Physico-Chemical Water Quality in Ghana: Prospects for Water Supply Technology Implementation

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During an extensive sampling trial in Ghana, a number of physico-chemical water quality problems have been identified. For example, pH values of the collected samples ranged from 3.69 to 8.88, while conductivity ranged from 10 to 45000 µS/cm and turbidity from 0 to > 542 NTU. Many water samples analysed breached the drinking water quality guidelines. High levels of heavy metals were found and also locations high in sulphate and nitrate. In some regions chemical contaminants such as fluoride occur naturally and result in a significant number of boreholes being capped. While such capping results in the protection of the population of exposure to such chemicals, it may increase the risk for microbiological safety if surface water sources are used.

Keywords: chemical contaminants, heavy metals, water quality, Ghana, boreholes

Introduction

Worldwide waterborne diseases are the cause of death and suffering of millions of people, especially children in developing countries. The World Health Organisation (WHO) [1] estimates that improving sanitation and hygiene could drastically reduce child mortality. Water is an integral part of achieving all of the UN Millennium Development Goals [2]. While immediate deaths are caused by waterborne diseases caused by pathogens, long term exposure to chemicals such as arsenic, fluoride, uranium, nitrate and boron may cause chronic illness, disability and death. Pathogen removal can be achieved by chemical or physical disinfection and chemical contaminants require advanced treatment such as adsorption or filtration.

This study focuses on Ghana. The majority of the Ghana's population (58%) live in rural areas. Many of these people live without the national infrastructure such as electricity grid and water services [3] and 66% of these people rely on surface water as a drinking water source, exposing them to waterborne diseases, such as diarrhoea, guinea worm and schistosomiasis [4, 5]. Unsafe water is a major cause of illness in the country, where one in ten children dies before the age of five [4]. The supply of clean water is limited by a lack of infrastructure, capacity and financial resources [6]. In an attempt to supply clean water boreholes are being drilled, which limits the contamination from waterborne diseases. However, waters are rarely monitored following bore construction for the presence of inorganic contaminants such as arsenic and fluoride [7-10]. Elevated concentrations above the WHO drinking water guidelines have been found of iron, manganese, arsenic, fluoride, lead and chromium in water sources in Ghana [11]. These may be naturally present in the groundwater, or may be caused by land-use and industry.

Gold mining is one of the main industries in Ghana accounting for 44% of Ghana's export earnings [12]. The large-scale extraction taking place in mainly Western and Ashanti region *e.g.* Bibiani and Obuasi, brings with it arsenic, mercury and sulphur contamination to water bodies, soil and even air pollution causing acid rain and degradation to the surrounding environment and impacts on human health [13-15]. Since legalisation of small-scale gold mining extraction in 1989, many people make a living through gold mining, employing extraction methods that inevitably release mercury into surrounding water sources [12, 16]. Although the major gold mining has taken place mainly in the south, exploration is now also taking place in the north, *e.g.* in the Upper East. Ghana is also one of the worlds largest the exporters of manganese and is additionally exploring bauxite (Aluminium containing minerals) [12], in mainly in the south western part of the country [17, 18].

Iron and manganese have also been found in elevated concentrations in water in Ghana. Iron is not a health concern in itself, however elevated levels of both iron and manganese affect the taste and quality of drinking water, leading to colouration of cooking utensils and food. This has caused hundreds of wells to be abandoned in favour of surface waters likely contaminated with harmful microorganisms [5, 11]. Smedley found that many of the arsenic-rich stream waters had high colloidal iron content and were highly coloured, suggesting high iron and organic content. The high arsenic concentrations were probably being facilitated by the binding to these compounds. Surface waters were described as "almost universally brown", rich in organic matter and colloidal iron [11]. Uranium content in Ghana is not well documented, Smedley [11] measured uranium concentrations of up to 7 µg/L in ground water by Obuasi. Gold can be enriched with uranium. Eugster [19] found up to 321 mg/kg when they analysed gold samples from various locations in the world and it may thus be released in conjunction with mining. Uranium has also been found in columbite-tantalite minerals mined in the Akim-Oda district in Ghana [20].

