban and 32% rural have access to reliable water supply services (MEWR, 2010).

Many freshwater resources are contaminated through human activities (Mason, 1996), rapid industrial technology, human population explosion, poor sanitation facilities and indiscriminate defaecation, sewage and waste disposal. The bare land after construction and building in marginal areas has accelerated surface run-off and erosion thereby increasing organic and faecal matter (Mkandawire, 2008) for groundwater wells which are primary supplement for surface waters.

The bacteriological quality of water sources is based on estimation of faecal coliforms. Faecal coliforms and streptococci are commonly used as indicator organisms for the microbiological quality of water and waste water (Clesceri *et al.,* 1998; Masamba and Mazvimavi, 2008). Human faeces contaminate water sources and contain micro-organisms including bacteria, cysts and protozoan. One gram of faeces contains 10,000,000 viruses, 1,000,000 bacteria, 1000 parasite cyst and 100 parasite eggs (UNESCO, 2007; Pritchard *et al*., 2008). The horizontal movement of contaminants from pollution sources such as waste dumps, pit latrines, sewage and animal dung pollute groundwater wells (Pritchard *et al*., 2008). Hence NEST (1991) reported that pit latrine located close to wells pollute them with faecal material. This study investigated the physico-chemical and bacteriological quality of groundwater in wells within Bombali District, Sierra Leone.

MATERIALS AND METHODS

Sampling: Water samples from 60 selected wells were collected from May – June 2010. Two samples were collected from each well for physico-chemical and bacteriological analysis in new plastic bottles with their caps tightly secured. The samples were placed in iced-coolers and transported to the laboratory, where they were stored in a refrigerator pending analyses.

Physico-chemical Assay: In-situ measurements of temperature, hydrogen ion concentration (pH) dissolved oxygen (DO) and dissolved iron were taken using mercury-in-glass thermometer, digital pH and DO meters and the Dr/2010 HACH spectrophotometer, respectively. Conductivity, salinity and total dissolved solids (TDS) were measured using the HACH portable conductivity meter (CO150). Turbidity was estimated using the turbidity meter. Copper (Cu), manganese (Mn), nitrate (NO_3^-), fluoride (Fl), chloride (Cl), aluminium (Al) and ammonia (NH_3) were determined spectrophotometrically (APHA, 2005).

Bacteriological Analysis: Bacteriological water quality analysis was carried out on all the water samples using the membrane filtration technique as provided by Oxfam DelAqua kit. 10ml, 20ml and 50ml volumes of water samples were measured out. The different volumes were filtered through filter pads. The filter pads were rested on filter membrane containing agar medium, coliform broth, in already sterilized Petri-dishes with cover. The Petri-dishes with their contents were incubated in an incubator for 3 hours at a temperature of 40^0C. Based on blue and pink colour of colonies formed, faecal and non-faecal coliforms were identified (Bonde, 1977), enumerated and expressed per 100ml of water sample.

Data Analysis: Data obtain were analysed for their central tendencies using descriptive statistics. Furthermore, the data of the physico-chemical analyses with the exception of temperature were compared to the WHO, Indian Council of Medical Research (ICMR) and United States Public Health Service (USPHS) water quality standards.

RESULTS AND DISCUSSION

Physical parameters: A temperature range of 25^0C – 29.9^0C was recorded during the study (Table 1). The temperature of the studied wells was highest at Makari and lowest at Manakoh locations. The temperature of these studied wells was not compared to WHO, ICMR and USPHS since these bodies have no standard for water temperature.

