CHAPTER 5

IODINE GEOCHEMISTRY AND HEALTH

It has been estimated that about 29% of the world population is at risk from some form of iodine deficiency disorder. It is the world's most common cause of mental retardation and brain damage with 1.6 billion people at risk, 50 million children affected and 100,000 cretins born every year. Pharaoh (1985) considers endemic cretinism to be the most important form of IDD, even though other diseases such as still births, abortions, congenital abnormalities and impaired mental function of children are also major health problems (Stewart and Pharoah, 1996).

These iodine deficiency disorders (IDD) are particularly severe in the lands of the tropical belt. The impaired mental function of people has serious direct and indirect impacts on all aspects of life among these people (Figure 5.1). Figure 5.2 illustrates the world distribution of areas affected by IDD and it is apparent that the problem has assumed serious proportions and needs worldwide attention. Among these countries are those in the South Asian region namely Bangladesh, Vietnam, Myanmar, Indonesia, Nepal, India and Sri Lanka. Table 5.1 shows the magnitude of the problem in these countries, all of which lie in the tropical environment.

The geochemistry of iodine and its chemical species and its impact on the health of a very large population of the world is one of the most important fields of study in the field of medical geology.

THE IODINE CYCLE IN THE TROPICAL ENVIRONMENT

Figure 5.3 illustrates a schematic model for the possible transformation and geochemical pathways of iodine in the tropical environment. The sea is a major source of iodine and in lands adjacent to the sea, the marine influence will be particularly strong and the distance from the sea will therefore be of some importance. The expected decrease of iodine from the sea towards the land however is not always regular and other factors such as atmospheric circulation may play an inhibiting role.

C.B. Dissanayake, R. Chandrajith, *Introduction to Medical Geology*, Erlangen Earth Conference Series,
DOI 10.1007/978-3-642-00485-8_5,

[redacted]

Fig. 5.1. A typical case of endemic goitre from Sri Lanka

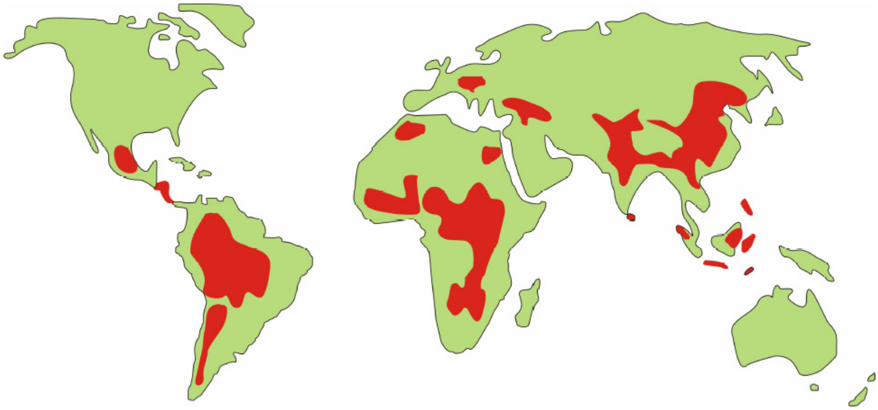

Fig. 5.2. World map showing areas affected by iodine deficiency. Other areas, especially in Africa and the Middle East, may also have iodine deficiency problems but have not been surveyed in detail (Dunn and van der Harr, 1990).

Table 5.1. The incidence of iodine deficiency disorders in some Asian countries (Source of data from WHO)

Country	Population (x1000)			
	At Risk from IDD	Goitre	Cretinism	Other Diseases
Bangladesh	37223	10230	491	2796
Bhutan	1446	993	95	704
Myanmar	14464	5700	404	2591
India	149580	54540	3338	18503
Indonesia	29772	10131	749	3569
Nepal	15056	9438	736	5145
Sri Lanka	1861	3107	140	580
Thailand	20438	7927	539	3331
Total	227740	102006	6488	36769

The high rainfall resulting in intense leaching of elements from the rocks and abundant laterite formation plays a major role in the geochemical cycle of iodine in the tropics. The presence of acid soils, organic matter and rapid groundwater flow also influence the leaching of iodine in the tropical environment to a marked degree. The most significant feature of the geochemical cycle of iodine is that the iodine abundance and mobility is most marked in the surface environment; these surface phenomena involving the soil-atmosphere interactions are of extreme importance.

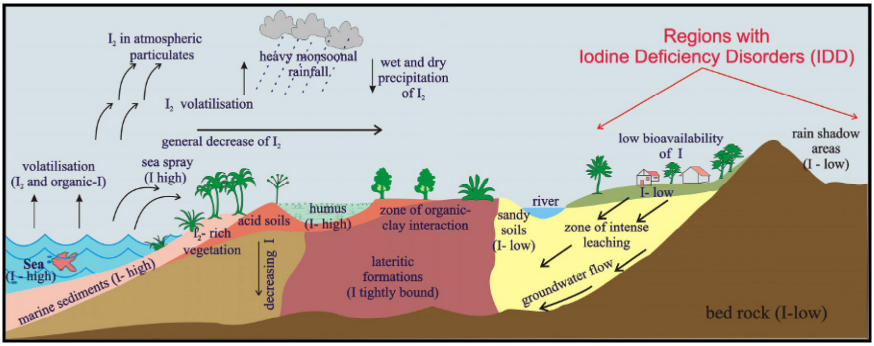

Fig. 5.3. The geochemical cycle of iodine (Dissanayake et al., 1998)

Radioactive iodine-129 (half life 15.7 Ma) has been released into the environment by nuclear weapons and the operation of nuclear facilities such as spent fuel reprocessing plants. The high mobility of iodine in the surface environment therefore becomes a critical factor in radioactive water management. The geochemical behaviour of iodine is now better understood as a result of studies of iodine radioisotopes (Muramatsu et al., 2004).

As shown in Figure 5.3, the sea which is the major source of iodine in the geochemical cycle has an average concentration of around 58 µg/L (Fuge and Johnson, 1986; Fuge, 1996). Iodate (IO_3^-) is the most stable form of iodine in sea water. It gets reduced to iodide (I^-) in surface waters by the biological action. Seaweeds and phytoplankton release iodine containing organic gases (CH_3I, CH_2I_2 etc) and these pass into the atmosphere where they undergo further chemical changes due to sunlight. The iodine in the atmosphere then migrates inland and is deposited inland by the climatic and topographic conditions (Johnson et al., 2003a). Figure 5.4 illustrates a simplified model showing part of the iodine cycle involving transport from marine to the terrestrial environment.

