

Concentration of Trace Metals in Boreholes in the Ankobra Basin, Ghana

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Abstract

Analysis of trace metals in groundwater from the Ankobra basin revealed high levels of iron, manganese and aluminium. Approximately 40% of boreholes had total iron concentration exceeding 1000 $\mu\text{g l}^{-1}$ (maximum WHO permissible limit). Aluminium concentration varied from 0.1 $\mu\text{g l}^{-1}$ to 2510 $\mu\text{g l}^{-1}$ with a median value of 10.0 $\mu\text{g l}^{-1}$. Approximately 20% of the boreholes had aluminium concentration exceeding the WHO maximum acceptable limit (200 $\mu\text{g l}^{-1}$) for drinking water. Manganese concentration was in the range 6–2510 $\mu\text{g l}^{-1}$ with a median of 356 $\mu\text{g l}^{-1}$. Roughly 25% of the boreholes had manganese concentration higher than 500 $\mu\text{g l}^{-1}$, which is the WHO maximum acceptable limit for drinking water. The concentration of mercury was higher than 1.0 $\mu\text{g l}^{-1}$ (WHO maximum acceptable limit) in 60% of the boreholes during the rainy season but below detection limit in the dry season, suggesting anthropogenic origin for mercury in the groundwater. Other trace metals that occurred, but in insignificant concentration in boreholes, include lead, arsenic, nickel and selenium. Most of the boreholes with high trace metal concentrations were located in and around the Bawdie-Bogoso-Prestea area.

Introduction

Ankobra basin is one of the main mining areas in Ghana. The major minerals mined in this area include gold, manganese, bauxite and diamond. Gold mining in this basin dates about 500 years ago but written records have restricted the period to 120 years (Marston *et al.*, 1992). The intense and uncontrolled mining activities in the basin have led to environmental degradation, including the pollution of surface water sources. Ankobra river, for instance, is documented to be highly polluted due to mining activities (WRRI, 1986). The Government of Ghana, increasingly apprehensive of the extent of pollution of surface water resources, has been providing communities with drilled borehole and hand dug wells as alternative source of potable water supply. Consequently, groundwater has become the principal and, sometimes, the only source of drinking water supply in the Ankobra basin. Apart from Tarkwa all major towns in the area, notably Bogoso, Aboso, Prestea, Huni Valley and almost all rural communities, rely solely on untreated groundwater as source of drinking water.

The preference of groundwater to surface water as a source of drinking water was based on the fact that groundwater excluded from the atmosphere would be less susceptible to pollution. This is true to an extent. However, groundwater in hard-rock aquifers, particularly in mining areas, is known to be vulnerable to quality problems that may have serious impact on human health. The rocks are often carbonate-deficient and give rise to poorly buffered water (Smedley *et al.*, 1995). Secondly, in gold and base metal mining areas, sulphides oxidation resulting from chemical and biogeochemical processes leads to the production of low *pH* ground-water that encourages the dissolution of trace metals into the groundwater system in very high concentrations. The ground-water, thus, becomes dangerous for human consumption. Trace metals such as Cr, Cd, Hg, Pb and U are known to be powerful nephrotoxins (Doul *et al.*, 1980). Renal injury caused by exposure to As, Au, Fe, Pt, Sb and Tl has also been demonstrated (Maher, 1976).

The main gold ore associated with the Birimian formation is refractory quartz-Fe/As sulphide lode gold (Marston *et al.*, 1992). Junner *et al.* (1942) pointed out that pyrite is common in many of the igneous rocks and quartz veins that intrude the Birimian and the Tarkwaian rocks. Thus, the existence of sulphides in the rock matrix and the moderately low *pH* groundwaters within the Ankobra basin (Kortatsi, 2004) suggest that there is the high probability of mobilization of some toxic trace metals into the groundwater and, for that matter, the drinking water supply of the Ankobra basin particularly in the Birimian rock areas where the sulphide ores are common. In

April whilst the lowest temperature is approximately 26 °C and occurs in August (Dickson & Benneh, 1980). The basin lies deeply in the forest ecological zone of Ghana. Semi-deciduous forest occurs in the northern half of the basin while the southern half is covered by tropical evergreen forest.

The geology of the Ankobra basin consists mainly of the lower Proterozoic rocks divided into the Birimian (lower and upper) system, unconformably overlain by the Tarkwaian system. Sills and dykes of igneous rocks ranging from felsite and quartz porphyry to meta-dolerite, gabbro and norite intrude into the Birimian and the Tarkwaian systems at several places. The Lower Birimian rocks underlie approximately 60% of the basin and are mainly pelitic in origin and consist of great thicknesses of alternating shales, phyllites, greywacke and argillaceous beds with tuffs and lavas. The Upper Birimian system covers approximately 8% of the Ankobra basin and is dominated by rocks of volcanic and pyroclastic origin. The rocks consist of a bedded group of green lavas (greenstones), tuffs and sediments with minor bands of phyllite that include a zone of manganiferous phyllites (Junner *et al.* 1942; Kesse, 1985).

The Tarkwaian system that forms nearly 15% of the rock cover occupies an elongated and narrow geosyncline about 16 km wide that stretches in a north-eastern to south-western direction. It consists of an overall thick clastic sequence of argillaceous and arenaceous sediments (mainly arenaceous) with two well-defined zones of pebbly beds and conglomerate in the lower members of the system (Junner *et al.* 1942). The Granitoid occupies about 10% of the Ankobra basin while the Eocene and Cretaceous deposits occupy approximately 3% of the basin. The Eocene and Cretaceous deposits occur along the coast. Fig. 2 is the geological map of the Ankobra basin.