Turbidity measured in Naphenometric Turbidity Units (NTU) varied between 47.0 NTU and 0.2 NTU and were recorded in Binkole and Mapaki communities wells, respectively. The study revealed that the turbidity of 44(73%) of the sampled well waters were within the recommended maximum concentration limits of 5 NTU, while 16(27%) were above the maximum permissible concentration recommended by WHO, ICMR and USPHS (Table 1). Turbidity is a physical factor that reduces the clarity of water. It is caused by suspended organic and inorganic matter, plankton and microbes in water. Suspended inorganic matter such as clay and silt are washed from hills into natural waters. Increased input of silt/fine particulate and organic debris washed from the catchment area into aquatic systems through run-off cause increase in water turbidity (Chima and Digha, 2007; Ibemenuga and Inyang, 2007). Water of high turbidity can be rejected by water users for aesthetic reasons. The thresh hold at which turbidity can be detected in water by the naked eye is above 5 NTU. Turbidity of above 70% of the studied wells was within the maximum permissible limits of 5 NTU (WHO, 2005).

Electrical conductivity (EC) measured in microSiemens per centimeter (μS/cm) (Commonwealth of Australia, 2002) using conductivity meter varied between 88.3 and 829.0 μS/cm among the sampled wells water (Table 1). Welcome (1985) described conductivity as a measure of the total amount of ions present in a body of water revealed that 57(95%) of the water samples were within the WHO recommended limits of 450 μS/cm. The remaining 3(5%) exceeded the recommended limit.

Table 1: Physical parameters of drinking water for wells in Bombali District, Sierra Leone

Location of wells	Physical parameters of water				
	Temperature (^{0}C)	Turbidity (NTU)	Conductivity (μS/cm)	TDS (mg/l)	Salinity (ppm)
IDA quarter	27.5	1.8	88.3	41.9	ND
Agriculture compound	27.5	0.4	129.4	69.5	ND
Polaris guest house	27.9	0.5	71.4	35.6	ND
Kamabai hospital	27.9	12.9	59.0	29.0	ND
Mapaki community	28.1	0.2	250.0	175.0	ND
Primary School Maso	28.0	2.4	89.7	46.8	ND
Makamray Primary School	28.1	2.0	355.0	118.9	ND
Rokortha	27.9	2.6	300.0	150.0	ND
Mayorlor	27.8	4.5	237.0	118.0	ND
Makama	27.9	20.0	292.0	164.0	ND
Kagbaneh	28.8	11.2	165.0	78.0	0.1
Mile 14	28.7	4.6	86.8	43.2	ND
Kapeteh	29.4	1.4	149.0	71.0	0.1
Boniya	28.9	1.2	64.7	32.3	ND
Mabonkani	28.7	1.5	164.0	82.0	ND
Kathala	29.0	14.5	235.0	117.0	0.1
Kamanka	29.0	3.1	52.0	255.0	0.1
Maken Kita	29.2	6.9	170.0	86.6	0.1
Bombali Bana	29.4	2.4	173.8	68.8	ND
Binkolo	29.2	47.0	82.0	41.0	ND
Makari	29.9	3.9	87.7	43.5	ND
Mafari	29.8	5.7	95.9	47.4	0.1
Mongoneh	29.6	10.7	164.7	83.3	0.1
Kabonka	28.5	8.5	292.0	145.0	0.1
Madiff	27.4	8.1	351.0	176.0	0.1
Mafinah	28.6	9.6	49.6	24.8	0.1
Rosint	27.5	7.5	177.2	88.3	0.1
Makothar	28.0	6.9	177.8	88.9	ND
Moria	28.1	7.2	50.5	25.0	ND
Masaybana	27.9	8.0	38.2	69.5	0.1
Mayorlor	28.0	1.2	378.0	188.5	0.1
Manakoh	25.0	2.2	131.0	65.1	ND
Kathatha Bana	28.1	0.6	108.0	54.0	ND
Bouniba	28.0	1.7	217.0	108.0	ND
Rosanda	28.3	0.8	237.0	118.8	ND
Masigbilol	28.2	0.9	398.0	188.4	ND
Mabando	28.3	2.3	244.0	122.0	ND
Mayabga	28.1	1.5	299.0	148.0	ND
Makolon`	28.0	1.2	296.0	147.0	0.1
Mathulah	28.3	1.6	421.0	210.0	0.1
Government hospital	28.6	1.2	378.0	189.5	0.1
Rogbaneh community well	28.9	1.5	829.0	414.0	0.1
New London	28.2	7.9	125.0	62.4	0.1
Police barracks	28.2	2.9	68.1	34.2	0.1
Masagbontolor	28.7	2.4	237.0	118.0	ND
Making	28.5	1.7	208.0	104.0	ND
Makeni Lol	28.4	1.4	237.0	118.0	ND
Malofthaneh	28.6	2.3	244.0	122.0	0.1
Rokontha	28.7	1.5	299.0	149.0	ND
Makaiba	28.8	1.6	421.0	210.0	0.1
Robonka	28.2	2.2	271.0	131.0	ND
Makump Bana	28.0	1.2	218.0	109.0	ND
Rofothaneh I	28.2	1.4	258.0	129.0	0.1
Robat	28.1	2.2	175.0	87.9	0.1
Maboleh	28.3	4.2	554.0	277.0	0.2
Makambo	28.1	3.9	531.0	265.0	0.2
Mamudu	28.4	1.3	403.0	201.0	0.1
Masorie	28.2	1.6	336.0	168.0	0.2