During the rainy season 2007 (July & August; in the rainy season immediately before the major flooding throughout the region) a sampling field trial was conducted collecting 230 samples mainly from boreholes (66% of the samples) but also wells (18%), surface waters (7%), piped (5%) and bottled water (3.5%) throughout Ghana. Extensive analysis of physico-chemical water quality was conducted and results are presented in this paper. The aim of this preliminary study was to determine likely hot spots of contamination for future treatment trials.

Materials and Methods

Sampling

Up to 20 samples were collected per day in 500 mL plastic bottles (see Figure 2). Bottles were transferred after initial analysis which was conducted as soon as practically possible, usually within 24 hours, into 25 mL sample vials. Where possible/relevant the name of the location, age of the borehole/well and handpump, funding agency, water charge, money collection system, maintenance arrangements and proximity of other water sources in the area were registered. A photograph of the pump and surrounding was taken to facilitate future identification of the location. It should be noted that based on the appearance it is often difficult to establish the nature of the water, *i.e.* bore or well or determine the depth of a bore. Surface waters (except wells) were sampled using gloves to avoid exposure to parasites. The sampling sites are indicated with circles on the map of Ghana in Figure 1.

Analysis

After collection all samples were filtered through a 0.45 µm syringe filter (Sartorius Minisart, non-pyrogenic CE) and stored in a 20 mL plastic vial. The remaining sample was analysed for pH, conductivity, temperature (Multiline P4 multimeter, WTW) and turbidity (Turbidimeter TN-100, Eutech Instruments). Filtered samples were stored at ambient temperature and airlifted to the UK at the completion of the trial. Upon arrival samples were kept at 4℃, separated and one portion acidified to pH < 2 (concentrated Aristar HNO_3) for ICP-OES analysis whilst the other portion was kept untreated for IC analysis. Major cations of concentrations over 0.1 mg/L were detected by inductively coupled plasma-optical emission spectroscopy (ICP-OES) (Perkin Elmer Optima 5300 DV). Cations of concentrations down to 0.01 µg/L were analysed with inductively coupled plasma – mass spectroscopy (ICP-MS) (Agilent 7500ce). Calibrations were verified by a standard reference material (ICP Multi Element Standard Solution VI CertiPUR) and a reference water (SRM 1640). Anions were analysed using ion chromatography (DIONEX, Sunnyvale, CA, USA). Limits of detection (LOD) as well as relevant drinking water quality guidelines are tabulated in Table 1.
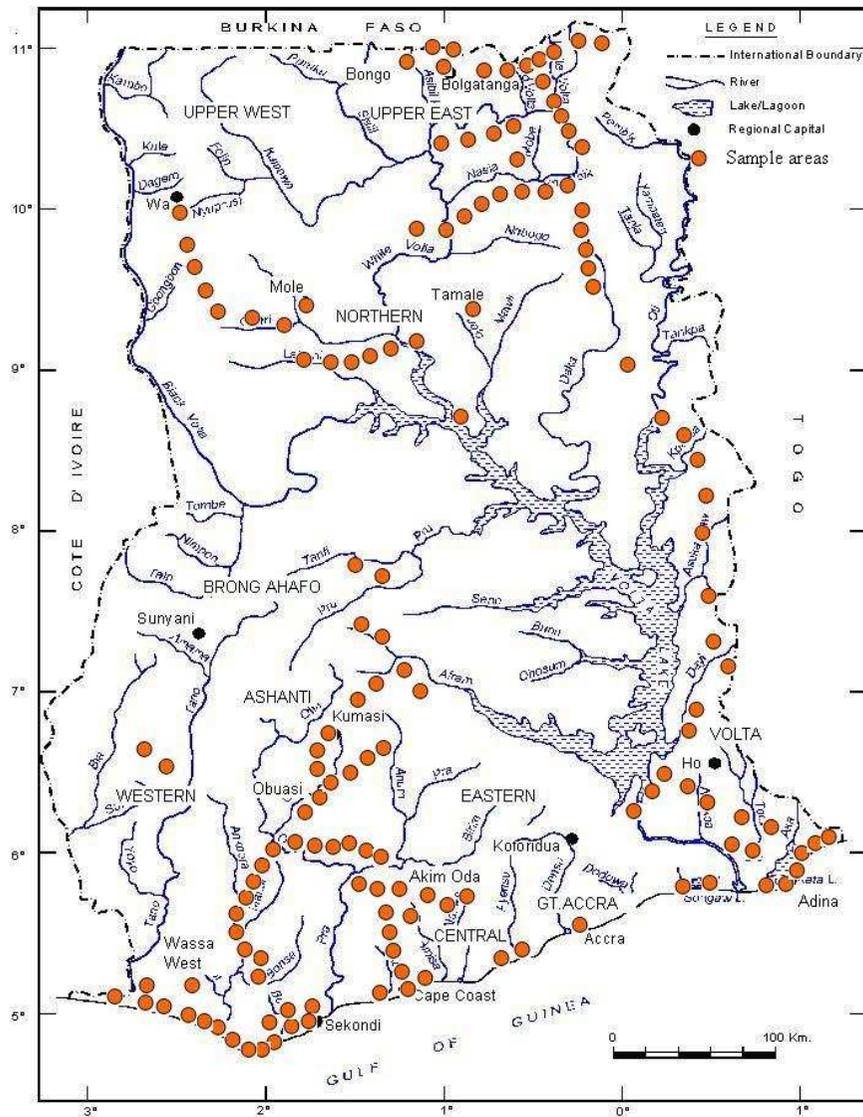
Figure 1: Map of Ghana with regions named and sampling sites indicated with circles.