Water samples were collected from boreholes and hand-dug wells, which were used for drinking and domestic water supply in the Ankobra basin between 15th and 20th November 1999. In all about 76 water samples were collected. Two samples, each in 100 ml acid-washed high-density linear polyethylene (HDPE) bottles, were collected at every sampling site with strict adherence to the sampling protocol described by Claasen, 1982; Barcelona *et al.*, 1985; Gale & Robins, 1989. The samples were filtered in the field using a hand-operated vacuum pump and conventional vacuum tubing with a 0.45- μ m cellulose acetate filter membrane. The samples meant for metals analyses were preserved by acidification to $pH < 2$ immediately after filtration using Merck™ ultra pure nitric acid while those for anion analyses were without preservation.

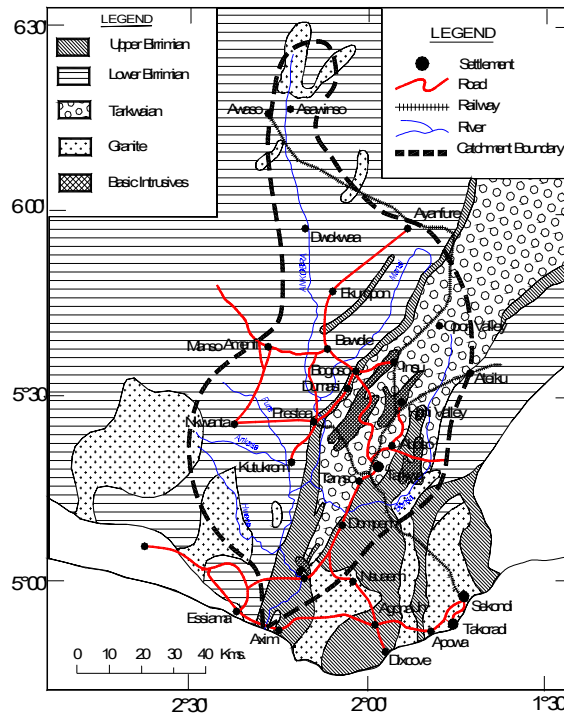


Fig. 2. Geological map of the Ankobra basin

On-site analyses of temperature, redox potential (Eh), pH and electrical conductivity were carried out using WTW-Multiline P4 Universal Meter in an anaerobic flow-through cell attached in line to borehole pump outlet. In order to avoid sampling stagnant annulus water around pump and pump systems, pre-pumping was carried out before the meter readings of the parameters (pH, Eh, etc.) were done. Since the boreholes were constantly in use, the average purge pumping time was 5 min. HACH Digital Titrator Model 16900 was used to carry out alkalinity titration at the wellhead. Major ions in the ground-water (sodium (Na^+), potassium (K^+), calcium (Ca^{++}), magnesium (Mg^{++}), bicarbonate (HCO_3^-), chloride (Cl^-), and sulphate (SO_4^-)) were analysed using Dionex DX-120 ion chromatograph at the Ecological Laboratory, University of Ghana. The analyses of all trace metals were also carried out using ICP-MS. ICP-MS analyses were carried out at the Geological Institute of the University of Copenhagen, Denmark.

As a quality control measure, the ionic balance of each sample was carried out. Generally the ionic balance for the analyses varied from 3.0% to 10.8%. However, more than 85% of the analyses have ionic balance within $\pm 5\%$. Ionic balance outside $\pm 5\%$ is largely associated with samples with very low conductivity values (total dissolved solids).

Results and discussion

Major ions and trace metals contents of drinking water (borehole) samples taken from the Ankobra basin are presented in Tables 1 and 2, respectively. Major cations (calcium, magnesium and sodium) are generally low in concentration. The concentration of Ca^{2+} varies from 0.3 to

70.5 mg l⁻¹. Concentration of Mg²⁺ lies in the range 0.2-46 mg l⁻¹, while Na⁺ and K⁺ are in the ranges 0.7–42 mg l⁻¹ and 0.4–25 mg l⁻¹, respectively. For most of the boreholes there is no predominant cation. In a few cases, however, Ca²⁺ and Na⁺ are apparently the predominant cations. The concentrations of major anions are generally low. Bicarbonate (HCO₃⁻) is by far the dominant anion. Its concentration varies from 0 to 380 mg l⁻¹ with a median value of 85 mg l⁻¹. The concentration of chloride (Cl⁻) varies from 4 to 194 mg l⁻¹ with a median value of 27 mg l⁻¹ whilst the concentration of sulphate (SO₄²⁻) varies between 0.5 mg l⁻¹ and 53 mg l⁻¹ with a median value of 14 mg l⁻¹.

TABLE 1

Statistical summary of the parameters determined in the 76 groundwater samples. Temperature in °C, pH in pH-units, EC in $\mu\text{S cm}^{-1}$, Ca to SiO₂ in mg l⁻¹.

Parameter	Min.	Max.	Mean	Median	Std dev.	WHO (1993) max.
Temp	25.8	29.2	27.0	26.9	0.7	
PH	3.7	6.9	5.6	5.7	0.6	6.5-8.5
EC	66.0	780.0	284.9	251.0	162.5	
Ca	0.9	115.0	17.8	10.6	21.5	
Mg	1.3	46.6	7.9	7.5	4.3	
Na	7.3	45.4	19.5	18.5	8.8	200.0
K	0.2	23.8	2.1	1.0	4.0	
HCO ₃	0.0	390.4	118.2	97.6	84.8	
SO ₄	1.0	34.4	8.2	5.5	6.9	250.0
Cl	2.0	110.0	25.6	16.9	23.0	250.0
NO ₃	0.0	30.3	4.9	1.0	7.4	50.0
SiO ₂	17.6	56.9	36.3	36.4	9.4	

TABLE 2

Statistical summary of trace metals in 76 groundwater samples from the Ankobra basin. Concentration in $\mu\text{g l}^{-1}$.

