

IODINE IN DRINKING WATER IN THE NORTHERN REGION OF GHANA Its Relationship to Iodine Deficiency Disorders

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ABSTRACT

Iodine (I) levels in various water sources of the Northern Region of Ghana are related to the underlying geology: the Basement Complex and the Voltaian sediments, and also the occurrence of goitre. Iodine is highest in the underground water (<0.3 to 983 mg/L). The mean I concentration measured in the Region was 42 mg/L, which is less than 30% the recommended daily requirement for an adult male. Iodine is higher in the groundwaters from the Voltaian sediments (especially the Middle Voltaian) than the Basement Complex. The observed trend was Basement Complex<Lower<Upper<Middle Voltaian. The explanation for this trend was due to the relatively more argillaceous sediments in the Middle Voltaian than the others. The rate of endemic goitre in the region underlain by the Lower Voltaian was explained by low I in the water sources. Some factors were suggested to explain the problem of I deficiency in the study area which include: (i) limited sources for I supplements to the people other than water; (ii) low I content from local foodstuffs produced from soils impoverished in I; (iii) I is not available to the body due to the presence of goitrogens; (iv) I content taken in is low and is not retained long enough in the body because it is not bioaccumulative: that is, it is readily excreted through sweat, urine, or faeces; and (v) probably the local food sources and vegetables may contain anti-thyroid agents.

KEY DESCRIPTORS: Basement Complex, Voltaian Sediments, Iodine Deficiency, Goitrogens, Water Sources.

INTRODUCTION

Iodine is one of the essential trace elements required by humans. This is because of the role it plays in normal body growth and development. The human body requires about 150 mg L⁻¹ of I daily in an adult male (Smith *et al.*, 1983). Deficiency in I thus results in diseases such as goitre. In Ghana, especially in the northern part of the country, reports have indicated the presence of goitre in many areas but no adequate reasons have been assigned since the causes of goitre are varied. Some of the causes include (i) iodine deficiency (ii) eating foods containing goitrogens (iii) disorders that interfere with the thyroid hormone production and (iv) selenium and zinc deficiency. It has been suggested that insufficient I in the body causes the I-producing gland

(thyroid) in the neck to swell, but the cause for low I in the body still remains unknown.

The effects of I on the human body also depend on its concentration. The effect may be hypothyroidism if the I concentration in the body is deficient while hyperthyroidism results if there is excess I. The general functions of these two conditions are opposite to each other. For example, in the hypofunction, the patient may have myxedema, decreased physical and mental growth. The stimulation of the thyroid gland by elevated thyroid-simulation hormone concentration in hypothyroidism normally leads to its enlargement known as goitre. Furthermore, overreaction of the thyroid gland due to high I excess in the body also produces goitre (Smith et. al., 1983).

It is also known that iodine-related goitre is not necessarily due to the lack of I in foods or water intake but probably to some agents known as antithyroids or goitrogens. Antithyroid substances may prevent the release of hormones that stimulate the thyroid gland or retard the iodination of hormones. These substances that interfere with iodination may include synthetic thiocarbamides, sulphonamides and iodine itself. High iodide concentration inhibits further iodination of tyrosine by elemental iodine. Iodine intake is inhibited when its concentration in the blood plasma rises above 30 mg/100 mL (Smith et al., 1983). Potassium thiocyanate is also an inhibitor of I intake. Ionic species such as NO_3^- , ClO_4^- , Br^- , BF^- and TcO_4^- are also inhibitors and have been suggested to be goitrogens (Smith et al., 1983). Limited or excess concentrations of some major and trace elements affect iodination of the thyroid leading to I deficiency have also been identified. These include Ca, Mg, F, As, Co, Mn, Zn, Cu, Mo and Sr. Some vegetables such as cabbages (*brassica genus*) are known to contain thiocyanate. Mustard seed oil contains isocyanates that can be converted to thiocyanates. Cyanogenic glucosides, which break into thiocyanates, have been found in maize and cassava. Goitrogens have also been found to occur in the milk of cattle fed on pasture and other feeds containing goitrogens (Fuge, 1987). Food and water are the main sources of I in human and animal body and one of the main evidences of its deficiency is the existence of goitre in these living organisms.

The disease has been found in some areas in Ghana including the Northern Region. In extreme cases of I deficiency cretinism may result. This study compares I levels obtained from water samples from selected groundwater, hand dug wells and surface water sources together with epidemiological data to confirm the prevalence rates of goitre occurrence in some selected districts of Ghana obtained by Ado (1994) since water forms a major source of I to humans. It is also the objective of this work to show the variation of I levels in selected water sources and the relationship to the major geological formations of the Northern Region, the Basement Complex (Birimian and granites) and the Voltaian Formation, and to assess goitre prevalence rate.

LOCATION, GEOLOGY AND CLIMATE

Location

The study area is the Northern Region of Ghana, which lies between latitudes 8° 00' and 10° 30'N and longitudes 0° 30'E and 0° 45'W. It is bordered on the north by the Upper East and West Regions, on the west by the Republic of Côte d'Ivoire, on the east by the Republic of Togo on the south by the Brong Ahafo and Volta Regions (Figure 1).