Table 1: Ions analysed as well as typical detection limits for each method and the WHO drinking water guideline for reference.

ELEMENT	METHOD	UNIT	LIMIT OF DETECTION	WHO GUIDELINE VALUE
Boron	ICP-MS	µg/L	2.551	500
Vanadium	ICP-MS	µg/L	0.011	
Manganese	ICP-MS	µg/L	0.057	400
Cobalt	ICP-MS	µg/L	0.051	
Nickel	ICP-MS	µg/L	0.054	20
Copper	ICP-MS	µg/L	0.173	2000
Zink	ICP-MS	µg/L	1.591	3000*
Arsenic	ICP-MS	µg/L	0.003	10
Selenium	ICP-MS	µg/L	0.306	10
Lead	ICP-MS	µg/L	0.006	10
Uranium	ICP-MS	µg/L	0.001	15
Chromium	ICP-MS	µg/L	0.068	50
Iron	ICP-MS	µg/L	0.001	300*
Cadmium	ICP-MS	µg/L	0.001	3
Mercury	ICP-MS	µg/L	-	1
Aluminium	ICP-OES	mg/L	0.02	0.2*
Magnesium	ICP-OES	mg/L	0.03	
Potassium	ICP-OES	mg/L	0.03	
Calcium	ICP-OES	mg/L	0.02	
Sulphur	ICP-OES	mg/L	0.1	
Barium	ICP-OES	mg/L	0.1	0.7
Fluoride	IC	mg/L	0.1	1.5
Bromide	IC	mg/L	0.2	
Chloride	IC	mg/L	0.2	250*
Sulphate	IC	mg/L	0.2	500*
Phosphate	IC	mg/L	0.1	3
Nitrate	IC	mg/L	0.2	50

*not a health based value, but an aesthetic, taste or practical guideline

Figure 2. Water Sampling in Ghana (A) Surface Water, (B) Handpump on bore/well, (C) Well which was contaminated by surface run off.

Results and Discussion

Common Ions: Aluminium, calcium, potassium, magnesium and total sulphur
The common ions aluminium (Al), calcium (Ca), potassium (K), magnesium (Mg) and total sulphur (S) are reported in Figure 3. These compounds are not of great health concern and in consequence not regulated, although Al is a known neurotoxin as has been related by some studies to Alzheimer's disease [21-23] and even bone fragility [24]. Due to the use of Al in water processes but also taking concerns over neurotoxicity into account, a practicable guideline value is recommended by the WHO as maximum 0.2 mg/L. Al concentrations in the samples ranged from the LOD to 68 mg/L with 199 samples (86% of samples) above that guideline value. The highest levels were found in various locations in the Volta Region and also in samples from Greater Accra. Consumers in Wassa West complained about the hardness of water, but still use some boreholes for drinking. High levels were also found just south of Wa in the Upper West. Ca concentrations ranged from LOD to 275 mg/L, K from LOD to 30 mg/L, Mg from LOD to 144 mg/L, and total S from LOD to 116 mg/L. While those values are not as such a health concern, the presence of multivalent cations such as Al and Ca may have treatment implications for certain processes.