Table 1 continues

Location of wells		**Physical parameters of water**				
		Temperature (^0C)	**Turbidity (NTU)**	**Conductivity (µS/cm)**	**TDS (mg/l)**	**Salinity (ppm)**
Matotoka		28.5	2.5	320.0	160.0	0.1
Standards	**WHO (2005)**	*	5	450	248	0.4
	ICMR (1975)	*	5	-	-	-
	USPHS (1962)	*	5	-	-	-

** = No value, - = Not available, ND = Not detectable*

The variation in the conductivity of the water samples may be due to environmental differences and variation in total dissolved solids. Egborge (1977) reported that the total dissolved solids influence the chemical density of water and the abundance and composition of the biotic communities. The total dissolved solids (TDS) recorded ranged from 24.8 to 277 mg/l. Although higher TDS values were detected from water sampled from Kamanka, Rogbaneh, Magbole and Makambo wells, these values are within the WHO standard (Table 1). The high TDS values may be due to several factors such as deforestation, soil erosion, agricultural activity, sewage and sewage effluents (Hynes, 1970; Alabaster and Lioyd 1980). Generally all the wells were within the WHO stipulated maximum permissible level.

Salinity was measured and the result obtained revealed that all the samples were within the WHO guide limit of 0.4ppm.

Chemical parameters: Data obtained showed that a range of 5.2 – 8.5 pH was obtained during the study (Table 2). pH was highest at Mathula. The pH of water samples measured with a digital HACH portable pH meter showed that hydrogen ion concentration of most of the samples were within the acceptable limits of WHO, EEC and ICMR standard of 6.5 – 8.5 for drinking waters (Table 2). Thus, many of the water samples indicated tendency towards alkalinity. Water samples from Police Barracks and Rogbaneh wells with pH range of 5.2 - 5.8 were outside the recommended values (Table 2). Thus these water sources are acidic. The acidity of water may be attributed to marshy and sandy sulphate soils. Acids lower pH and bases increase pH of water (Mader, 1993). Fluctuation in pH reflects the biological activity and changes in the natural chemistry of waters, as well as pollution (Lind, 1974). Nitrate-nitrogen ranged from 1.8 – 20.0mg/l. All the water samples contained nitrate-nitrogen which according to APHA (2005) are usually present in low concentrations in natural water, and are often the most abundant inorganic form of the element. The study revealed that 5 (5%) of the samples exceeded the WHO permissible limit (Table 2). All the samples fell below the ICMR and USPHS standards. The presence of nitrogen in the wells may be due to nitrogen containing fertilizers, breakdown of dead plants and animals, including animal wastes on the catchment area. On land, nitrates from cattle feedlots seep into the soil and move readily into groundwater; high nitrate concentrations in drinking water can kill (Lewis *et al*., 2004) as well as constitute a health hazard to a juvenile fauna (Boyd, 1979). Various health concerns have been expressed regarding the issue of drinking water containing high levels of nitrates (WHO, 1996; L'hirondel, 2002; Ward *et al.,* 2006; Adelekan, 2010; WHO, 2005).