Geology

The Northern Region is geologically classified into three major formations. These are the Precambrian Birrimian Formation, found in the western margin of the study area, the Buem Series situated in the south-eastern part of the area; and the Voltaian sedimentary formation, which occupies the central basin of the study area (Figure 1). The Birrimian Formation is intruded by granites and termed the Basement Complex in this paper. These are said to be the oldest rocks and consist of metamorphosed sediments (Kesse, 1985). The granites are also divided by chemical composition into the Cape Coast, the Dixcove and the Bongo granite complexes, the latter being of limited area. The Buem Series is relatively younger than the Basement Complex but older than the Voltaian Sediments. However, the area underlain by the Buem did not form part of the current study.

The Voltaian formation consists of sedimentary rocks and is divided into three major age groups, the Upper (V3), the Middle (V2) and the Lower (V1) Voltaian. The Upper Voltaian consists of basal sandstone, interstratified shales, siltstone, mudstones, and an upper member of pure sandstone. It is located in the central part of the Voltaian Basin. The Middle Voltaian, which is the intermediate member, consists of interstratified shales, siltstones, mudstones and sandstones with intercalations of limestones and evaporites at the base and fine to coarse textured sandstones at the top. It is situated between V3 and V1. The Lower Voltaian is the lower member of the basal sandstone and is overlain by shales and quartzitic to feldspathic sandstone. These form the Gambaga and Konkori Highlands. It is found along the western and northern margins of the Northern Region.

Climate and Soils

The study area has a tropical continental climate and is in the savannah zone of West Africa at the fringes of the Sahel region. The movement of the Inter-Tropical Convergence Zone (ITCZ) influences the climate. The mean annual rainfall ranges from 900 to 1200 mm. Most of the rain falls in the period between May and September, which accounts for 70 to 80% of the annual total rainfall. Day temperatures are relatively high, especially during the dry season. The mean annual day temperature ranges between 26 to 37°C.

The dominant soil groups occurring in the area include Savannah Ochrosols, Groundwater Laterites (Petrosols), Tropical Black Earths, Savannah Lithosols, Grey Acid

Gleisols, Grey and Brown Calcium Vleisols and Sodium Vleisols (Brammer, 1962; Obeng 1975). Generally, the soils have very low organic matter contents and low nutrient status (Brammer, 1962). In addition, they have low moisture content because of the less reliable rainfall pattern. Most of the iron-pan soils are on extensive flat lowland areas and are poorly drained (Brammer, 1962).

The savannah ochrosols consist of red and brown, well-drained friable, porous loamy soils developed over the Voltaian sandstone, areas underlain by the phyllites and schists with some granites towards the south-west of the zone of the Basement Complex (Brammer, 1962). They occupy gently undulating to gently rolling topography. Usually, red or reddish-brown soils predominate. In depressions, soils are usually grey acid or neutral Gleisols, but Sodium Vleisols appear to occur in some valley bottoms. The texture of such soils varies according to the parent materials (Brammer, 1962). The groundwater laterites cover extensive areas in the Voltaian Shales (V2) and granites in the Interior Savannah zone. The groundwater laterites range from about 5 to 60 cm of pale-coloured, sandy or silty loam overlying vesicular, orange and black iron pan. These, according to Brammer (1962), occur on upland parts of very gentle topography under savannah vegetation.

Sampling and Analysis

Groundwater and surface water samples were collected and filtered using 0.45mm from selected boreholes and rivers from a dugout (dam) from Adibo, the White Volta at Yapei, the Black Volta at Buipe and the confluence of the two at Makango from the Northern Region in 1997 and 1998 and sent to the University of Reading for analysis. In all 59 samples (comprising of 55 boreholes and 4 surface water systems) were analyzed. A mean from three analytical readings was obtained as the I concentration for each sample. During the same period, rainwater samples from Tamale were also collected and analysed for iodine. Iodine was analyzed by using the pyrohydrolytic decomposition method described by Rae and Malik (1996).

RESULTS

Physicochemical properties

The field pH in the Basement Complex ranged from 5.0 to 7.4 with a mean of 6.6. Generally, the specific electric conductivities (SEC) were low with mean of 529 mScm^{-1} and a range from 170 to 1781 mScm^{-1} , indicating low total dissolved solids. In the Voltaian sediments the pH ranged from 4.8 in the V1 to 8.6 in the V2 series, with a mean of 7.0. Most of the samples had values above 7.0. However, of the individual geological units, the V1 appeared more acidic with most samples having a pH below 7.0. The specific electrical conductivity (SEC) averaged 800 mScm^{-1} with minimum and maximum values of 54 and 5230 mScm^{-1} respectively. The highest conductivity was obtained in the V2 series. Few samples indicated relatively higher SEC in V3 and V2, which were characterized by correspondingly high Cl or SO_4 with Na and Ca as the main cations (Pelig-Ba, 2000).