Turbidity
Turbidity is a major concern of surface waters in particular during the rainy season. Values of up to 542 NTU (see Figure 4) were measured in surface waters such as the Black (420 NTU), Red (310 NTU) and White (542 & 323 NTU) Volta Rivers, Oti River (345 NTU) and various surface ponds used to collect rainwater (422 & 376 NTU). Various wells also showed high turbidities of up to 176 NTU. While most bore waters showed turbidities < 2 NTU, some were as high as 266 NTU and such high values were often attributable to iron (85%). The turbidity of the surface/well water did have such a clear correlation and is likely to be due to larger particles such as organic matter and dissolved solids. Many of the high turbidity waters were difficult to filter; in particular those with an opaque white-yellow appearance (see Figure 5A). The turbidity can most likely be attributed to clays in surfaces waters while pathogens and bacteria are also measured in turbidity. The WHO has not set a health based guideline, but recommends that turbidity should ideally be below 0.1 NTU for effective disinfection. 87% of the samples were above this guideline.
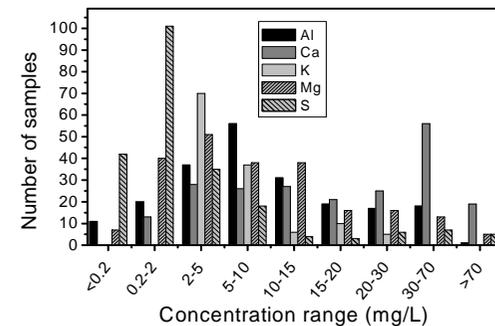

Figure 3. Occurrence of major elements aluminium, calcium, potassium, magnesium and sulphur. WHO guideline for Al is 0.2 mg/L.
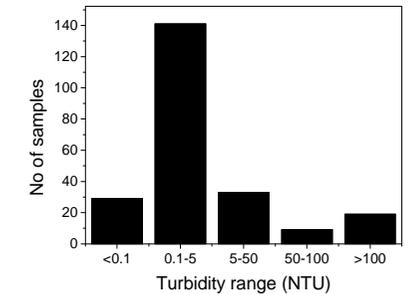

Figure 4. Distribution of turbidity found in samples. Recommended value for effective disinfection is 0.1 NTU.

Figure 5. Water Sampling in Ghana (A) Appearance of opaque-yellow well water, (B) Corrosion of pump by high total dissolved solids near seashore, (C) Worn through handpump piston from heavy usage.

Conductivity and total dissolved solids (TDS)
Electric conductivity is an indication of water salinity. TDS was calculated by adding the ions measured in solution (Figure 6). A health-based value has not been proposed by the WHO, however they note that a TDS above 1200 mg/L may be objectionable to consumers, as may a too low value. While generally low in surface waters, some brackish (1500-5000 mg/L) groundwaters were identified (5% of samples), mainly on the coast along Greater Accra and Volta region. Further, along the coast, seawater intrusion was observed in several locations with conductivities as high as 48.3 mS/cm, resulting in significant pump corrosion (see Figure 5B). Other handpumps fail due to over usage by shear material wear (Figure 5C) and as a result of a number of factors many handpumps were out of operation. While the maintenance and repair was in good order in some communities, in many others the communities were waiting for aid organizations to return to fix assets.

pH Value
The pH values of the samples ranged from 3.7 to 8.9 (see Figure 7). A total of 115 samples (about 50%) were outside the guideline values of 6.5-8.5. While the health impacts of such non-compliance

are not clear, values of very low pH would make waters corrosive and hence place further strain on equipment. The highest pH was found in Lake Bosomtwi which has volcanic history. Generally forested soils would be expected to be more acidic [25] due to the increased rain fall (naturally acidic) [26], compared to the dry Savannah areas in the north. However, also very low pH values were found in the Northern Region.
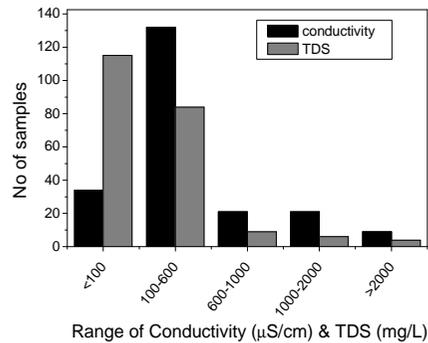