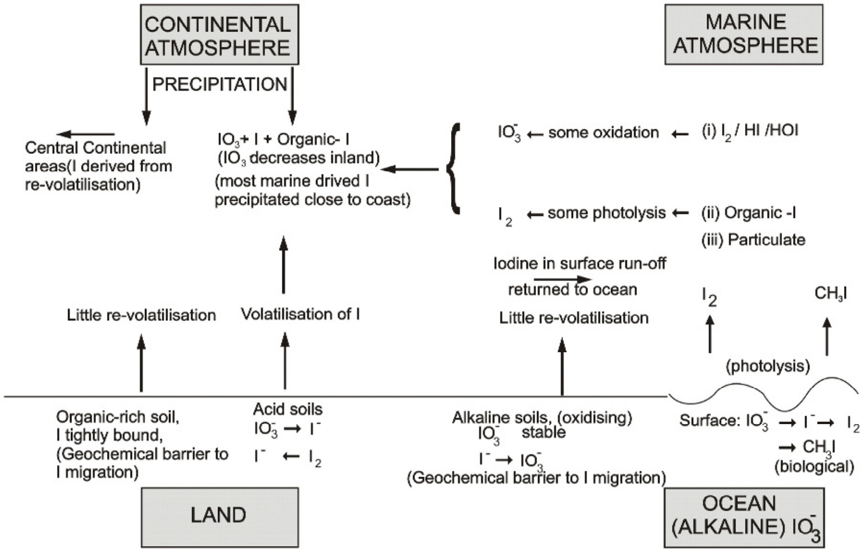

Fig. 5.4. Iodine transport from the marine to the terrestrial atmosphere (Fuge, 1996)

The distribution of iodine in the earth's crust was studied and the data compiled by Muramatsu and Wedepohl (1998). From among the magmatic and metamorphic rocks (Table 5.2), metasedimentary gneisses, mica schists and granulites have as little as 12 to 25 µg/kg I and have lost from 75 to >95% of their iodine content at metamorphic temperatures. Granites, granodiorites, tonalites, and basalts are even lower in iodine and contain 4 to 9 µg/kg I almost independent of the class of magmatic rock. Table 5.3 illustrates soil iodine levels of some parent rock materials.

Table 5.2. Iodine in magmatic and metamorphic rocks (µg/kg I ± SD) (SD, standard deviation of two to four determinations, mostly three determinations) (Muramatsu and Wedepohl, 1998)

Gneisses mica schists, amphibolites, marbles of upper continental crust	
Gneiss, Variscan Loja near Persenbeug, Lower Austria	9.8 ± 2.8
Gneiss, Variscan KTB deep hole Windischeschenbach Bavaria, Germany	38 ± 2
Gneiss, Variscan KTB deep hole Windischeschenbach Bavaria, Germany	46 ± 9
Gneiss, Variscan HTKB deep hole Windischeschenbach Bavaria, Germany	36 ± 3
Garnet sillimanite gneiss, Caledonian E Frivole near Arendal, Norway	8.2 ± 0.6
Two-mica gneiss, Alpine Brione Verzasca Valley, Switzerland	4.0 ± 0.6
Mica schist Panafrican Damara Belt, Namibia	18 ± 2
Amphibclite Panafrican Amphibolite Belt Augaigas Farm W Windhoek, Namibia	23 ± 3
Marble, Alpine Kleintal Gleinalpe Scyria, Austria	31 ± 6
Granulites of lower continental crust	
Hypersthene perthite granulite, Caledonian 1 km S Tveite Arendal, Norway	11 ± 1
Hypersthene plagioclase granulite, Caledonian 450 m N Skuggerik Arendal, Norway	10 ± 1
Hypersthene perthite plagioclase granulite, Caledonian Ferry to Tromoey Arendal, Norway	15 ± 2
Granite, granodiorites, tonalites	
Granites, Variscan Germany (composite of 14)	82 ± 3
Hydrothermally altered granites (greisens), Variscan, Germany (composite of 24)	165 ± 5
Granite, Variscan Schrems, Lower Austria	4.3 ± 1.1
Granite, Variscan Eisgarn, Lower Austria	2.0 ± 0.4
Granite, Variscan Weinsberg, Lower Austria	2.0 ± 0.4
Granite, Variscan Mauthausen, Lower Austria	2.4 ± 0.5
Granite (Rapakivi-type), Svecofennian Balmoral Rauma Bottnia, Finland	9.2 ± 1.1
Granite, Westerly RI, USA (USGS Standard G-2)	38 ± 3
Granodiorite Azuma-mura, Gumma Japan (GSJ Standard JG-1)	5.0 ± 1.8
Granodiorite trondhjemite, Variscan Melibokus Odenwald, Germany	9.9 ± 1.0

Granodiorite Silver Plume Ouarry, CO USA (USGS Standard GSP-1)	15 ± 2
Tonalite, Alpine Melirolo S Chiavenna, North Italy	7.8 ± 0.8
Tonalite, Variscan Rastenberg, Lower Austria	4.4 ± 1.1
Dacitic rhyolite, Medicine Lake, CA/OR, USA	35 ± 6
Rhyolite (obsidian), Wada Toge, Nagano Prefecture, Japan (GSJ Standard JR-2)	69 ± 11
Andesites	
Andesite, Manazuru-machi, Hakone, Japan (GSJ Std. JA-1)	17 ± 4
Andesite, Tumago-mura, Gunma, Japan (GSJ Standard JA-2)	4.2 ± 0.4
Andesite, Guano Valley, OR, USA (USGS Standard AGV-1)	59 ± 9
Andesite, Medicine Lake, CA/OR, USA	13 ± 3
Basalts	
Quartz tholeiite, Tertiary Borken Hessian Depression, Germany	7.4 ± 0.5
Alkali olivine basalt, Tertiary Bramburg Goettingen	5.8 ± 0.5
Alkali olivine basalt, (basanitite), Tertiary Rhuender Berg Hessian Depression, Germany	8.8 ± 2.9
Olivine nephelinite (melilite bearing) Tertiary Westberg Hofgeismar Hessian Depression, Germany	14 ± 5
Olivine nephelinite (melilite bearing) Tertiary Hoewenegg Hegau, Germany	10 ± 1
Peridotites	
Spinell Iherzolite, Balmuccia Ivrea Belt, North Italy	11 ± 2
Spinell Iherzolite, Baldissero Ivrea Belt, North Italy	12 ± 2

Muramatsu and Wedepohl (1998) have given values of 119 µg/kg, 777 µg/kg and ~300 µg/kg I respectively for the continental crust, oceanic crust (including seawater) and the bulk Earth's crust. Nearly 70% of I is thought to be found in ocean sediments. From among the sedimentary rocks and organic matter (Table 5.4), the high average concentrations of 30 mg/kg I in deep-sea carbonates and 2.5 mg/kg in continental limestones had been accumulated by planktonic and shallow sea organisms, respectively. Deep-sea shales and continental shales carry high concentrations of iodine.