Trace metal	Detection limit	Minor and trace metals concentration					St Dev.	WHO (1993) recommended Maximum for drinking water
		Min	Max	Mean	Median			
Ag	0.01	<0.01	<0.01	<0.01	<0.01			
Al	0.10	<0.1	2510	127.0	<0.01	472.0	200.0	
As	0.05	<0.05	49	3	1	9	10.0	
B	0.50	<5.00	88	13	7	17	300.0	
Ba	0.04	27.00	495	130	96	102	700.0	
Be	0.10	<0.10	<0.10	<0.10	<0.10			
Cd	0.02	<0.02	<0.02	<0.02	<0.02		3.0	
Co	0.02	<0.02	45	6	3	9		
Cr	0.20	1.00	7	3	3	1	50.0 (p)*	
Cu	0.04	<0.04	267	24	7	41	2000.0 (p)	
Fe	10.00	1.00	13100	1709	268	3065	300.0	
Hg	0.01	<0.01	133	46	41	37	1.0	
Li	0.10	<0.10	28	10	9	8		
Mn	0.02	6.00	1510	419	356	364	500.0 (p)	
Mo	0.03	<0.03	<0.03	<0.03	<0.03		70.0	
Ni	0.06	<0.06	76	11	6	14	20.0	
Pb	0.03	<0.03	26	2	1	5	10.0	
Rb	0.01	<0.01	21	3	2	5		
Sb	0.03	<0.03	2	<0.03	<0.03		5.0 (p)	
Se	0.50	<0.50	17	3	1	4	10.0	
Sr	0.10	25.00	847	279	227	220		
Th	0.02	<0.02	1	<0.02	<0.02			

Ti	5.00	< 5.00	133	46	41	37	
Tl	0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	
U	0.01	< 0.01	3	< 0.01	< 0.01	1	
V	0.02	< 0.02	4	1	< 0.02	1	
Zn	0.10	8.00	1680	266	81	387	3000

- *p* stands for provisional.

It can be observed from Table 2 that the analytical results have not revealed the heavy metal loadings initially anticipated of a mining area as the Ankobra basin. However, the concentrations of aluminium, arsenic, barium, iron, manganese and mercury in some of the boreholes are high enough to pose either physiological or sensory problem, or both, for the usage of the boreholes as sources of drinking water. The concentration of these trace metals in relation to others is illustrated in the box plot in Fig. 3. As can be seen from the box plot, iron, copper and selenium are largely variable and have relatively large inter-quartile range while others have relatively small inter-quartile range. Aluminium, arsenic, cadmium and molybdenum, like other heavy metals not listed, have very small inter-quartile range with their respective median values below detection limits. The individual trace metals are discussed below.

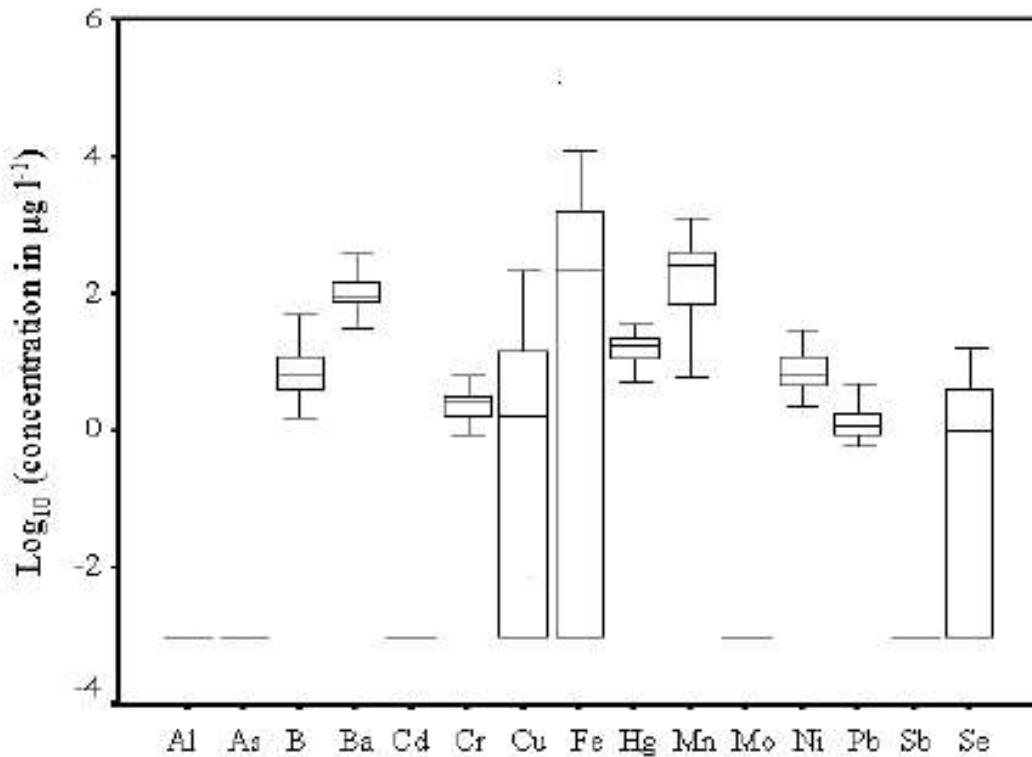


Fig. 3. Box plot of log of trace metals concentration of boreholes of the Ankobra basin

Aluminium

Aluminium (Al^{3+}) concentration in the boreholes in the Ankobra basin is in the range 0.1-2510.0 $\mu\text{g l}^{-1}$ with a mean, standard deviation and median values of 127.0 $\mu\text{g l}^{-1}$, 472.0 $\mu\text{g l}^{-1}$ and 10.0 $\mu\text{g l}^{-1}$, respectively. Approximately 20% of the boreholes have Al^{3+} concentration exceeding

the WHO (1993) maximum acceptable limit ($200 \mu\text{g l}^{-1}$) for drinking water supply. Al^{3+} concentration, as can be observed from the spatial distribution of the Ankobra basin (Fig. 4), is relatively high in the Bawdie, Bogoso, Insu and Tamso in the middle of the basin and generally low elsewhere. Fig. 5 shows the temporal variation in the concentration of aluminium in three of the boreholes from which the highest Al^{3+} concentrations were measured. The concentration in well 44-I-45-4 at Dumasi appears to follow a seasonal trend, i.e. it is high during the rainy period and low during the dry or hamattan period. On the contrary, the concentrations in wells 20-I-89-1 and 20-I-89-2 at Tamso remain almost constant suggesting seasonal independence.