Table 1: Iodine concentrations in groundwater and surface waters in selected samples from the study area (R*= river)

LOCATION	GEOL.	pH	Eh	DO	I	LOCATION	GEOL.	pH	Eh	DO	I
Kojo-kura	V3	6.64	197	3.6	62.2	Mankango R*	V3	6.64			5.6
Tolon 2	V3	4.04			4.2	Kpembe	V3	7.72	221		30.5
Ache-bunyo	V1	6.84			122.0	Afayili	V3	8.10	176	6.7	66.3
Tarkpaa 4	V3	5.94			6.8	Bimbila Tr.Co	V2	6.66	257	0.0	3.1
Nyange	CB	7.38			<0.3	Kpandai	V2	6.69	239	0.0	46.8
Mandari	CB	5.69			24.4	Adibo 2	V2	7.02	235		13.7
Jantige	CB	6.73			<0.3	Adibo Dam	V2	8.39			5.3
Baale	CB	6.65	271		<0.3	Gnani	V2	7.24	225		47.0
Waka-waka	CB	7.17	260	2.4	5.6	Seripe	CB	6.53			7.3
Klambabete	CB	7.23			13.9	Yemo-Karaga	V2	7.59	209	0.0	36.8
Sawla Yipala	CB	6.78	249	5.5	3.6	Gbangu	V2	7.78	191		73.8
Kpabla	V3	7.94	185	3.4	105.0	Gbangu Well	V2	7.71			11.6
Mona	CB	6.93			<0.3	Saboba	V2	7.05	235	4.9	26.4
Limo	V2	6.28			63.2	Wajoga	V2	7.62	202	0.0	343.0
TTC	V3	7.08	230		6.0	Gambaga	V1	4.84	369		2.0
Sung 2	V2	7.73			67.4	Langbensi	V1	5.09			<0.3
Sang	V2	7.30			19.8	Duu	V2	6.63	283		1.5
Gunsi (1)	V2	7.18	238		<0.3	Busunu	V2	6.29	272		27.5
Sambu	V2				23.9	Busunu Well	V2	5.85			10.9
Nyingasori	V2	7.52			983.0	Yapei White Volta R*	V3	7.59			4.9
Kpatinga	V2	6.24			10.0	Buipe Yipala	V3	7.59			27.0
Sekpe	V2	7.42	215		44.6	Buipe Black Volta R*	V3	7.35			5.8
Anyanto	V1	6.82	252	3.8	<0.3	Senyon 1	CB	5.65			5.0
Mankarigu	V1	6.00	220	6.3	<0.3	Soma	CB	5.04			0.8
Kasepe	V1	7.63			<0.3	Kalba	CB	6.93	324		1.0
Tempiela	V1	8.41	153		7.9	Gbongbondori	CB	7.30			50.0
Samene	V1	8.45	150	7.4	<0.3	Nassoyiri	CB	6.62			3.3
Walewale	V2	8.58			<0.3	Kabampe	V1	6.81			1.8
Nagbo	V1	8.17	168	0.0	20.0	Damongo	V1	7.17			25.0
Jawani	V1	8.14	169	0.1	7.1	Tamale Rain 1	V3				1.5
						Tamale Rain 2	V3				1.4

Source: Field Survey (1997/8)

The Basement Complex

Iodine levels in the area ranged from <0.3 to 50 mg L^{-1} (Table 2). Apart from the Gbongbondori, Mandari and Klambable all samples had I values below 10 mg L^{-1} . Igneous rocks such as granites, intrusive and extrusive have been shown to contain I ranging from 200 to 580 mg L^{-1} (Fuge, 1987). It was not possible to analyze I in both rock and soil due to logistical problems. But the amount of I derived from such rocks will depend on a factors such as (i) the I content of the local country rocks and soils, (ii) the rate of weathering of these rocks and (iii) the period contact between the water and rock matrix or fragments resulting from weathering processes.

Table 2: Iodine concentrations in groundwater for samples from the Basement Complex of the Northern Region

Location	I (mg L^{-1})	Location	I (mg L^{-1})
Nyange	<0.3	Senyon	5.0
Mandari 2	24.4	Soma	0.8
Baale	<0.3	Gbongbondori	50.0
Jantige	<0.3	Kalba	1.0
Wagawaga	5.6	Nassoyiri	3.3
Klambable	13.9	Seripe	7.3
Sawla-Yipala	3.6	Mouna	<0.3
MEAN			11.2

Source: Field Survey (1997/8)

These crystalline rocks also contain low or no organic matter. Low I levels in these rock types are therefore attributed to the lack of principal source minerals, low clay and low organic matter content.

The Voltaian Sediments

i. Iodine Content in rainwater and surface waters

Two rainwater samples had I concentrations of only 1.4 and 1.5 mg L^{-1} . However, Fuge *et al.* (1987) showed that an area between the Welsh coast and about 84 km inland had I concentration decreasing from 2.2 to 1.0 mg L^{-1} . Tamale is over 600 km from the nearest coast and a mean of 1.45 is therefore comparatively within-range. However, this also depends on the duration and intensity of winds bringing moisture from the sea to inland areas. The surface water sources such as the White Volta at Yapei and Mankango had concentrations of 4.9 and 5.6 mg L^{-1} respectively; the Black Volta at Buipe had a concentration of 5.8 mg L^{-1} , while a dugout at Adibo (V2) had a concentration of 5.3 mg L^{-1} which are almost the same order of magnitude. The mean I concentration in all the sampled surface waters was 5.3 mg L^{-1} but was slightly above that obtained for other surface waters reported by Fuge and Johnson (1986).