Table 5.3. Summary of statistics for soil iodine contents classified by parent material (in mg/kg) (Johnson, 2003a)

Parent Material	Number	Min.	Max.	Mean	Geo. mean
Alluvium	157	0.1	56.5	3.56	1.28
Carbonates	117	0.1	22.6	4.38	3.05
Other Sedimentary	157	0.06	38.7	4.58	2.00
Igneous Extrusive	114	0.1	72	14.16	6.31
Igneous Intrusive	21	0.4	83.2	10.66	3.75
Metamorphic	41	0.1	21	3.37	1.15
Peat	4	11.6	68.4	32.9	26.52
Sand	32	0.1	9.8	1.56	0.71

Table 5.4. Iodine in sedimentary rocks and organic matters (µg/kg ± SD) (Schnetger and Muramatsu, 1996, Muramatsu and Ohmoto, 1986, and Muramatsu et al., 1983)

Pelagic Sediments	
Clay, Atlantic Ocean (16°54′ N, 59°31′ W) 5 m sediment depth, 5030 m water depth (A 160, 8) ≤ 1% $CaCO_3$	4700 ± 108
Clay, Atlantic Ocean (19°05′ N, 59°42′ W) less than 6 m sediment depth, 5300 m water depth (A 160, 7) ≤ 1% $CaCO_3$	1660 ± 167
Clay, Pacific Ocean (20°49′ N, 125°0.5′ W) 4530 m water depth (Y2P 831, 25) 3% $CaCO_3$	2680 ± 215
Clay, Pacific Ocean (14°55′ N, 124°12′ W) 8.2 m sediment depth, 4270 m water depth (50BP 240) 2.6% $CaCO_3$	5330 ± 135
Clay, Atlantic Ocean (16°54′ N, 59°31′ W) 2.65 m sediment depth, 5030 m water depth (A 160, 8) 29% $CaCO_3$, 0.22% C	5240 ± 410
Foraminifera ooze, Pacific Ocean (15°39′ S, 114°18′ W) 3221 m water depth (42 HG 84) 81% $CaCO_3$, 0.28% C	20000 ± 340
Shales, Corg –rich shales	
Shales, marine Paleozoic, W Europe (composite of 36) 2% $CaCO_3$, 1.9% C, 0.24% S	827 ± 22
Shales, marine Paleozoic, Japan (composite of 14) 1.3% $CaCO_3$, 0.4% C, 0.12% S	4520 ± 85
Shale, marine Triassic, Friedland near Goettingen Germany	758 ± 81
Shale, Corg-rich Archean Fig Tree, South Africa (Capetown Fg 14)	248 ± 20
Shale, Corg-rich Upper Cambrian Oslo Fjord, Norway (Pr 631)	510 ± 21
Shale, Corg-rich Lower Ordovician Kopingbland, Sweden (Pr 635)	2110 ± 207
Shale, Corg-rich Upper Permian Kupferschiefer West Drente, Netherlands (Pr 785) 4% C	413 ± 23
Shale, Corg-rich Upper Permian Kupferschiefer Calberlah Braunschweig, Germany (Pr 724) 7.4% C	6150 ± 230
Shale, Corg-rich Upper Permian Kupferschiefer Eisleben, Germany 6.9% C, 16% $CaMg(CO_3)_2$	4840 ± 42
Shale, Corg-rich, Etzel near Bremen, Germany, 16% C	526 ± 47

Shale, Corg-rich Lias-ϵ Hohenassel near Hildesheim, Germany (R3/300 m) 6.5% C	2970 ± 293
Shale, Corg-rich Lias-α Levin brickyard Goettingen, Germany	195 ± 3
Shale, oil-bearing Green River Formation, USA (USGS Standard SGR-1) 3.2% C, 20% $CaCO_3$	334 ± 45
Greywackes, sandstones	
Greywackes, Paleozoic Central Europe (composite of 17) (Pr 1025) 4% $CaCO_3$, 0.1% S	168 ± 20
Greywacke Lower Carboniferous Langelsheim Harz Mountains, Germany (B 18)	103 ± 7
Greywacke Lower Carboniferous Andreasbach Harz Mountains, Germany (5IIIb)	63 ± 1
Greywacke Lower Carboniferous Clausthal Silberhuette Harz Mountains, Germany (C 4)	138 ± 2
Greywacke Lower Carboniferous Soesetal Harz Mountains, Germany	52 ± 5
Greywacke Lower Carboniferous Gr. Steimkertal Harz Mountains, Germany (Pr 683)	80 ± 6
Quartz sandstones, Carboniferous Germany (composite of 11) (Pr 680) 80% quartz, 2% $CaCO_3$	123 ± 11
Quartz sandstones, Lower Triassic Germany (composite of 23) (Pr 910) 65% quartz, 2% $CaCO_3$	144 ± 11
Quartz sandstones, Cretaceous Germany (composite of 11) (Pr 1014)	
Limestones	
Limestones, Devonian Germany (composite of 32) 0.1% S	1610 ± 127
Limestones, Middle Triassic Reckershausen Goettingen, Germany (Pr 900)	260 ± 47
Limestones, Middle Triassic Dransfeld near Goettingen, Germany (Pr 901)	792 ± 154
Limestones, Jurassic Germany (composite of 45) 0.17% S	3370 ± 275
Limestones, Upper Jurassic W Eroden, Germany (Pr 983)	1970 ± 83
Limestones, Upper Jurassic Solnhofen, Bavaria, Germany (Pr 984)	3870 ± 79
Limestones, Cretaceous Germany (composite of 16) 0.1% S	1940 ± 96
Organic matter, cool	
Orchard leaves, dry (Standard NIST 1571)	215 ± 64
Brown algae, *Hijikia fushiforme*, Japan (mean of four dry samples)	490,000 ± 126, 000
Brown algae, *Undaria pinnatifida*, Japan (mean of two dry samples)	87,000 ± 64,000
Red algae, *Gloiopeltis furcata*, Japan (mean of five dry samples)	100,000 ± 14,000
Red algae, *Porphyra tenea*, Japan (one dry sample)	44,000
Oyster tissue, dry (Standard NIST 1566a)	4100 ± 300
Hard coal, Queen Luise Mine Upper Silesia, Poland	4210 ± 1615

From a medical geology point of view, the iodine status of soils is most important. The amount of soil and its ability to retain it are two factors that need consideration in the study of the geochemical pathways of iodine. As illustrated in Figure 5.5, Fuge and Johnson (1986) discussed three main forms of iodine in the soil, namely (a) mobile iodine (b) insoluble iodides (c) fixed iodine. The property of the soil which fixes the iodine was termed Iodine Fixation Potential (IFP).