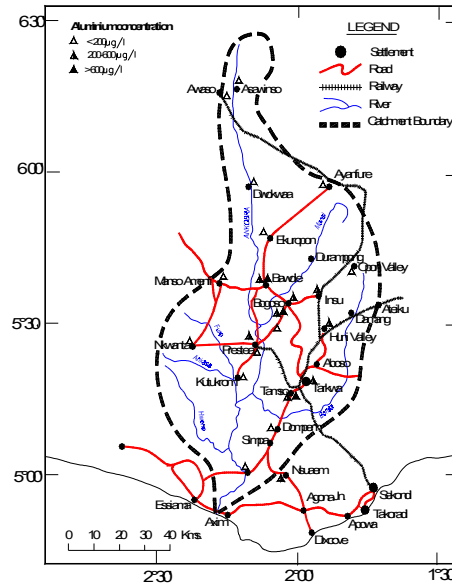


Fig. 4. Spatial variation in the concentration of aluminium in selected boreholes in the Ankobra basin

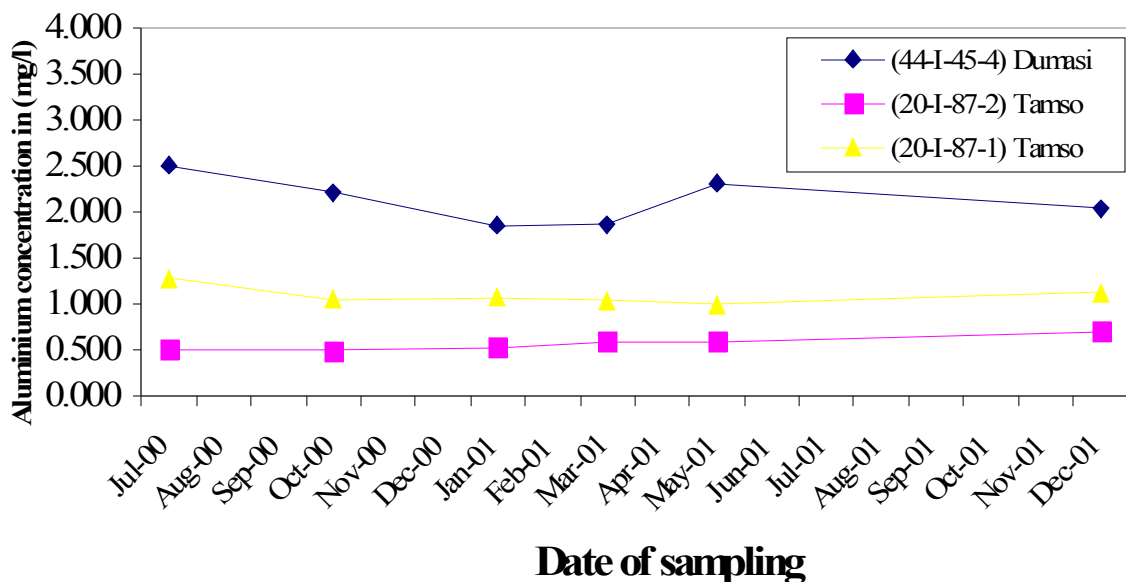


Fig. 5. Temporal variation in the concentration of aluminium in selected boreholes in the Ankobra basin.

Generally, Al^{3+} appears to have only little deleterious effect on humans. Nonetheless, its toxicity has been associated with central nervous system dis-orders including Alzheimer's disease and dialysis dementia (Moskowitz *et al.*, 1986). The greatest problem associated with the metal, however, is the incidence of discolouration it produces in drinking water and its distribution systems. It is in this regard that the WHO (1993) limited its concentration in drinking water supply to $200 \mu g l^{-1}$.

Arsenic

The concentration of arsenic (As) in boreholes ranges from 0.05 to $49.00 \mu g l^{-1}$ (Table 2). Approximately 5% of the boreholes have arsenic concentration slightly in excess of the WHO (1993) guideline limit of $10 \mu g l^{-1}$. This low percentage suggests that arsenic presently poses only limited potential physiological problem to the use of groundwater for drinking purposes. The concentration of As is generally very low (i.e. around detection limit) almost throughout the basin and only significant around Bawdie, Bogoso and Prestea areas. Fig. 6 illustrates the spatial distribution of arsenic in boreholes in Ankobra basin. The very low concentration of arsenic in the shallow ground-water, in spite of the high presence of pyrite and arsenopyrite in association with the gold ore, suggests a level of co-precipitation of arsenic with ferric oxyhydroxide in the creeks before possible infiltration into the aquifer. Arsenic is a known carcinogen (an agent producing and exciting cancer) and a toxin (Smedley *et al.*, 1995).