(ii) Iodine in Hand-dug wells and Boreholes

Hand-dug wells were all shallower than the boreholes sampled in the study area. Iodine concentrations in these hand-dug wells (Table 3) were generally lower than the concentrations in the nearest boreholes within the vicinity, but higher than all surface waters sampled in this study. For example the boreholes at Gbangu (73.8 mg L^{-1}) and Busunu (27.5 mg L^{-1}) have higher concentrations in the hand-dug wells (Table 3).

Table 3: Iodine levels for duplicate samples in hand-dug wells.

Location	I (mg L^{-1})	Location	I (mg L^{-1})
Busunu Well	10.9	Limo Well	63.2
Gbangu Well	11.6	Walewale	<0.3
Tolon Well	4.2		
MEAN			18.0

Source: Field Survey (1997/8)

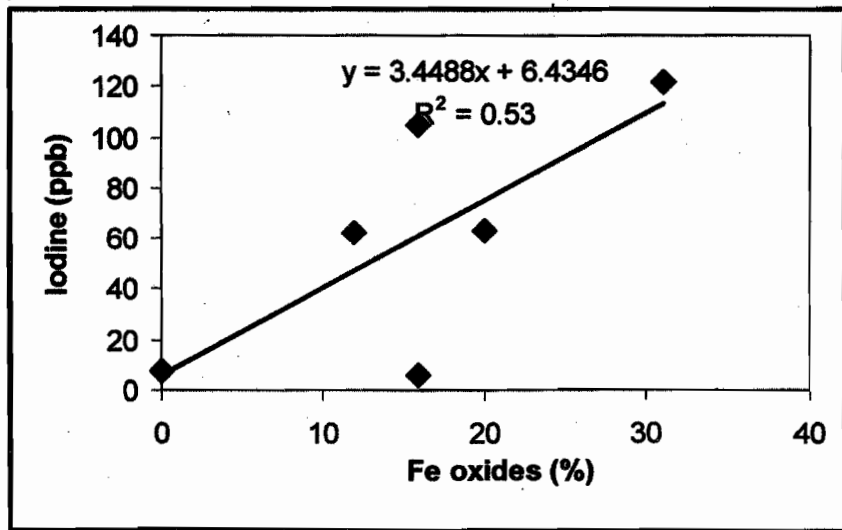
In samples from the Upper Voltaian which includes Tamale Town, I concentrations were relatively higher than those from the Basement Complex and the Lower Voltaian but less than in the Middle Voltaian. The mean concentration was 35.8 and a range from 6 to 66.3 mg L^{-1} was obtained. However, a hand-dug well at Limo located in this formation showed an I level of 63.2 mg L^{-1} higher than most boreholes. At the time of sampling, the well was being rehabilitated and it was evident that organic debris consisting remains of crops cultivated during the past farming season which normally include millets, cowpea, maize and even uncultivated grasses had entered the well. Furthermore, as the location of the site was on a farmland, suggested that domestic manure and possibly fertilizers that might have been applied during the past seasons could be some anthropogenic sources of I. The well was shallow (about 5.6 m deep) and therefore the relatively high I content probably pointed to a possible anthropogenic source. The highest I levels were obtained from boreholes located in the Middle Voltaian. Only two samples (Gunsi 1 and a well at Walewale) had values below detection ($<0.3 \text{ mg L}^{-1}$) while Wajoga and Nyingasori recorded the highest concentrations of 343 and 983 mg L^{-1} respectively.

The soils at Gunsi are largely sandy with little organic matter status thus I concentration is low and therefore below detection. The mean concentration of I in the Middle Voltaian was 107 mg L^{-1} , which is about 71% of what is required by an adult male. At Nyingasori in particular, the borehole was located in a valley along a flood plain. The soils along this plain are clay-dominated. Total organic carbon (TOC) analyses performed for selected soils at Gushiegu closed to the Nyingasori showed low values ($0.28 - 0.69\%$) (Pelig-Ba, 2000), which one cannot attribute the high I concentration in the borehole to organic matter. The soils in this area are derived from shales, which are argillaceous in texture and dominated by clay especially smectite clays (Pelig-Ba, 2000). Hence the high I concentration in this case could be attributed to high argillaceous material and the clay content. Carbonates and shales are shown to

have I concentrations of 2700 and 2300 mg L⁻¹ (Fuge and Johnson, 1986) and these can easily break down when in contact with water. These rock types also form the Upper and Middle Voltaian series, so water from where these form the aquifer material is likely to contain high I and this also explains the relatively high I content in the Nyingasori borehole.