Shulpate was measured in mg/l. All the water samples are well below the WHO recommended limits (Table 2).

Calcium was ubiquitous occurring in all the locations. The values obtained from all the samples are below the standards for chemical drinking water values. Calcium is needed for bone formation, prevention of porous bones, blood clotting and other vital metabolic reactions. Calcium though an essential element can be poisonous causing tetany seizure, cardiovascular failure and death (Perschbacher and Wurts, 1999).

The WHO drinking water standard for chloride is 250mg/l. The study revealed that all the water samples had chloride values below the permissible standard.

Table 2: Chemical parameters of drinking water for wells in Bombali District, Sierra Leone

Location of wells	Chemical parameters of water										
	pH	Nitrate-nitrogen (mg/l)	Sulphate (mg/l)	Calcium hardness $CaCO_3$ (mg/l)	Chloride (mg/l)	Ammonia (mg/l)	Fluoride (mg/l)	Aluminium (mg/l)	Iron (mg/l)	Copper (mg/l)	Manganese (mg/l)
IDA quarter	7.2	2.6	2.0	12.0	10.0	ND	0.25	0.01	0.2	0.05	0.01
Agriculture compound	6.5	9.1	7.0	35.0	15.0	ND	0.65	ND	0.3	0.02	0.02
Polaris guest house	6.1	4.2	3.0	8.0	9.0	ND	0.28	0.02	0.2	0.01	ND
Kamabai hospital	6.5	7.0	ND	12.0	6.0	ND	0.02	ND	0.15	0.01	0.10
Mapaki community	6.8	6.4	1.0	28.9	30.0	ND	0.67	0.01	0.01	0.16	0.01
Primary School Maso	7.0	6.1	4.0	18.4	15.0	ND	0.32	ND	ND	0.05	0.01
Makamray Primary Sch.	7.1	5.1	2.0	36.0	35.0	ND	0.30	0.01	0.03	ND	ND
Rokortha	6.9	6.5	25.0	40.0	20.0	ND	0.85	ND	0.07	0.05	0.1
Mayorlor	7.0	4.5	6.0	22.0	20.0	ND	0.30	0.03	0.06	0.04	0.01
Makama	6.7	3.4	17.0	33.0	15.0	ND	0.71	0.01	0.6	0.02	0.5
Kagbaneh	6.5	5.5	3.0	28.2	20.0	ND	0.25	0.06	ND	0.05	0.04
Mile 14	6.7	3.8	3.0	19.6	25.1	ND	0.71	0.02	ND	ND	0.02
Kapeteh	6.8	2.6	1.0	7.2	17.6	ND	0.72	ND	ND	0.01	ND
Boniya	6.7	4.4	5.0	4.6	15.6	ND	0.12	0.01	0.05	ND	0.12
Mabonkani	6.2	2.8	3.0	14.0	11.2	ND	0.18	0.03	0.15	ND	0.04
Kathala	6.5	5.6	5.0	8.8	29.6	ND	0.32	0.01	1.5	0.04	ND
Kamanka	6.7	10.6	3.0	10.0	21.2	ND	0.17	ND	0.6	0.02	0.08
Maken kita	6.8	7.0	2.0	12.0	6.8	ND	0.12	ND	0.15	0.01	0.10
Bombali Bana	6.6	15.0	5.0	12.0	0.52	ND	0.42	0.01	0.15	0.06	0.08
Binkolo	6.8	7.6	9.0	14.0	17.2	ND	0.66	0.01	1.8	0.40	0.17
Makari	6.6	17.5	3.0	4.0	11.2	ND	0.39	ND	0.15	0.01	0.12
Mafari	6.5	7.6	1.0	4.8	13.2	0.01	0.57	0.01	0.05	0.03	0.13
Mongoneh	6.6	10.6	2.0	7.2	4.0	0.01	0.49	ND	1.15	ND	0.30
Kabonka	6.9	2.8	1.0	16.0	40.8	ND	0.53	0.03	0.05	ND	0.01
Madiff	6.1	4.8	3.0	15.2	64.0	0.09	0.07	0.06	ND	0.01	0.02
Mafinah	5.8	3.4	1.0	6.8	22.0	ND	0.21	0.02	ND	0.04	0.02
Rosint	6.1	4.4	3.0	4.0	41.0	ND	0.20	0.01	ND	ND	0.31
Makothar	6.3	4.8	2.0	14.0	16.0	ND	0.21	0.02	0.5	ND	ND
Moria	6.5	7.4	5.0	5.0	3.2	ND	0.19	ND	ND	0.01	0.10
Maasaybana	6.6	2.2	8.0	2.0	23.6	0.01	0.10	0.01	0.05	0.19	0.02
Mayorlor	6.7	1.8	ND	45.0	34.0	0.01	0.44	0.04	ND	0.02	0.01
Manakoh	6.8	4.6	ND	12.0	8.0	ND	0.14	ND	ND	0.03	0.02
Kathatha Bana	6.3	3.4	ND	15.0	10.0	0.01	0.15	ND	ND	0.16	ND