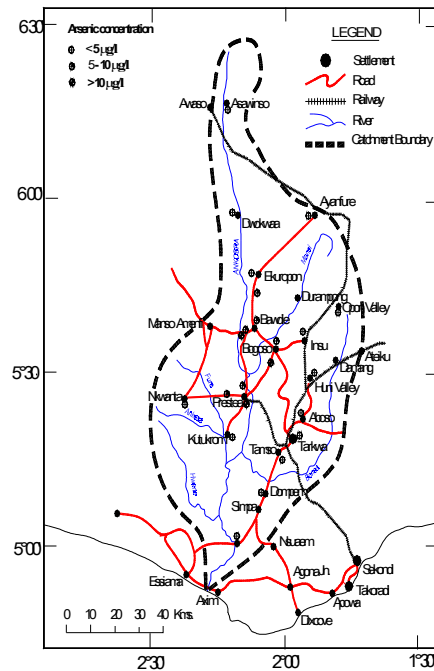


Fig. 6. Spatial variation in the concentration of arsenic in selected boreholes in the Ankobra basin

Skin cancer has been associated with long-term, low-level exposure to arsenic through drinking water (WHO, 1993), and there is suggestive evidence of increasing risk of bladder, kidney, liver and lung tumours as well. As indicated earlier, the boreholes that have significant arsenic concentration are mainly located in the neighbourhood of Bawdie, Bogoso and Prestea in the Birimian rock areas. Thus, people living in communities in Bawdie-Bogoso-Prestea area may, potentially, be at risk of diseases associated with long-term low-level arsenic ingestion. Nonetheless, as noted by Wang & Huang (1994), no morbidity cases would be expected where arsenic concentration of drinking water (groundwater) remains less than 0.1 mg l^{-1} . However, drinking water in the Bawdie-Bogoso-Prestea area needs to be constantly monitored in order to forestall any physiological problems that may arise due to unexpected increases in arsenic concentration.

Barium

The WHO (1993) recommended limit of barium for potable water is $700 \mu\text{g l}^{-1}$ (Table 2). Barium concentration in the water higher than the above limit may result in gastrointestinal tract disorder, vomiting and diarrhoea, and breakdown of the central nervous system causing violent tonic and chronic spasms followed, in some cases, of paralysis (Bowning, 1961; Patty, 1962)

The concentration of barium in boreholes (drinking water) from the Ankobra basin is generally lower than the WHO guideline value for drinking water (Table 2). Barium

concentration, therefore, does not pose any threat to present or future use of boreholes for drinking purposes.

Iron

Iron apparently is the most problematic trace metal associated with the drinking water in the Ankobra basin. Its common form in groundwater under Eh – pH conditions similar to those existing in the Ankobra basin (Fig. 7) is the soluble ferrous ion (Fe^{2+}). When exposed to air, the ferrous ion (Fe^{2+}) is oxidised to the ferric state (Fe^{3+}) that is insoluble and precipitates as ferric hydroxide (Appelo & Postma, 1999). This causes brown colouration of the water and stains sinks and laundered textiles. For the aesthetic effect that it produces, WHO (1993) decided to limit its concentration in potable water to $300 \mu\text{g l}^{-1}$. However, an upper limit of $1000 \mu\text{g l}^{-1}$ should suffice for most purposes (WHO, 1993).

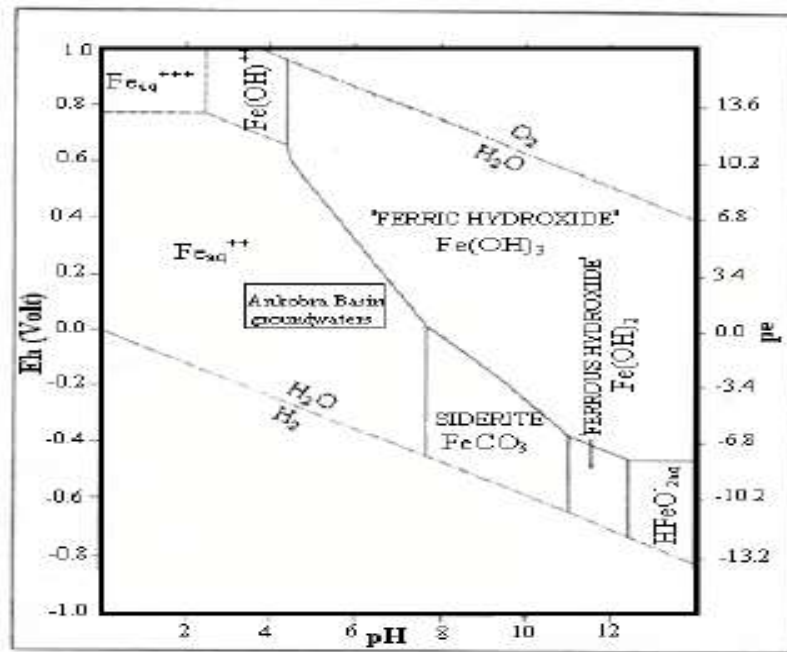


Fig. 7. pH – Eh relationship of groundwater in the Ankobra basin

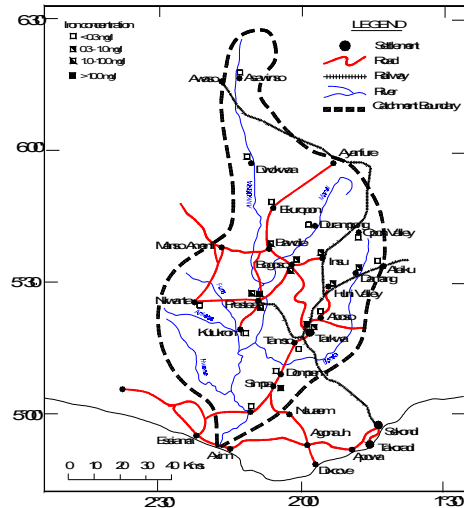


Fig. 8. Spatial variation in the concentration of iron in selected boreholes in the Ankobra basin.