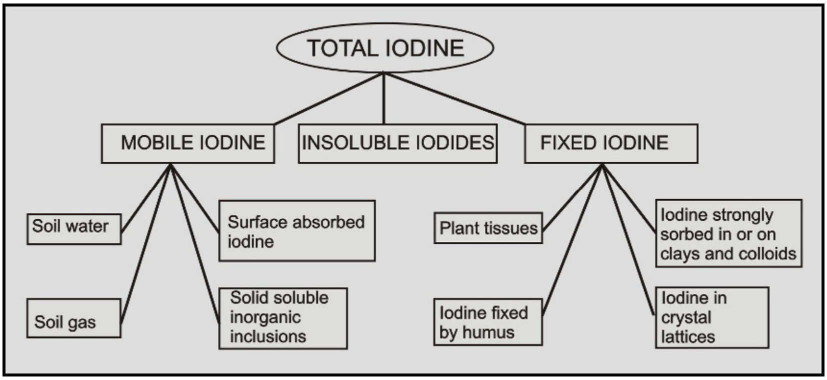

Fig. 5.5. Suggested forms of iodine in soils (Fuge and Johnson, 1986)

The IFP is particularly important for tropical soils since Fe-Mn and Al oxides are abundant in such soils and these have the ability to fix iodine strongly. The organic matter in the soil also absorbs iodine strongly and the bioavailability of iodine may therefore be relatively small.

In view of the fact that the tropical environment is characterized by laterite formation and in which Fe, Mn, and Al oxides are very common, the iodine geochemistry is markedly influenced by these minerals. Whitehead (1974) has shown that the sorption of iodine by aluminium and iron oxides is markedly influenced by pH, greater sorption in acidic conditions and no sorption under neutral conditions. Johnson et al. (2003a) and Johnson (2003b) compiled global soil data for iodine and were of the view that the geometric mean for the iodine levels in soil is 3.0 µg/g. On a textural classification for soils, the following order for mean values of I was determined. Figure 5.6 illustrates the distribution of the reported iodine results.

Peat (7.0)> clay (4.3)> silt (3.0)> sand

In studies pertaining to the effect of iodine concentration on IDD, it is of extreme importance to note that it is the bioavailable iodine and not the total iodine in the soil that would influence the incidence of IDD. Generally less than 10% of the soil iodine is known to be extracted with cold water and this is considered as a good indication of the bioavailability of iodine.

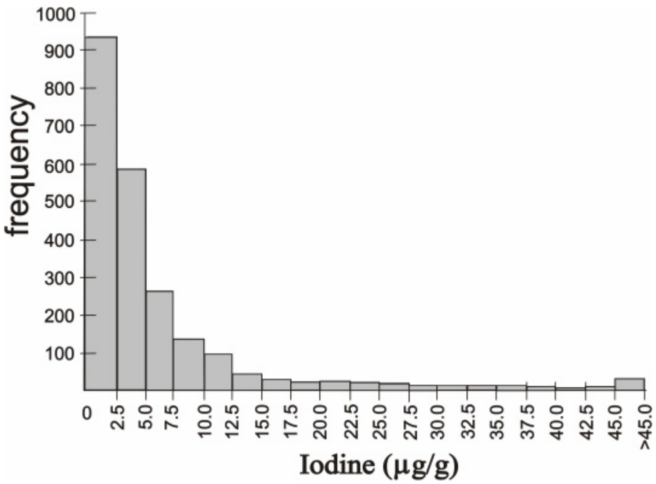

Fig. 5.6. Histogram showing the distribution of reported iodine concentrations in soil (Johnson, 2003)

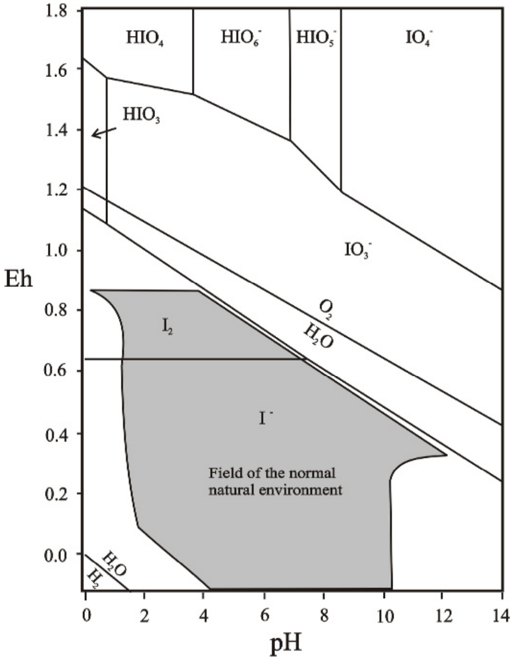

Fig. 5.7. Eh-ph diagram for iodine (Vinogradov and Lapp, 1971)

From among the chemical species of iodine, iodide is the most mobile form in the soil and which is easily available to plants. Iodate is relatively less mobile. Acidic soil conditions are known to favour iodide and the alkaline oxidizing conditions prefer the less soluble iodate form. Figure 5.7 illustrates the Eh-pH diagram for iodine.

Iodine sorption on clays and humic substances

In the tropical soils, clay minerals and humic substances are two of the important iodine fixers. Since much of the population of the developing countries in the tropical belt live in close association with the immediate physical environment, the IFP of soils needs to be carefully considered in epidemiological studies. Organic matter, mostly humic substances however display a much higher IFP than clay.

Hamid and Warkentin (1967) studied ^{131}I as a tracer for water movement in soils and observed that iodine is adsorbed onto clay particles. This observation was also made by Vinogradov and Lapp (1971). In an experiment conducted, De et al. (1971) added iodide solutions of varying temperature to soil clays and observed that only the clay minerals took up iodide with illite adsorbing more iodide than kaolinite or montmorillonite.

Humic substances in the environment are known to play a major role in the speciation and geochemical mobility of chemical elements. The conversion of chemical species into toxic or non-toxic forms has important implications on the health of individuals living in a particular geochemical habitat. Dissanayake (1991b) described the association of certain metals in the environment with organic groups of humic substances that had been studied from the point of view of the incidence of some geographically distributed diseases such as cancer, where selenium and molybdenum appear to play an important role.

It was shown in Figure 5.5 that iodine is strongly fixed by humus, and soils rich in humus therefore tend be enriched in iodine but with low bioavailability depending on pH conditions. As noted by Johnson et al. (2003a), contrary to what might be expected, organic-rich soils, though high in iodine content, do not provide much iodine to the food chain in view of its strong fixation to humus and hence low bioavailability.

The nature and the mechanism of the fixation of iodine within the humus structure is not well known, but the sizes of the iodine ion and its oxyanion are perhaps of special importance in this process.

For the humic compounds which comprise the bulk of naturally occurring organic matter in soil and water, a discrete structure cannot be given. Among the many different functional groups present are carboxyl, phenolic, enolic hydroxyl, alcoholic hydroxyl, quinone, hydroxyquinone, carboxyl, ester lactone, ether and amino groups (Rashid and King, 1970). It is generally accepted that the major oxygen containing functional groups are carboxyl (-COOH), hydroxyl (-OH) and carbonyl (>C = 0).