The Lower Voltaian, covers the areas around the Gambaga Scarp and the Konkori Highlands in the west Gonja area, had I levels ranging from <0.3 to 122 mg L⁻¹. Achebunyo in the West Gonja had the highest I concentration, probably due to the relatively higher clay content. The TOC for the soil samples in Achebunyo was very low (0.1 – 0.27%) (Pelig-Ba, 2000) suggesting that high clay content may be responsible for the relatively high I content in this borehole. However, the oxides of metals especially those of Fe (goethite and haematite) could act as binders. The scatter in Figure 2 illustrates the correlation of I content with total Fe oxides and shows a positive correlation between the two. This suggests that the Fe oxides have a positive relation with I content in the soil. This explains the high I concentration at Nyingasori. Depending on the geochemical conditions I can then be released into groundwater. But areas around the Gambaga Highlands within the V1 series, underlain by quartzitic and feldspathic sandstones, had a maximum of 20 mg L⁻¹, with less than 10 mg L⁻¹, and a mean concentration of 15.5 mg L⁻¹. The nearest location around the foothills where soil samples were collected was Kbirri where TOC ranged from 0.45 to 0.70%.

Figure 2: Plot of Fe oxides (goethite and haematite) composition with iodine concentration



Source: Field Survey (1997/8)

This was about the highest TOC value in the study area. On contrary, soils around the foothills were rather sandy and very loose with very little clay content and contained low content of oxides of Fe (Pelig-Ba, 2000). The concentration of I in the study area was different in each geological environment and it was evident from the mean values that those waters from the Voltaian sediments generally had higher I content than those from the crystalline basement.

Table 4: Summary of iodine concentrations in the groundwater from geological units in the Northern Region, Ghana.

Geological Unit	I (mg L⁻¹)
Basement Complex	11.2
Upper Voltaian	35.8
Middle Voltaian	107
Lower Voltaian	15.5

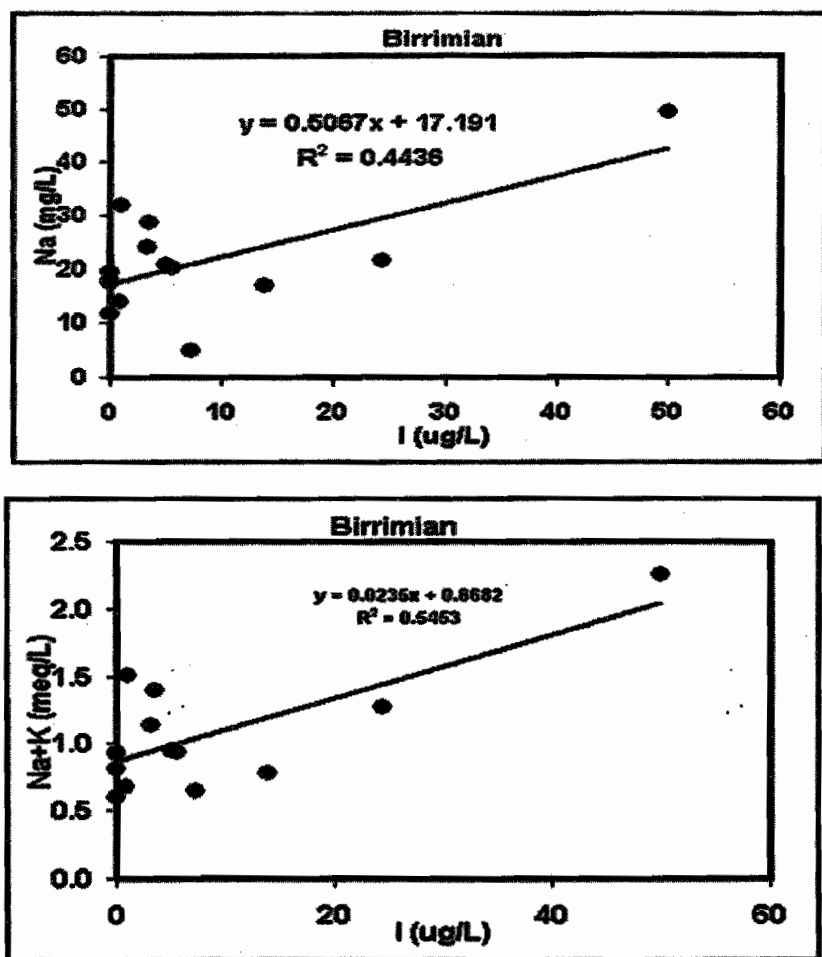
Within the Voltaian sediments variations also occur, suggesting that stratigraphy, soil type and organic matter content may have a significant influence on the enrichment of iodine in those areas. The enrichment varies as follows; Basement Complex < Lower Voltaian < Upper Voltaian < Middle Voltaian (Table 4).

Iodine Geochemistry

Iodine as a trace element is a constituent of various minerals and does not form separate minerals of its own like other trace elements. However, known minerals containing I are usually iodides of metals such as AgI, Ca(IO₃)₂, CuI, Cu(OH)(IO₃), and polyhalides, iodates and periodates (Kabata-Pendias and Pendias, 1992 and Wedepohl, 1978). Iodine contents in rocks and soils are very variable. From data provided by Fuge (1987) and Kabata-Pendias and Pendias (1992) crystalline rocks appear to contain lower iodine concentrations than sedimentary rocks especially shales. High I content is attributed to the presence of high organic matter and clay content in these sedimentary rocks. In particular, common minerals such as biotite, muscovite, hornblende, feldspar and olivines contain between 70 to 500 ppb (Wedepohl, 1978). Most compounds of I are generally soluble in water and therefore it is easily released into the environment during weathering of rocks. Iodine concentration is generally higher in soils rich in organic matter or hydrous oxides of Fe and Al, and chlorite-illite groups of clays.