Table 2 continues

Location of wells		Chemical parameters of water										
		pH	Nitrate-nitrogen (mg/l)	Sulphate (mg/l)	Calcium hardness $CaCO_3$ (mg/l)	Chloride (mg/l)	Ammonia (mg/l)	Fluoride (mg/l)	Aluminium (mg/l)	Iron (mg/l)	Copper (mg/l)	Manganese (mg/l)
Rosanda		7.2	5.6	1.0	28.0	13.0	ND	0.26	0.01	ND	0.13	ND
Masigbilol		7.3	3.0	1.0	38.0	25.0	ND	0.39	0.01	ND	0.25	0.01
Mabando		6.8	4.4	ND	25.0	22.0	0.01	0.23	0.02	ND	0.20	ND
Mayabga		6.3	3.4	ND	35.0	27.0	ND	0.25	ND	ND	1.00	0.01
Makolon		6.8	6.2	ND	15.0	12.0	ND	0.14	0.01	ND	0.25	ND
Mathulah		8.5	4.6	3.0	55.0	36.0	ND	0.31	ND	0.06	0.04	0.02
Government hospital		6.7	1.8	ND	45.0	35.0	ND	0.44	0.01	ND	0.02	0.01
Rogbaneh community		5.2	20.0	2.0	50.0	65.0	ND	0.60	0.02	0.14	0.06	0.02
New London		6.1	2.4	14.0	24.0	20.0	ND	0.20	0.01	0.5	0.30	0.02
Police barracks		5.7	4.6	2.0	12.0	8.0	ND	0.14	ND	0.4	0.03	0.02
Masagbontolor		6.8	5.6	3.0	28.0	30.0	ND	0.26	0.02	0.10	0.13	0.01
Making		6.5	3.2	2.0	17.0	18.0	ND	0.24	0.03	ND	0.14	ND
Makeni Lol		7.2	5.6	1.0	28.0	30.0	0.01	0.26	0.01	ND	0.13	ND
Malofthaneh		6.8	3.0	1.0	38.0	25.0	ND	0.39	0.02	ND	0.20	0.01
Rokontha		6.3	3.4	4.0	35.0	27.0	ND	0.25	0.04	0.01	0.08	0.01
Makaiba		6.8	4.6	3.0	55.0	38.0	0.01	0.13	0.06	0.06	0.04	0.02
Robonka		6.5	2.4	2.0	24.0	20.0	ND	0.26	0.02	ND	0.02	ND
Makump Bana		6.7	2.2	3.0	22.0	18.0	ND	0.24	0.01	ND	0.16	0.01
Rofothaneh I		6.9	6.2	4.0	26.0	20.0	ND	0.25	ND	ND	0.03	ND
Robat		6.3	3.1	1.0	16.0	10.0	ND	0.11	ND	0.04	0.03	0.01
Maboleh		6.3	7.5	3.0	56.0	55.0	0.01	0.58	0.06	0.02	0.04	0.01
Makambo		7.0	5.4	4.0	45.0	35.0	0.01	0.48	0.05	0.02	0.18	ND
Mamudu		6.8	6.5	5.0	50.0	40.0	ND	0.36	0.04	0.02	0.25	ND
Masorie		6.7	3.4	2.0	42.0	32.0	ND	0.32	0.02	ND	0.21	ND
Bathyanka		6.3	4.6	4.0	38.0	42.0	0.01	0.31	0.04	0.06	0.04	0.02
Matotoka		6.9	4.8	3.0	26.0	18.0	ND	0.36	0.02	ND	0.42	0.01
Standards	WHO (2005)	6.5-8.5	10	400	500	250	1.5	2.0	0.2	0.3	2.0	0.4
	ICMR (1975)	6.5-8.5	20	400	200	-	-	-	-	0.3	3.0	0.1
	USPHS (1962)	-	45	250	-	250	-	-	-	0.3	1.0	0.05