Figure 6. Distribution of conductivity and TDS found in samples. Consumers may find water distasteful above a TDS of 1200 mg/L
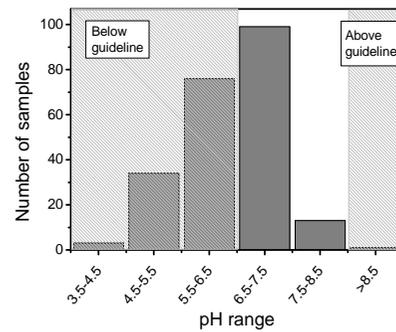

Figure 7. Distribution of pH values found in samples

Chloride, nitrate and sulphate
The ranges of chloride, sulphate and nitrate are displayed in Figure 8. Chloride (Cl^-) and sulphate (SO_4^{2-}) do not have health based guidelines, but may cause concern due to taste if found at too high levels. The WHO, suggest that Cl levels over 250 mg/L may decrease the acceptability of the water due to taste, as well as leading to corrosion of metals. Cl concentrations in the samples ranged from 0.14 mg/L to about 20 g/L, of which 7% of the total samples were above the taste guideline.
Sulphate does not have a health-based guideline value, however the WHO recommends that concentrations higher than 500 mg/L should be reported to "the health authorities" due to problems to the gastrointestinal tract [1]. Sources can be both natural and industrial. The concentrations of SO_4^{2-} in the samples ranged from 0.14 to 2184 mg/L, where the highest value for chloride and sulphate corresponded to the highest TDS sample. Apart from in Adina on the east coast, the highest SO_4^{2-} concentrations were found bore holes in the Northern Region. These results confirmed consumer complaints where the community actually used the well water rather than that from the bore due to the high sulphate levels.
Nitrate (NO_3^-) is a contaminant that is regulated as it has significant health effects, especially on infants where nitrate is one of the causes of methaemoglobinaemia (or "blue-baby syndrome") [27, 28]. Low levels of nitrate are naturally present in water, however high levels result from anthropogenic sources such as sewage or fertilisers. Nitrate concentrations ranged from LOD to 508 mg/L which is more than 10 times higher than the guideline value. Out of the total number of samples taken, 17% from both bores and well in various locations in the country and were above the guideline value.

Fluoride
Fluoride (F) offers protection against dental caries at low concentrations but at higher levels causes serious problems such as dental and skeletal fluorosis. The levels of the samples taken across Ghana ranged from below the LOD to 19 mg/L (Figure 9), with 8% containing levels higher than the WHO guideline. As expected, most sources of high F levels were found in the Northern Region, in the Bongo district. Several water sources in this area had F levels over the guideline value, both wells and boreholes. The people there suffer visibly from teeth problems, and a number of organisations are trying to find a solution to the high F levels –especially as many boreholes are simply capped if the F levels are found to be too high [29]. However, high F levels were also found

scattered in different locations of the country, such as just north of Obuasi, Mole National Park, Accra and some locations along the coast. The highest F level (19 mg/L) was found in a borehole in Adina on the coast of the Volta Region. Extremely high levels were found in the same sample also of other elements such as Al, Ca, Mg, S, B, Mn, Fe, Cl and SO_4^{2-} indicate a serious contamination problem. The conductivity of this water was thus high: 48.3 mS/cm and the water surrounding the pump was of intense red colour (see Figure 5B). This water source was understandably not used for drinking as it had a sulphurous smell and a salty taste, but the community members use it for washing.
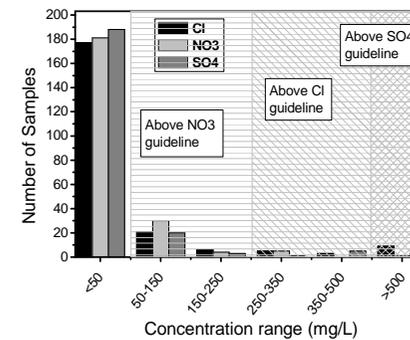