Iodine in the Basement Complex was correlated with Na, (Na+K) and (Na+Ca) in the area of study and the r² values of 44 and 55% were obtained for Na and Na+K respectively while the correlations with Ca and Mg were very low (<13%) (Figure 3).

Figure 3: Plot of iodine against Na and Na+K concentration in groundwater from the Birrimian Formation



Source: Field Survey (1997/8)

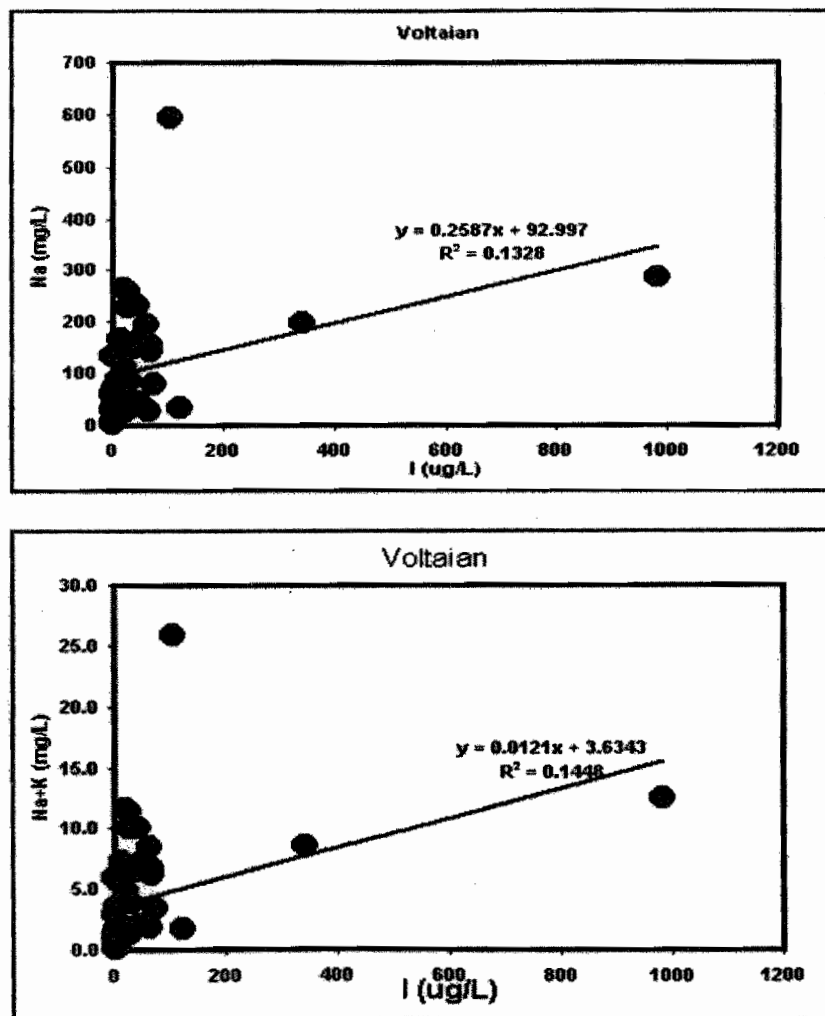
The linkage with Na is probably due to its abundance in seawater or from the same source point.

The relatively high regression coefficients between I and Na or (Na+K) suggest that I normally exist as iodide or iodate salts of Na and K.

In the Voltaian sediments lower correlations of I with the alkali and alkali earth metal ions than in the Basement Complex were also observed (Figure 4). Although the con-

centrations are relatively higher in the Voltaian sediments than in the Birrimian, the low correlation in the sediments suggests that source of iodine is different from Na and K even though the source minerals are normally iodides or iodates of Na and K.

Figure 4: Plot of Na and Na+K against iodine concentration in the Voltaian sediments



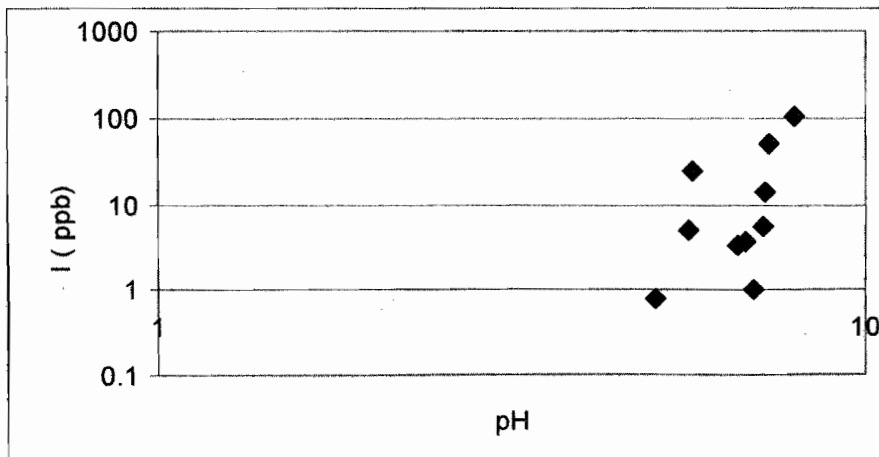
Source: Field Survey (1997/8)