At low pHs (e.g. pH <4) absorption of a negative ion such as I^- or IO_3^- could perhaps be brought about by a reaction such as that shown in the lower part of Figure 5.7 (humic structure) where the I^- or IO_3^- ions become bound to the positive ion.

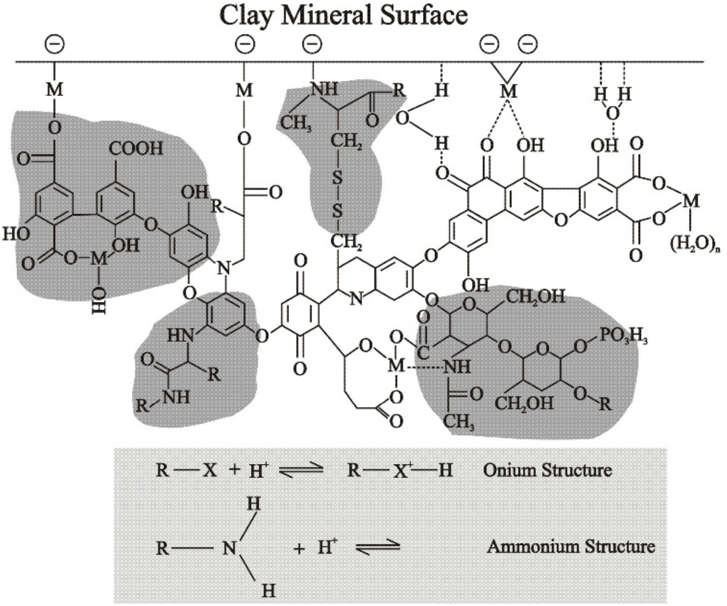

Fig. 5.8. Postulated structure of humic material in association with clay A- lignin, B- peptide C- cellulose or chitin M- Metal (Koss, 1977) Iodine species could perhaps be bound to the onium and ammonium structures (Dissanayake et al., 1998)

Figure 5.8 illustrates a postulated structure for humic materials and its bonding with the surface of clay. Such humus-clay associations as found in tropical soils may function as good loci for the adsorption of iodine. The organic matter-clay interactions in tropical soils and their implications on the geochemical cycle of iodine is therefore worthy of detailed investigation.

Effect of Microbial Activity on Iodine Geochemistry

Several studies have shown that microbial activity may play an important role in the iodine cycle. This is of special importance to tropical countries, notably with flooded soil such as in the rice fields, where microbial activity may be intense. Razaq et al. (1987) had shown that in calcareous soils, some part of the anionic iodine is converted to molecular I_2 through microbial or enzymatic processes or reactions with by-products. It was reported by Higgo et al. (1991) that microorganisms play a role in the sorption of both I^- and IO_3^-. Behrens (1982) had shown that microorganisms are involved in the loss of I^- from fresh water aquatic systems and it was suggested that the reactions were extra cellular, possibly enzymatic oxidation of I^- to I_2, which then reacts with organics probably proteins. Sheppard and Hawkins (1995), however, were of the view that microbes may play only a minor and indirect role in iodine sorption through the decomposition of organic matter.

Muramatsu and Yoshida (1999) studied the effects of microorganisms on the fate of iodine in the soil environment. They observed that the behaviour of iodine in the soil environment was influenced by microbial activities, perhaps their products (e.g. enzymes) as well, both in the sorption and desorption processes. In the case of flooded soils (e.g. rice paddy soils) iodine was desorbed due to the reducing conditions (low Eh) created by the effects of soil microorganisms. It is expected that evaporation of biogenerated methyl iodide from the soil-plant system may also result in lowering of iodine levels in soils, specifically in rice fields and marshes. Muramatsu and Yoshida (1999) observed that the influence of soil microorganisms is significant for both stable and long–lived radioactive iodine in the environment.

They incubated a number of soil samples collected from paddy fields, farms and forests, with radioactive iodine tracer. Where the samples were incubated with the antibiotics streptomycin and tetracycline, which are specific inhibitors for prokaryotes (mainly bacteria), iodine volatilization ceased. When cycloheximide, a specific inhibitor for eukaryotes (filamentous fungi and yeast), was added, there was no significant change, indicating that soil bacteria contribute to iodine volatilization from soil environments.

From among the isolated 100 bacterial strains from a variety of environments, it was found that about 40% of these strains showed significant CH_3I production, with some strains showing very high (1-5% of the total) production of CH_3I.

Iodine in Drinking Water

Water contains the more mobile form of iodine, thus, the iodine content of water is a good index of the iodine status of the environment (Johnson et al., 2003b). However drinking water does not represent a major source of iodine (Fig 5.9) (iodine in air, water etc), even though it is more amenable to chemical analysis. A threshold value of 3 µg/L has been given as a marker value for iodine deficient environments. Depending on a variety of environmental factors, the iodine contents in drinking water markedly varies. Results reported so far reveal a range from <0.1 to 150 µg/L with the average being 4.4 µg/L (Johnson et al., 2003b). It is known that deep-water sources are richer in iodine than surface waters. Drinking water provides only about 10% of the Recommended Dietary Allowance (RDA), i.e. about 150 µg per day for iodine. In areas, particularly in rural parts in developing countries of the tropical belt, where food is obtained only from the immediate physical environment and where iodine supplementation is not available, water my contribute a greater iodine input of ~20%.

Iodine in Food

Since iodine is not an essential element for plants there is no direct correlation between iodine in soil and its content in the crops. Excessive iodine however is toxic to plants as shown by the occurrence in rice of ‘Reclamation Akagare’ disease, a physiological disorder caused by flooding paddy fields on iodine-rich soils (Johnson et al., 2003b). Table 5.5 shows the iodine contents of some foods.

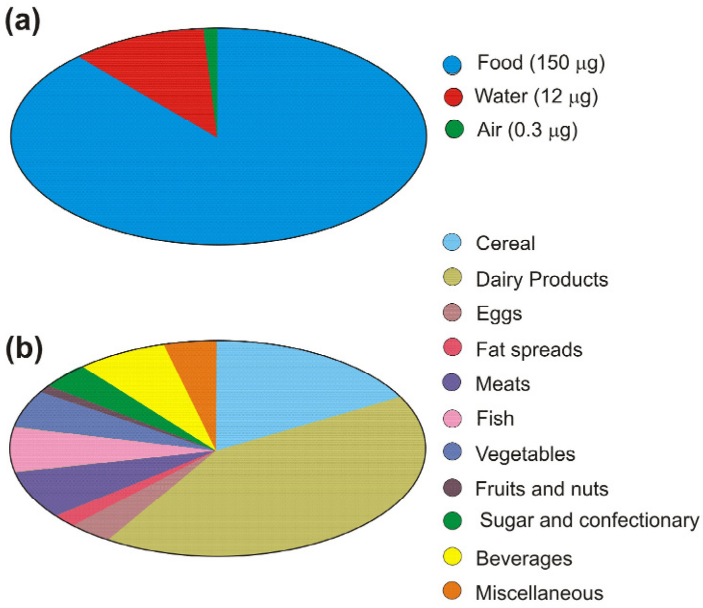

Fig. 5.9. (a) Diagram showing the estimated relative proportions of food, water and air to the daily iodine intake of a person living in a developed country. (b) Chart showing the relative contribution of iodine to the diet from different foods (Data from U.K. National Diet and Nutrition Survey) (from Johnson et al., 2003b; reproduced with kind permission from the British Geological Survey)