Approximately 40% of the boreholes have total iron concentration greater than 1.0 mg l^{-1} . The spatial distribution of iron in the Ankobra basin is shown in Fig 8. Iron concentrations were apparently high in the middle and also to the south-west of the basin. The highest concentrations were obtained from boreholes within and around Prestea, Tarkwa and Simpa. Fig. 9 illustrates the temporal variations in total iron concentration in some selected boreholes within the basin. Within the limit of sampling and analytical error, the variations were only little. Thus, total iron concentration in borehole did not show any season dependence. The incidence of high iron concentration in boreholes in the Ankobra basin has resulted in low patronage and, in a few cases, to total rejection of some of the boreholes. In order to solve the iron problem, there is the need to build simple aerators or iron removal plant attached to boreholes, particularly in the areas underlain by the Birimian rocks.

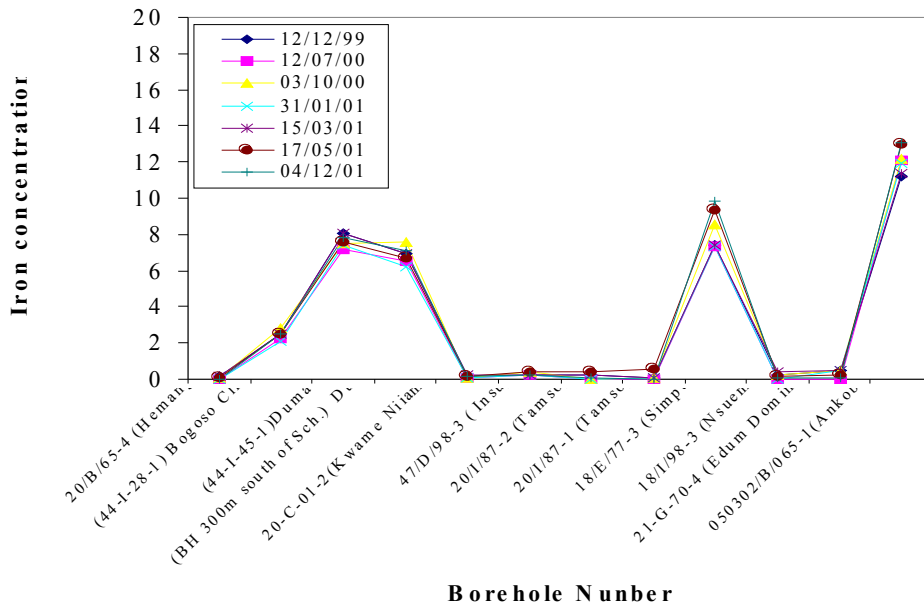


Fig. 9. Temporal variation in the concentration of iron in boreholes within the Ankobra basin

Lead

High lead concentration in drinking water may result in metabolic poisoning that manifests in symptoms such as tiredness, lassitude, slight abdominal discomfort, irritation, anaemia and, in the case of children, behavioural changes (WHO, 1980). The WHO (1993) recommended limit for the level of lead in drinking water is $10 \mu\text{g l}^{-1}$. Approximately, 9% of the bore-holes in the Ankobra basin have lead levels slightly higher than WHO (1993) recommended guideline limit. The relatively high lead concentrated waters were observed in bore-holes in the areas underlain by the Birimian rocks, particularly in the Bogoso-Prestea area. Nonetheless, the lead levels were only slightly above the recommended limit and should not cause alarm.

Manganese

In the Ankobra basin, manganese occurs mainly as manganese and manganiferrous oxides, particularly in areas underlain by the Birimian rocks (Junner *et al.*, 1942). Manganese, generally dissolves under mildly reducing conditions to produce the mobile divalent manganous ion (Mn^{2+}). When exposed to air, the manganous ion is oxidised to the hydrated oxides that form black colouration and can stain plumbing fixtures and laundered textiles (Hem, 1992; Hounslow, 1995). WHO (1993) limited the concentration of manganese in drinking water to $500 \mu\text{g l}^{-1}$. Manganese (Mn^{2+}) concentration in ground-water in the Ankobra basin varies from 6 to $2510 \mu\text{g l}^{-1}$ with a median of $356 \mu\text{g l}^{-1}$ and exceeded the WHO limit in approximately 25% of the boreholes. This percentage is high enough to affect the patronage of bore-holes and also to impact some physio-logical effect. It is, therefore, necessary to remove manganese from bore-holes by building manganese removal plant similar to iron removal plants attached to the boreholes. Since most of the wells that have high iron content incidentally also have high manganese content, iron removal plant may dually remove both iron and manganese through co-precipitation process.

The spatial distribution of manganese in the groundwater is shown in Fig 10. Boreholes with high manganese concentration are situated around Tarkwa, Huni Valley and Simpa. The

temporal variation in the concentration of manganese, as illustrated in Fig. 11, has shown only little variation in the concentration of manganese ions in boreholes between the beginning of January 2000 and December 2001. The greatest variation (840–1340 $\mu\text{g l}^{-1}$) occurred in the borehole (18-E-77-3) at Simpa. Nonetheless, the variations were not seasonally dependent as both the highest and lowest values were measured in the dry season November to April. Thus, as in the case of iron, manganese concentration in the groundwater is apparently independent of season.