In the Voltaian, I could be derived from the carbonates rocks and even dead organic matter in addition to rainfall, which may constitute diffused sources. Iodine exists

mainly as the iodate (IO_3^-) in NaIO_3 in oxidising environments or iodide (I^-) in reducing waters (Hem, 1992). Iodine also occurs in natural brines obtained from underground wells. Its source in the terrestrial environment is also attributed to sea spray brought inland by rain and wind.

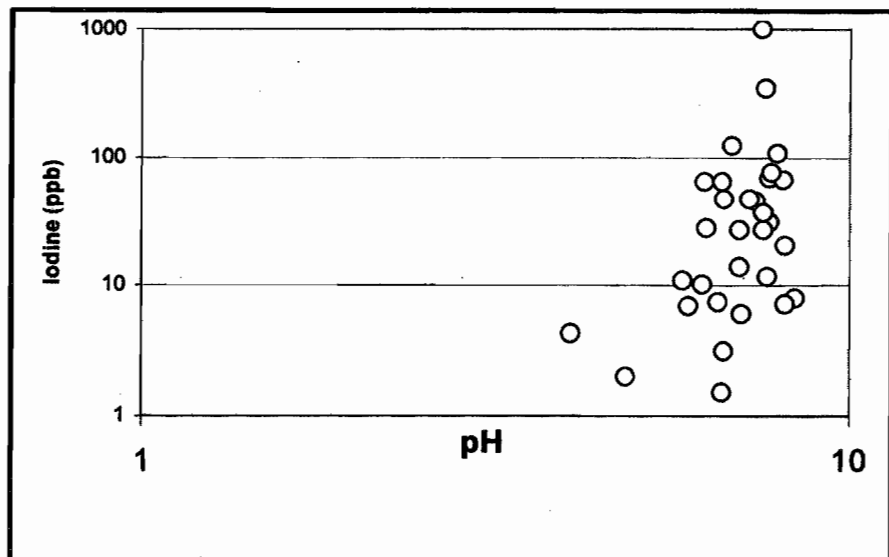
However, Whitehead (1979) identified several factors that affect the geochemistry of I in Derbyshire in the U.K. These are (i) type of rock (ii) direction of prevailing wind from the sea (iii) exposure to the site and (iv) age of the soil. These factors governing the retention of I reflect partly the inputs over the course of soil development and partly the ability to retain the iodine against leaching and volatilisation. Another factor according to Saikat et al. (2004) that influences the iodine geochemistry is pH regime of the soil. However, Fuge (1996) also stated that Eh-pH conditions govern the form and mobility of I in soil. In acidic oxidizing conditions, free iodine exists in the form as iodide (I^-) and can be converted to I_2 , which is mobile and volatile where as in acidic reducing conditions, the iodide ion becomes stable and is not converted to the mobile and volatile iodine. But in alkaline conditions the I present is not likely to be converted to I_2 but into the more stable IO_3^- and hence it is not mobilized. Although I was not obtained for soils but water, the values indicated a considerable variation in the study area reflecting partly to type geology and the geochemical conditions. From the plots of pH against I concentration in Figures 5 and 6, it is evident that high iodine concentrations are observed in less acidic conditions especially when the location is oxidizing suggesting that the more stable IO_3^- is likely to be available. Another important factor that accounts for the variation of iodine in groundwater is the type of soil forming the overburden.

Figure 5: Log plot of pH against iodine content of water sources from the Birrimian formation



Source: Field Survey (1997/8)

Figure 6: Log plot of pH against iodine content of water sources from the Voltaian sediments



Source: Field Survey (1997/8)

The soil at Gunsi in the Yendi District is basically sandy and free flow of water could leach the available iodine away while clay and oxides of Fe are better in holding I. Sandy soils with a lot of canopy tend to obtain the iodine from the vegetation and this may also explain local variations.

Epidemiological Data

Ado (1994) reported on the prevalence rate of goitre for selected districts in Ghana. Among those listed with high prevalence were the Tolon-Kumbungu (21.9%), East Mamprusi (38.3%) and Bole Districts (17.6%) and located in the V3, V1 and the Basement Complex (Birrimian) respectively. The results do not cover the entire area underlain by the sub-geological units but they show that the V1 probably has the highest prevalence rate corresponding to the lowest I content in the water sources within the Voltaian. No district underlain by the V2 series was reported to have a problem of I deficiency during the study by Ado (1994). This could be that no district was either identified to have the disease or that the area was deliberately not covered during the study due to other reasons. If it was for the first reason, then it is suggested that the I content in the water and from other sources were high enough to prevent people from getting infected with the iodine deficiency diseases in this geological unit.