** = No value, - = Not available, ND = Not detectable*

Two (20%) of the samples contained ammonia. The maximum value (0.09mg/l) occurred in Madiff (Table 2). Ammonia was not detected in 48(80%) of the water samples. The results indicated that the values recorded from all the samples did not exceed the drinking water standard (Table 2). Though fluoride occurred in all the samples, the values were below WHO recommended concentrations for drinking water. The minimum and maximum values ranged from 0.02mg/l-0.85mg/l. Fluoride occurs in a combined form in rocks and soil in a wide variety of minerals such as fluorspar (fluorite), cryolite, apatite, topaz (Masonda *et al.*, 2007; Pritchard *et al.*, 2008). They stated further that concentration of fluoride in excess of 1.5mg/l can lead to mottling of teeth and skeletal fluorosis. Also tooth decay increases with concentration as low as 0.3mg/l.

Aluminium is present in all the samples and within the WHO permissible standard. Aluminium has been linked with diseases such as arthritis, brittle bone disease and Alzheimer's disease, a form of senile dementia (Mason, 1996). Iron was detected in 34 (57%) samples. Out of this number, 1(2%) contained iron with value within WHO, ICMR and USPHS permissible limits (Table 2). Fifteen (25%) and 18(30%) of all the samples had values respectively above and below the recommended concentrations. Iron was not detected in 26(43%) wells. Iron is needed for the production of haemoglobin (Mader, 1993). Iron is used in steel and other alloys (Masamba and Mazvimavi, 2008). It stains, imparts taste to water and makes water turbid because of Fe(OH) precipitate.

Copper was present in most of the sampled waters (52, 87%). The values recorded did not exceed WHO, ICMR and USPHS standards. Copper was absent in water samples from Makamry, Mile 14, Bonuja, Mabonkanu, Mongoneh, Kabonka, Rosint and Makothar wells. Though widely distributed and an essential element, acute toxicity of copper may results in hypotension, coma haemolytic anaemia and death (Asonye *et al.*, 2007). Seven (12%) of the wells had manganese above WHO, ICMR while 13(22%) exceeded the USPHS permissible limits. The highest value occurred in Makama well. Surprisingly, 17(28%) water samples had no manganese. Manganese imparts taste and causes 'wad' formation in boreholes. Manganese is used in steel alloys, batteries and food additives (Clesceri *et al.*, 1998; Masamba and Mazvimavi, 2008).