Figure 8. Distribution of chloride, nitrate and sulphate concentrations in samples
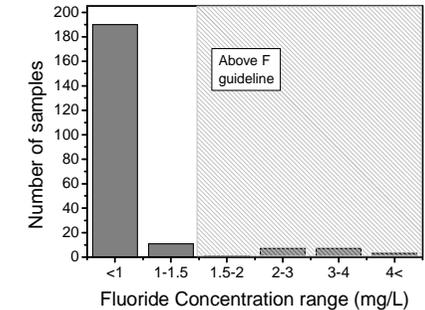

Figure 9. Distribution of Fluoride concentrations in sample. The guideline value is 1.5 mg/L

Boron
Boron (B) is found naturally in the environment. Food rich in B include vegetables, fruit, legumes and nuts, but also in detergents and soap which may give rise to B in the discharge of sewage treatment plants [30]. B is toxic to the male reproductive tract and the provisional WHO guideline value is set to 500 µg/L. The concentrations measured ranged from below LOD to 2034 µg/L (Figure 10). About 3% of the total samples had concentrations above the guideline value, however, particularly high levels of B were found in samples taken in the Northern Region of Ghana, especially in communities in the district of West Gonja (south-west of Tamale). The pH in these waters was slightly alkaline, about pH 8. Conductivity was between 800-1200 µS/cm. One sample with very high levels of B (960 µg/L) also had high levels of F (2.8 mg/L).

Iron and Manganese
Iron (Fe) and manganese (Mn) are naturally present through-out the environment and are generally perceived as safe, as often as taste will deter users from drinking water rich in these compounds. The concentration range of Fe varied widely from below LOD up to 82 mg/L (Figure 10). Despite not having a health based guideline for Fe, a value of 0.3 mg/L is mentioned in the WHO drinking water guidelines as a safe concentration, with the comment that taste will often be affected below this level. Out of the total samples, 6% were above this value. Levels above the guideline were found especially in rivers in *e.g.* in the Western Region, around the mining town Obuasi in the Ashanti Region and in boreholes in some locations in the Northern Region. In the locations where such extremely high Fe levels were encountered, the consumers also noticed high colouration and some bores were no longer used for drinking purposes. Out of the samples containing high levels of Fe, 85% were associated with high turbidity (> 10 NTU).
The Mn concentrations ranged from below LOD to a maximum of 5.7 mg/L (Figure 10). The WHO guideline value is set as 0.4 mg/L and 10% of the total samples were above this. Mn is an essential element but at high concentrations may have neurological effects [31]. It is often present in surface waters with low oxygen content. High levels can be due to industry or mining [32]. The highest levels were found in boreholes in for instance Akrofuom (south of Obuasi, ~400-700 µg/L), odd locations in Northern Ghana (> 2000 µg/L) and and along the coast (~1000-5000 µg/L). Some bores were

disused due to the taste. High levels (up to 1000 µg/L) were also found in the Wassa West district around the town Bompieso. Despite high Mn levels this water was used for drinking. It was noted that some small scale mining was taking place close to the village, which might explain the high Mn levels found.

Arsenic, Lead and Uranium

Even though these elements are part of the earths crust they are not essential to humans. Arsenic (As) is well known for the catastrophic mass poisoning it has caused in *e.g.* Bangladesh through tube wells [33]. Arsenic has also been found in the mining areas in Ghana [29]. Confirming findings by prior studies, elevated levels of As were found in Obuasi municipality (with a history of mining activity). The concentrations across the country ranged from below LOD to 28 µg/L (Figure 11), with one sample containing as much as 169 µg/L (Bolgatanga municipality in northern Ghana). A few water samples (1%) contained three times the set guideline value of 10 µg/L. In a bore hole by Lake Bosomtwi high Cl and NO_3 levels accompanied the As, which could indicate pollution from mining or agricultural activities. High levels of Fe and Mn were also found in this area, although it is interesting to note that the samples with high As do not necessarily contain high levels of Fe/Mn.