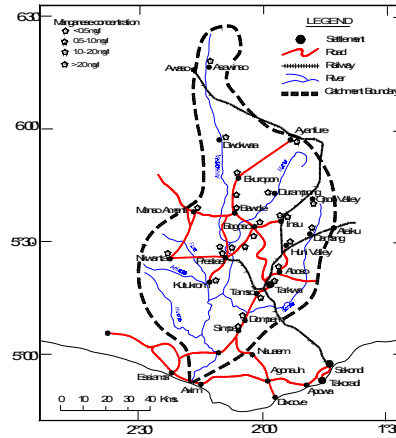


Fig. 10. Spatial variation in the concentration of Manganese in selected boreholes in the Ankobra basin

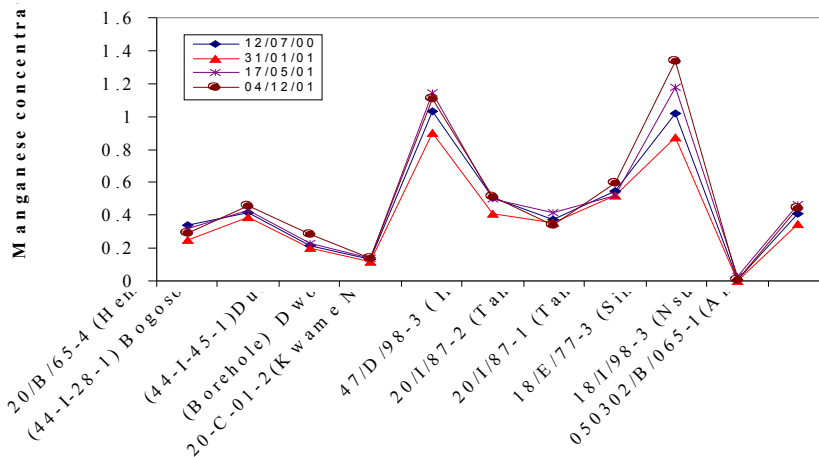


Fig. 11. Temporal variation in manganese concentration in selected boreholes in the Ankobra basin
Nickel

WHO (1993) recommended that the level of nickel in drinking or potable water should not exceed $20 \mu\text{g l}^{-1}$. Only 3% of the boreholes in the Ankobra basin have nickel (Ni) concentration slightly in excess of the WHO recommended limit. Nickel does not, therefore, pose any threat to groundwater use for drinking water in the Ankobra basin.

Selenium

Selenium is biologically beneficial to the metabolic requirement of animals when taken in the concentration range $0.1\text{--}10 \text{ mg kg}^{-1}$ of food. Selenium is, however, considered toxic to man if ingested in higher concentrations, and symptoms associated to selenium toxicity are similar to those of arsenic (Fairhill, 1941). Selenium concentration in the Ankobra basin is in the range $< 0.5\text{--}17.0 \mu\text{g l}^{-1}$, and only about 3% of the boreholes, and wells have selenium concentration above WHO recommended limit of $10.0 \mu\text{g l}^{-1}$. Thus, selenium does not pose major threat to groundwater development in the Ankobra basin.

Zinc

In the Ankobra basin, zinc is found mainly in the sphalerite (ZnS) and tennantite [$(\text{Cu}, \text{Fe}, \text{Zn})\text{As}_4\text{S}_{13}$] which form 0.03% of the sulphide ore in the Prestea mine (Owusu-Ansah, 2000; personal communication).

Zn occurs as a natural mineral in many drinking waters. It is an essential dietary nutrient and beneficial element in human metabolism (Vallee, 1957). Excess zinc, however, produces aesthetic effect (metallic taste) on the water. It was for this reason that WHO (1993) recommended a limit of $3000.0 \mu\text{g l}^{-1}$ for drinking water.

Zinc concentration in the groundwater in the Ankobra basin exceeded WHO recommended limit in only 1% of the boreholes. Thus, zinc concentration poses no quality problem for groundwater usage as drinking water in the Ankobra basin.

Mercury

The toxicity of mercury depends on its chemical form. The form of mercury associated with rocks, and with mining and smelting and, thus, likely to be associated with groundwater in the Ankobra basin is inorganic or non-carbon-containing mercury. Inorganic mercury has played an important role in the processing of gold ores in the Ankobra basin. Gold processing using mercury involves a process known generally as mercury amalgamation. Though, large mining companies are no longer using this method for gold extraction, the small scale miners still rely very heavily on mercury amalgamation for their operation. Both short and long-term oral exposure to inorganic mercury salts can lead to kidney damage, including kidney failure. It can also cause nausea, vomiting, pain, ulceration and diarrhoea (WHO, 1980). Toxicity to the brain and nervous system has been reported following large doses of inorganic mercury taken medicinally (WHO, 1980).

In the Ankobra basin, the concentration of mercury (Hg) in the boreholes varies in the range $< 0.01\text{--}133 \mu\text{g l}^{-1}$ (Table 2) with median value of $41 \mu\text{g l}^{-1}$. These values were observed in the boreholes only in the rainy period. In the dry season mercury concentrations were largely below detection. The temporal variation in mercury concentration in the Ankobra basin is illustrated in Fig.12. It appears mercury concentration in the wells is related to the recharge regimes of polluted surface water. This is likely to occur during the wet season than in the dry season. The low concentration observed in the samples taken in May could be due to delayed recharge water reaching the aquifer. Consequently, the occurrence of mercury in the groundwater bodies is largely due to contamination from surface sources, perhaps, as result of the indiscriminate use of mercury for gold processing in the Ankobra basin.

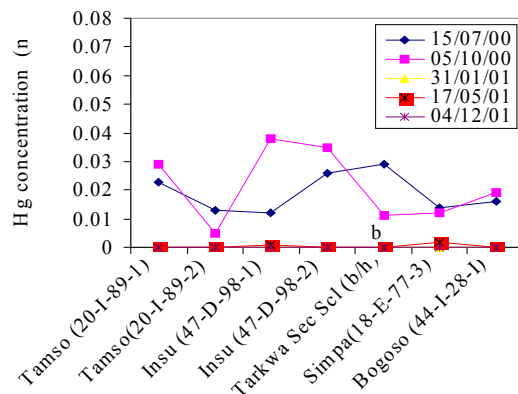


Fig. 12. Temporal variation in mercury concentration in boreholes from Ankobra basin.