Table 5.5. Iodine content in some foods (http://www.healthyeatingclub.com)

Food	Iodide content (µg/100 g food)
Iodized salt	3000
Sea food	66
Vegetables	32
Meat	26
Eggs	26
Dairy products	13
Bread and cereals	10
Fruits	4

The iodide content of foods and total diets vary depending on geochemical, soil and other conditions. The major natural food sources for iodine are marine fish, shell fish, marine algae and seaweeds, and dairy products. Arable crops contain less than 50 µg/kg (fresh wt.) iodine in the order, legumes >vegetables >fruit. Since iodine is not mobile in plants, it is not concentrated in seeds. Grain crops such as rice are poor in iodine and since rice is the staple diet in many tropical countries, this observation is of special importance.

In those countries where sea food is consumed more, the general iodine intake is high bearing in mind that iodine can average 1000-2000 μg/kg (fresh weight) in some fish.

Plate Tectonics, High Altitudes and Iodine Cycling

It has been observed that in many mountainous regions of earth there appears to be a deficiency of iodine and an increased incidence of iodine disorders (Stanbury and Hetzel, 1980). High altitudes are considered as special domains with characteristic climate, soil, trace element deficiencies, human and animal health. Evidence has accumulated that populations at high altitude are prone to develop essential element deficiencies as exemplified by iodine and selenium (Iyengar and Ayengar, 1988).

In medical geology, the factors related to the occurrence of deficiencies and excesses are broadly classified as:

(a) Geochemical components in the environment, most notably in the soil. These may have a stronger influence in the soil-plant-animal-human health food chain.

(b) The bioavailability of trace elements in a given diet. This can be taken to mean the fraction of the trace elements in the diet that is absorbed by the gastrointestinal tract and which is available for metabolism.

(c) Inter-element interactions. Some elements such as calcium, lead and zinc, when in excess in the diet may interfere with the absorption of zinc, iron and copper (Underwood, 1977).

(d) The health status of the subjects per se. Special circumstances. e.g. life at high altitudes, entailing living under complex stress and related environmental constraints (Iyengar and Ayengar, 1988).

Johnson et al. (2003b) studied the levels of iodine and IDD in the mountains of Morocco. They chose the Ounein Valley in the Atlas Mountains as a case study following an earlier study by sociologists and nutritionists.

The remote mountainous area lay ~150 km inland from the Atlantic coast. Agadir, an area on the coast was selected as a control study. As shown in the box and whisker plots (Figure 5.10), Ounien valley had very low iodine in both surface waters and soils. As expected, IDD was higher in the Ounein valley located in the high altitude area than in the Agadir area.

It is worthy of note that altitude is not necessarily a causal factor in IDD. Non-mountainous areas are also known to have a high incidence of IDD. However it is the effect of the high altitude on the geochemical pathways of iodine that should be taken into account. The geochemical cycle of iodine as illustrated in Figure 5.3 shows why some mountainous areas are seriously deficient in iodine.

The theory of plate tectonics figures prominently in the iodine cycle of the crust and mantle. The iodine pathways within this cycle have an impact on the incidence of IDD, when the geological and geographical locations of the habitats concerned are taken into account. Stewart (1990) commented on the influence of plate tectonics in iodine cycling and noted IDD belts occurring in Asia. Kelly and Snedden (1958) and Kochipillai et al. (1980) also suggested such occurrences in Papua New Guinea and Myanmar.

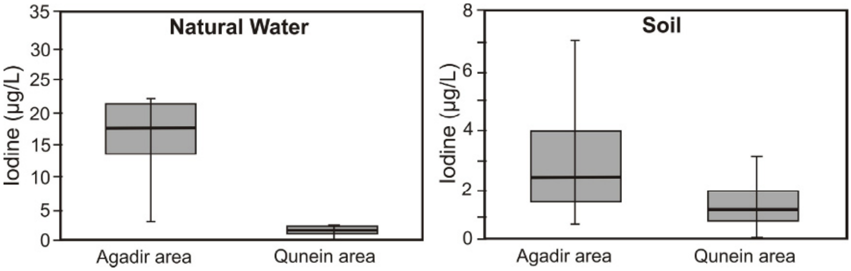

Fig. 5.10. Total iodine content in water and soils of Agadir and Ounein regions of Morocco (source: Johnson et al., 2003b; reproduced with kind permission from the British Geological Survey)

In their very recent study, Muramatsu et al. (2004) investigated the recycling of iodine in the subduction zone at the Chiba prefecture of Japan which produces one third of the world's iodine from brines. Here the iodine concentrations are in excess of 100 mg/L and typically contain methane (Figure 5.11). The Kazusa Group, which was the host formation of the brines, consisted of marine sediments of Pliocene to Pleistocene age. Here the average I concentration was more than 2000 times higher than that of seawater. Comparison with sea water showed that those elements which are accumulated in marine sediments (e.g. I, Mn, Ba) were the most enriched in the brines.

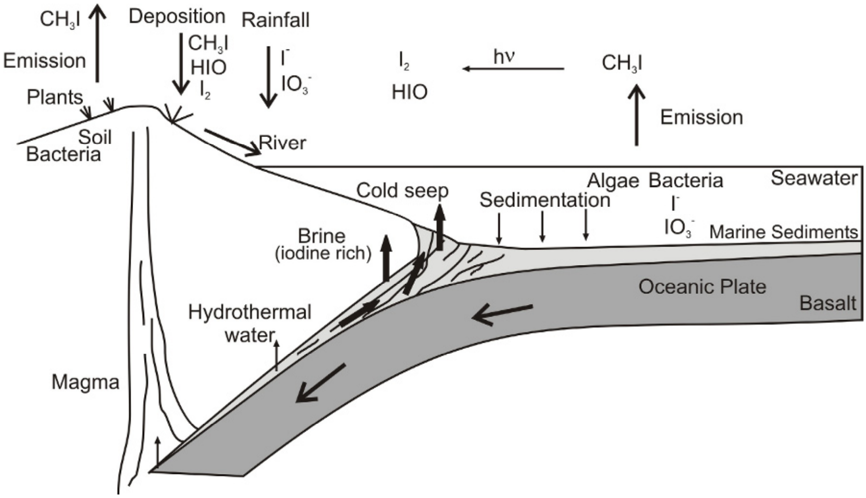

Fig. 5.11. Recycling of iodine in subduction zone (after Muramatsu et al., 2004)

Muramatsu et al. (2004) showed that iodine enrichment in the brines was caused by remobilization from subducted marine sediments associated with the release of pore waters in the fore-arc area. Similar enrichments of iodine had also been observed in other fore-arc areas such as those of New Zealand and Trinidad.