Bacteriological quality of water: Twenty eight percent (28%) of the water samples had high levels of coliforms. The values recorded exceeded the WHO (1993) recommended values of cfu/100ml and <10cfu/100ml of water for faecal and non-faecal coliforms (Table 3). Thirty six (60%) of the samples were heavily polluted by faecal coliform, the values being much higher than the recommended values. Twenty two (37%) of the sampled waters had non-faecal coliforms above the recommended value. However, 24(40%) and 38(63%) of the water sampled were within the recommended guidelines for faecal and non-faecal coliforms, respectively. In all, only 18(30%) of the sampled waters were coliform free, while 42(70%) were not. Thus more than half of the water samples analysed did not meet the WHO standards for faecal coliform and non-coliform for potable water. Faecal coliforms may indicate the presence of pathogens mainly bacteria, which are responsible for water-related diseases such as cholera, diarrhoea, typhoid and other gastro-intestinal disorders (Obire and Agunda, 2002; Mkandawire, 2008). Clearly water used for drinking must be free of pathogens (Mason, 1996). The presence of faecal coliforms in most of the wells may be due to movement of pollutants from closely located waste dumps, pit latrines and leaking septic tanks as well as indiscriminate defaecation around the wells. The most frequently used indicators of faecal pollution are the coliform bacteria (e.g. *Escherichia coli*), *Streptococci* and *Closteridium perfringens* (Mason, 1996). Bonde (1977) had indicated that the presence or absence of faecal coliforms, especially, *E. coli* was a better indicator of sewage contamination than total coliforms.

Conclusion: Most of the physical results were within the acceptable limits for the district. In Binkolo, turbidity value was recorded in excess of recommended value.

Table 3: Bacteriological parameters of drinking water for wells in Bombali District, Sierra Leone

Location of wells	Bacteriological parameters of water		Location of wells	Bacteriological parameters of water	
	Faecal coliforms per 100ml	Non-faecal coliforms per 100ml		Faecal coliforms per 100ml	Non-faecal coliform per 100ml
IDA quarter	65	30	Mayorlor	15	0
Agriculture compound	45	40	Manakoh	0	0
Polaris guest house	0	10	Kathatha Bana	5	0
Kamabai hospital	0	0	Bouniba	0	0
Mapaki community	10	0	Rosanda	10	0
Primary School Maso	0	35	Masigbilol	0	0
Makamray Primary School	0	10	Mabando	0	15
Rokortha	45	15	Mayabga	20	5
Mayorlor	0	10	Makolon	5	0
Makama	0	0	Mathulah	0	0
Kagbaneh	35	20	Government hospital	15	0
Mile 14	20	45	Rogbaneh community	45	50
Kapeteh	15	0	New London	35	40
Boniya	0	0	Police barracks	35	20
Mabonkani	50	40	Masagbontolor	20	35
Kathala	0	0	Making	0	0
Kamanka	45	0	Makeni Lol	10	0
Maken kita	80	30	Malofthaneh	0	0
Bombali Bana	0	0	Rokontha	0	0
Binkolo	25	5	Makaiba	0	0
Makari	75	30	Robonka	15	0
Mafari	5	5	Makump Bana	0	0
Mongoneh	0	0	Rofothaneh I	10	15
Kabonka	0	5	Robat	0	0
Madiff	0	0	Maboleh	0	0
Mafinah	45	0	Makambo	20	30
Rosint	10	0	Mamudu	10	15
Makothar	25	0	Masorie	25	0
Moria	20	0	Bathyanka	15	10
Masaybana	45	0	Matotoka	25	10
Standards WHO (2005)	0	<10	Standards WHO (2005)	0	<10
ICMR (1975)	-	-	ICMR (1975)	-	-
USPHS (1962)	-	-	USPHS (1962)	-	-

- = Not available

The results indicate that most of the chemical results did not exceed the acceptable limits. The hydrogen ion (pH) value recorded in Police barrack and Rogbaneh community wells fell below the acceptable limit. Iron and manganese had values above guidelines with highest values occurring in Binkolo and Makama, respectively. Only 30% of the wells yielded water of good bacteriological quality. This calls for further effective and efficient monitoring of wells to prevent contaminants.

Recommendations: The physical, chemical and bacteriological constituents of water yield by these wells should be monitored regularly. Communities should be taught to filter, boil and cool water from these wells before drinking. Communities should be taught basic sanitation and hygiene practices. Communities should be taught simple chlorination techniques to ensure that the water is bacteriologically save for drinking.

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