DISCUSSION OF RESULTS

From Table 4, I concentration was higher in groundwater than the other sources. Studies by Fuge and Johnson (1986) suggest that I content in rain and snow is about 2 mg L^{-1} , while surface water has a mean of about 5 mg L^{-1} . These values compare favourably with the results of this work, with rain and surface means of 1.45 and 5.3 mg L^{-1} respectively (although the spatial distribution and number of rainwater samples are lower in this study).

The mean I concentration in the various water sources studied is 42 mg L^{-1} (Table 5). This is far less than 30% of the daily requirement by an adult male. For this level of I, an adult may require to take greater quantities of water about 3.5 to 4 litres of water a day in order to meet the daily requirement. This may not necessarily be through only drinking but also using such water for food preparations.

Table 5: Summary of I concentrations in the water sources from the Northern Region (* excludes rain water)

Water Source	No of samples	I (mg L^{-1})
Rainwater	2	1.5
Surface water	4	5.3
Hand-dug well	5	18.0
Borehole	50	47.5
*MEAN	59	42.1

Source: Field Survey (1997/8)

However, the low concentrations obtained from water sources suggest that the geochemical sources of I do not either contain high I content or the rate of release to the water sources is very slow probably due to inadequate geochemical conditions. In spite of this water sources in this region contain relatively higher I levels than other areas that have been declared goitrous or non-goitrous regions in literature. For example, Day and Powell-Jackson (1972) found extreme goitrous areas in the Himalayas where I content was less than 1 mg L^{-1} but the non-goitrous areas in British Isles had 2.5 mg L^{-1} in their water. The non-goitrous areas in the British Isles had I content below that obtained in the groundwater in this study area, suggesting that the daily I intake in the British Isles and other places was not from water alone but probably from other sources. Several factors may be suggested to explain the problem of I deficiency in the study area: (i) limited sources for I supplements to the population other than water; (ii) low I content from local foodstuffs produced from soils deficient in I; (iii) I is not available to the body due to the presence of goitrogens; (iv) I content taken in is low and is not retained long enough in the body because it is not bioaccumulative: it is readily excreted through sweat, urine, or excreta; and (v) probably the local food sources and vegetables may contain antithyroid agents.

A high goitre prevalence rate has generally been attributed either to low iodine intake or the presence of antithyroid agents or goitrogens. In Ghana, and particularly northern Ghana, little or no work is available to demonstrate the availability or absence of such species as thiocarbamides, thiocyanate or sulphonamides in the local foods and vegetables. This is important because the quality of agricultural products varies with the soil type. Geological differences should also be considered important, especially in the case of the inorganic species that are causative factors for goitre by acting as anti-agents.

Food crops and vegetable plants obtain their source of I from the soil and any soil low I may be reflected in these sources. Soil organic matter helps to retain I (Fuge and Johnson, 1986) and where soils are impoverished in organic matter, I level may be low. In the Northern Region, and the Northern Savannah belt as a whole, frequent bush fires destroy organic matter and none is available to retain the fertility. Although soil I was not analyzed, low I in groundwater may partly be attributed to low soil I with the assumption that water filtration through the soil profile is what carries I to the groundwater table.

High I concentrations in a hand-dug well at Limo as well as others in the study area could partly be derived from anthropogenic sources such as fertilizers or farm yard manures, through the absorption and release by clays or oxides of Fe and Mn. This is because many of the activities around the well site are farming activities in which the people do to improve on their crop yield. Soils from the Basement Complex and the Lower Voltaian have low organic matter and clay content (Brammer, 1962; Pelig-Ba, 2000) because soils derived from basement rocks are quartzitic and feldspathic sandstones contain less organic matter and most are less weathered to produce either argillaceous material or clay minerals. Therefore there is little retention of iodine and other soluble species in the soil matrix.

The mean I concentration for groundwater is lower than the minimum daily requirement by an adult male. People relying solely on such water sources for I may be at risk or have to consume large quantities to be able to obtain the right I concentration otherwise food supplements such as iodized salts and sea foods should be used.

CONCLUSION

Iodine concentration has been found to be low in the water sources in the Northern Region. This is partly attributed to the very low organic matter content of the soils, which reduces their ability to adsorb and release element when required. Rather, the result is the possible leaching of the element to lower depths than the reach of normal boreholes, and partly due to lack of source minerals of the element, which can release it either during weathering or dissolution when these minerals are in contact with water. It was observed that oxides Fe form an important phase that can adsorb the I and release it depending on the geochemical conditions. Higher I concentration in the

Voltaian than Basement Complex could be a result of higher pH in the Voltaian basin. Some groundwater sources indicate high I content yet the prevalence rate of I deficiency is high. Antithyroid agents or goitrogens may be responsible in some cases but the source of these agents still remains an important issue for future research. Local diets may play a significant role in determining the sources and type of antithyroid agents. It is suggested that antithyroid agents in locally cultivated food-stuffs and vegetables be the focus of further work, together with inorganic species that are significantly responsible for I deficiency problems such as goitre.

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