Since the largest reservoir of crustal iodine is found in marine sediments where it is closely associated with organic material, and since the cosmogenic radioisotope ^{129}I is long lived, this isotopic system could be used to study sediment recycling in subduction zones. Snyder and Fehn (2002) studied the ^{129}I/I ratios in volcanic fluids from four geothermal centres and a number of crater lakes, fumaroles, hot springs and surface waters in Costa Rica, Nicaragua and El Salvador.

The iodine ages indicated that the magmatic end member for the volcanic fluids originates in the deeper parts of the subducted sediment column, with small additions from older iodine mobilized from the overlying crust. The higher concentrations of iodine in geothermal fluids, combined with iodine ages demonstrated that remobilization in the main volcanic zone (and probably also in the fore-arc area) is an important part in the overall marine cycle of iodine and similar elements (Snyder and Fehn, 2002).

IODINE AND HEALTH

Iodine is needed by the human body for the synthesis of thyroid hormones by the thyroid gland. The bioavailable iodide ion is obtained from food and water and dietary iodine is converted into the iodide ion before absorption by the gastrointestinal tract, and all biological actions of iodide are attributed to thyroid hormones. The thyroid cells are the only cells in the body which can absorb iodine and the metabolic role played by the thyroid gland therefore is extremely important, considering the fact that every cell in the body depends on thyroid hormones for regulation of their metabolism.

The thyroid gland located in the front part of the neck is the biggest gland in the neck. It has two lobes-one left and the other right and wraps around the trachea joined by a narrow band termed the isthmus. The only function of the thyroid gland is to produce the thyroid hormone which is known to regulate the metabolism of the body.

The thyroid hormones made by the thyroid gland are thyroxine (T_4) and Triiodothyronine (T_3) by the process of the thyroid cells combining iodine and the amino acid tyrosine. These hormones then enter the blood stream and are circulated throughout the body. It has been estimated that the normal thyroid gland produces about 80% T_4 and 20% T_3. Triiodothyronine hormone (T_3) however is known to have about 4 times the strength of T_4.

An important gland termed the pituitary gland located at the base of the brain has a control on the thyroid gland. When T_3 and T_4 levels drop, the pituitary gland produces the Thyroid Stimulating Hormone (TSH) which then stimulates the thyroid gland to produce more hormones. After this takes place, the pituitary gland decreases its TSH production, thereby maintaining an equilibrium. The pituitary gland however, does not act alone. It is regulated by another gland termed the hypothalamus, which is a part of the brain. It produces the TSH Releasing Hormone (TRH) which stimulates the pituitary gland to release TSH.

IODINE DEFICIENCY DISORDERS (IDD)

Iodine deficiency is known to occur when the iodine intake is lower than the recommended levels. WHO, UNICEF and ICCIDD (WHO, 2001) have recommended that the daily intake of iodine should be:

90 µg for pre-school children (0 to 59 months)
120 µg for school children (6 to 12 years)
150 µg for adults (above 12 years)
200 µg for pregnant and lactating women

When the mean daily intake of iodine is less than 25 µg the thyroid may no longer be able to synthesize sufficient amounts of thyroids hormones. The resulting low level of thyroid hormones in the blood (hypothyroidism) is the main factor responsible for causing damage to developing brain and other harmful effects known collectively as Iodine Deficiency Disorders (Table 5.6). WHO (2001) in the document on "The assessment of iodine deficiency disorders and monitoring their elimination" states:

Table 5.6. The Spectrum of the Iodine Deficiency Disorders (IDD) (WHO, 2001)

Fetus	Abortions
	Stillbirths
	Congenital anomalies
	Increased prenatal mortality
	Increased infant mortality
	Neurological cretinism:
	Mental deficiency, deaf mutism, spastic diplegia squint
	Myxoedematous cretinism:
	Dwarfism, hypothyroidism
	Psychomotor defects
Neonate	Neonatal hypothyroidism
Child & adolescent	Retarded mental and physical development
Adult	Goitre and its complications
	Iodine-induced hyperthyroidism (IIH)
All ages	Goitre
	Hypothyroidism
	Impaired mental function

"Iodine deficiency through its effects on the developing brain has condemned millions of people to a life of few prospects and continued underdevelopment. On a worldwide basis, iodine deficiency is the single most important preventable cause of brain damage. People living in areas affected by severe IDD may have an intelligence quotient (IQ) of up to about 13.5 points below that of those from comparable communities in areas where there is no iodine deficiency (Bleichrodt and Born, 1994). This mental deficiency has an immediate effect on child learning capacity, women's health, the quality of life of communities and economic productivity".

Since most iodine absorbed in the body finally appears in the urine, urinary iodine excretion is a good marker of very recent dietary iodine intake. The assessment of a population's iodine nutrition can be made by a profile of iodine concentrations in urine, and is the most practical biochemical marker for iodine nutrition (Table 5.7).

Table 5.7. Epidemiological criteria for assessing iodine nutrition based on median urinary iodine concentrations in school-aged children (source WHO, 2001)

Median Urinary Iodine (µg/L)	Iodine Intake	Iodine Nutrition
<20	Insufficient	Severe iodine deficiency
20-49	Insufficient	Moderate iodine deficiency
50-99	Insufficient	Mild iodine deficiency
100-199	Adequate	Optimal
200-299	More than adequate	Risk of iodine-induced hyperthyroidism within 5-10 years following introduction of iodized salt in susceptible groups
>300	Excessive	Risk of adverse health consequences (iodine-induced hyperthyroidism, autoimmune thyroid diseases)

When the thyroid gland is enlarged it is termed 'goitre'. The term 'nontoxic goitre' refers to the enlargement of the thyroid which is not associated with overproduction of thyroid hormone or malignancy.

The cause of goitre can be due to (a) deficiency in iodine intake and bioavailability as seen in many developing countries of the tropical belt with marked malnutrition and (b) an increase in TSH as a result of a defect in normal hormone synthesis within the thyroid gland. Goitre is graded according to the WHO classification shown below:

Grade 0 –	No palpable or visible goitre
Grade 1 –	A goitre that is palpable but not visible when the neck is in the normal position (i.e. the thyroid is not visibly enlarged). Thyroid nodules in a thyroid which is otherwise not enlarged fall into this category.