Conclusion

The analytical results did not reveal heavy trace metals loading of the groundwater originally anticipated of a mining area. All except aluminium, arsenic, barium, iron, manganese, mercury and nickel have concentrations well below the WHO (1993) guideline values in all domestic boreholes used for drinking water supply. Mercury poses the greatest potential physiological threat for groundwater usage as a source of drinking water in the Ankobra basin. Its concentration exceeds the WHO guideline limit of $1.0 \mu\text{g l}^{-1}$ in all the wells during the rainy season but remains universally below detection during the dry season, suggesting the recharge of mercury contaminated water from the surface during the rainy season.

Arsenic and barium concentrations were higher than WHO recommended limits of $10 \mu\text{g l}^{-1}$ and $700 \mu\text{g l}^{-1}$, respectively, in less than 5% of the boreholes and do not, therefore, pose significant physiological problem for the use of the groundwater for drinking purposes. On the other hand, the concentrations of aluminium, iron and manganese are higher than WHO guideline limits of $200 \mu\text{g l}^{-1}$, $300 \mu\text{g l}^{-1}$ and $500 \mu\text{g l}^{-1}$ in more than 20%, 40% and 25% of the wells and boreholes, respectively, and, therefore, ostensibly pose significant potential aesthetic problems to groundwater quality. The aesthetic problems connected with these minor and trace ions as regards the groundwater can be greatly reduced by building simple iron removal or aerators attached to the outlet of boreholes. Iron and manganese are oxidised to form nearly insoluble hydroxide sludges. The sludges can be removed in a settling tank or by means of coarser filter. Aeration may not only remove iron and manganese but also other trace metals that may co-precipitate with iron (ferric oxyhydroxide).

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References

- Appelo C. A. J. and Postma D. (1999). Chemical analysis of groundwater. In *Geochemistry, groundwater and pollution*. AA Balkema/Rotterdam. /Brookfield.

- Barcelona M., Gibb J. P., Helfrich J. A and Garske E. E.** (1985). Practical guide for groundwater sampling. *Illinois State Water Survey ISWS Contract Report 374*.
- Bowling E.** (1961). *Toxicity of industrial metals*. Butterworth, London.
- Claasen H. C.** (1982). Guidelines and techniques for obtaining water samples that accurately represent the water quality for an aquifer. *U.S. Geological Survey Open File Report*. 49 pp.
- Dickson K. B. and Benneh G.** (1980). *A New Geography of Ghana*. Longmans Group Limited, London.
- Doul J., Klassen C. D. and Amdur M. O.** (1980). *Casaret and Doul's Toxicology*, 2nd edn. Macmillan Publishing Co., New York. pp. 239–245.
- Fairhill L. T.** (1941). Toxic contaminant of drinking water. *J. N. E. Wat. Wks. Ass.* **55**: 400.
- Hem J. D.** (1992). Study and interpretation of the chemical characteristics of natural water. *U.S. Geological Survey Water Supply Paper 2254*.
- Gale I. N. and Robins N. S.** (1989). The sampling and monitoring of groundwater quality. *British Geological Survey. Hydrogeology Report*, No. 89/37.
- Hounslow A. W.** (1995). *Water Quality Data Analysis and interpretation*. Lewis Publishers, Boca Raton, New York.
- Junner N. R., Hirst T. and Service H.** (1942). *Tarkwa Goldfield*. Memoir No.6. Gold Coast Geological Survey.
- Kesse G. O.** (1985). *The Mineral and Rock Resources of Ghana*. AA/ Balkema/Rotterdam/ Boston.
- Kortatsi B. K.** (2004). *Hydrochemistry of groundwater in the mining area of Tarkwa-Prestea, Ghana*. (PhD Thesis.). University of Ghana.
- Maher J. F.** (1976). Toxic nephropathy. In *The kidney*. (B. M. Brenner and F. C. Rector Jr, ed.), W. B. Saunders, Philadelphia.
- Marston R. J., Woolrich P. and Kwesi J.** (1992). Closely associated stock work and Paleoplacer gold mineralisation in the early Proterozoic Tarkwaian System of Ghana. Regional Trends in African Geology. *Proceedings of the 9th International Geological Conference, Accra. 2nd–7th November 1992*. Geological Society of Africa/ Geological Society of Ghana.
- Moskowitz P. D., Coveney E. A., Hamilton L. D., Kaplan E. and Medeiros W. H.** (1986). *Identifying human population at risk from acid deposition mobilised materials in drinking water supplies: A preliminary pilot study. Acid precipitation and health – part 1*. Water Quality Bulletin.
- Patty F. A.** (1962). *Industrial hygiene and toxicology*, vol. II. John A. Wiley, New York, pp. 998–1002.
- Service** (1938). *Annual Report of the Gold-Coast Geological Survey*.
- Smedley P. L., Edmonds W. M., West J. M., Gardner S. J. and Pelig-Ba K. B.** (1995). Vulnerability of Shallow Groundwater Quality due to Natural Geochemical Environment. Health problems related to Groundwater in the Obuasi and Bolgatanga Areas, Ghana. *Report Prepared for ODA under the ODA/BGS Technology Development and Research Programme, Project 92/5*.
- Vallee B. L.** (1957). Zinc and its biological significance. *Arch. ind. Hlth*, **16**: 147.
- Wang L. and Huang J.** (1994). Chronic arsenism from drinking water in some areas of Xinjiang, China. In *Arsenic in the environment, Part II: Human Health and Ecosystem effects*. (J. O. Nriagu, ed.), pp. 1259–172. Wiley, New York.
- World Health Organisation (WHO)** (1980). *Recommended health-based limits in occupational exposure to trace metals*. Technical Report Series, No. 647. Vienna, Austria.
- World Health Organisation (WHO)** (1993). *Guidelines for drinking water quality. Revision of the 1984 guidelines. Final task group meeting. Geneva 21–25 September 1992*.