High levels Pb were also found. Overall the concentrations ranged from below the LOD up to 34 µg/L (Figure 11). 2% were found to be above the guideline value. The highest containing sample was taken from a borehole in the town Akrofuom. The pH of the water was very acidic (pH 3.69), which would lead to a higher dissolution of heavy metals. This town is located south of Obuasi and thus may be subject to contamination from the mining activities in the area. High levels of Mn and NO_3 were also detected in this sample.

Uranium (U) is not commonly analysed when testing drinking water quality, but due to its chemical toxicity (let alone its radioactivity), the guideline value is set to 15 µg/L and 1% of the samples contained U over this level. These samples were found in a borehole in Odome in the Volta Region, close to the border to Togo. This sample also measured high conductivity (1886 µS/cm) and worryingly contained F levels four times greater than the guideline value, NO_3 values 10 times the guideline value as well as high Cl. Another sample with high U was found in a well used for irrigation in Accra. This water had extremely high conductivity (6.47 mS/cm) and also contained very high Cl levels (2232 mg/L), high F (2 mg/L). Apparently waste water from hotels and the airport residential area drain into this area and may thus cause the contamination measured, as well as well as possible intrusion of seawater. Extremely high levels of U (257 µg/L) were detected in a sample from a borehole in a community in the Assin North district. U was also detected in a close by community, though below the limits of the drinking water guideline. Generally U was detected in samples from the Western and Central Region.
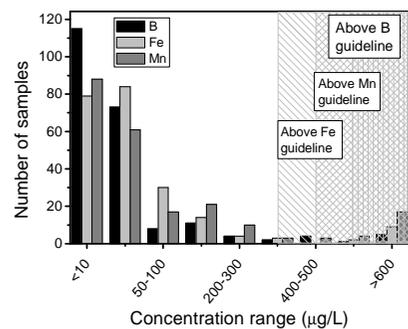
Other Elements

Other elements were also measured in the water, such as cadmium (Cd), barium (Ba), copper (Cu), nickel (Ni), selenium (Se) cobalt (Co), vanadium (V) and zinc (Zn). The levels found of these however were mainly below the WHO guideline values. Mercury (Hg) analysis was attempted but unfortunately not successful, probably due to the high volatility of the metal requiring very efficient preservation [34].

Conclusions

A wide variety of inorganic contaminants have been identified in different locations in Ghana. The variation is probably due to natural variations in geology and also human mining and industrial activities. High levels of Al were found to be quite widespread, along with Fe and Mn, especially in the Volta Region. Presence of F was not only found in the most northern regions but also in different locations in the southern part of the country. Water sources from the mining areas in Central and Eastern Region showed high levels of As, Pb and even some U. High levels of B were found in the Northern Region, especially west of Tamale. Seawater intrusion seems to be a problem in the coastal areas, which were high in salts and pH values were found to be extreme in places. The lacking available data in a form such as a national database is problematic and regular sampling of bores as well as the coordination of bore installations would be useful. This study has provided a first overview of the chemical contamination issues of water sources from various locations throughout Ghana and will allow for more detailed investigations where necessary. It also provides a basis for evaluation of suitable water treatment technology, where de-centralised systems seem a sensible option. Areas with high levels of metals may require a relatively advanced treatment. A more detailed analysis of the contaminants is planned, together with compilation of the socio-economic data collected. Of interest would be to carry out more detailed sampling in areas of apparent high contamination and also to investigate how the water sources are affected by the dry season.

Acknowledgements

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Figure 10. Boron, iron and manganese distribution of samples. Guideline values for Fe, Mn and B are 300, 400 and 500 µg/L respectively.

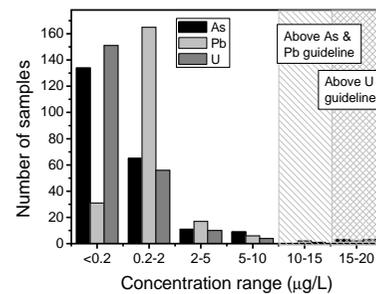*Figure 11. Arsenic, lead and uranium distribution of samples. Guideline for As and Pb is 10 µg/L and for U 15 µg/L.*

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