Grade 2 – A swelling in the neck that is clearly visible when the neck is in a normal position and is consistent with an enlarged thyroid when the neck is palpated.

Hypothyroidism is a condition in which the body lacks sufficient thyroid hormones. It is caused by:

(i) Result of a previous or present inflammation of the thyroid gland. A high percentage of the cells of the thyroid are damaged or dead and this affects the production of sufficient hormone. A common cause of thyroid gland failure is autoimmune thyroditis, also termed Hashimoto's thyroditis. This is related to the immune system of the patient.

(ii) Medical treatments such as surgical removal of a part or all of the thyroid gland.

Hyperthyroidism, on the other hand, is the condition caused by the overproduction of thyroid hormones.

Endemic cretinism

Endemic cretinism is considered to be the most important iodine deficiency disorder (Pharoah, 1985). There are two types of endemic cretinism that are considered even though they may be the end members of a clinical spectrum. These are (i) neurological forms and (ii) myxoedematous forms (McCarrison, 1908). Among the characteristic features of neurological endemic cretinism, in its fully developed form, are severe mental deficiency accompanied by squint and deaf mutism, motor spasticity with disorders of the arms and legs of a characteristic nature. The myxoedematous type shows less severe mental retardation than the neurological type, but shows severe hypothyroidism, extreme growth retardation and incomplete maturation. The latter type is particularly common in Zaire whereas the neurological type is more commonly seen in mountainous areas with IDD. Since thyroid hormones are associated with cognitive and motor measures and are related to brain development, IDD are of special importance in human health (Stewart and Pharoah, 1996).

Goitrogens

Goitrogens are substances capable of producing thyroid enlargement by interfering with thyroid hormone synthesis. Goitrogens can be biological or mineralogical substances and research is being carried out on the possible goitrogens and their effect on the thyroid.

There are many naturally occurring agents that could function as goitrogens in man. Animal and in-vitro tests have shown that they possess antithyroid effects. Among the chemical groups which contain these compounds are sulphurated organics (such as thiocyanate, isothyanate, goitrin and disulphides), flavonoids, polyhydroxyphenols and phenol derivatives, pyridines, phthalate esters and metabolites, PCB's and PBB's, other organochlorines (e.g. DDT) and polyaromatic hydrocarbons. Goitrogens were classified by Gaitan (1990) into:

(a) agents acting directly on the thyroid gland
(b) agents causing goitre by indirect action.

The former group was further subdivided into (a) those inhibiting the transport of iodide into the thyroid (e.g. thiocyanate and isothyocyanate) (b) those acting on the intrathyroidal oxidation and organic binding process of iodide (c) those interfering with proteolysis, dehalogenation and hormone release.

The indirect goitrogens were thought of as increasing the rate of thyroid hormone metabolism. Goitrogens are effective particularly when the iodine intake is low and when goitrogens are continually ingested over a long period. Some foods such as cassava (manioc), cabbage, Brassica *sp*. among others are known to possess goitrogenic properties. Cassava in particular has been subjected to many investigations for its goitrogenic activity (Bourdoux et al., 1978; Delange et al., 1976).

Djazuli and Bradbury (1999) studied the cyanogen content of cassava roots and flour in Indonesia. They noted that 30 samples of cassava starch and other specialized products had a mean cyanogen content of only 5 mg/kg, whereas 29 samples of cassava flour, chip and gaplek had a much higher mean cyanogen content of 54 mg/kg. The WHO safe value for cassava flour is 10 mg/kg whereas in Indonesia it was 40 mg/kg. The study of Cassava is of special importance for the tropics since it is the third most important food source after rice and maize.

Badly prepared cassava is known to yield very high contents of cyanogenic glucosides and is converted to thiocyanate after ingestion and which in turn competes with iodide for entry into the thyroid. Its effect is particularly marked where there is an existing iodine deficiency. Peterson et al. (1995) showed that in the Central African Republic, where cassava is the main staple crop, improved cassava processing could reduce the IDD.

Geochemical goitrogens are those materials found in the geological environment, particularly in the tropics and which make the bioavailability of iodine significantly low. The availability of environmental iodine to the diet depends on several factors such as soil chemistry and soil physics, input from atmosphere, humic substances, Al and Fe oxides and clay. These materials, depending on the existing physico-chemical conditions may become geochemical goitrogens. As shown by Stewart and Pharoah (1996), in the presence of a goitrogen, iodine will act only as a limiting factor and it is the iodine to goitrogen ratio that acts as the determinant of the outcome.

Stewart et al. (2003) cautioned against the direct correlations of the incidence of IDD with environmental iodine. At present, the argument for environmental iodine deficiency is:

- Biochemical iodine deficiency is the immediate cause of the disorders.
- The source of dietary iodine is the diet
- The diet depends on the environment.
- Where IDD occurs, particularly in a community that lives close to the land, the local environment must be deficient in iodine.

Stewart et al. (2003) considered this argument to be too simple. Their study of endemic goitre in England and Wales showed that there is a lack of the expected correlation between the distribution of environmental iodine and the presence or absence of endemic goitre. This indicates that many factors, notably the activity of geochemical goitrogens complicate the direct application of correlation between IDD and environmental iodine.

As mentioned earlier in this chapter, the organic matter and clay content of soils are highly significant in such correlative studies. Shinonaga et al. (2001) carried out an important study that highlights the complex factors involved in such correlations.

These authors studied the concentrations of iodine in cereal grains cultivated at 38 locations in Austria from cereal producing sites in an agriculture area. They determined the soil to grain transfer factors (TF), which are known to vary depending on the plant species, soil characteristics, chemical forms of iodine and climatic conditions.

As shown in Table 5.8, the TFs correlated positively with iodine concentrations in cereal grains ($r = 0.70$, $p<0.001$) and a relatively good negative correlation ($r = -0.68$, $p<0.001$) was found between TF and iodine in soil. The correlation coefficient between iodine contents and clay contents in soil obtained was $r = 0.75$ ($p<0.001$). It was found that the larger the amount of clay minerals in the soil, the higher was the iodine concentrations in the soil. There was however no clear relationship between TF and organic matter and also TF and soil pH.

As mentioned earlier, humic substances are important in the iodine fixation in soil. Cooksey et al. (1985) showed that the associated constituents of humic substances (HS), resorcinol, orcinol, phloroglucinol, pyrogallol, 3, 4- and 3, 5-dihydroxybenzoic acids were potent inhibitors of the thyroid peroxidase enzyme and of thyroidal ^{125}I uptake and/or its incorporation into thyroid hormones using thyroid slices. Resorcinol was found to be goitrogenic in rats and interestingly it was found in the water supply of an endemic goitre district in western Colombia.

Recently it has been show that selenium deficiency may have significant effects on thyroid hormone metabolism and possibly on the thyroid gland itself. Here the function of type 1 deiodinase (a selenoprotein) is impaired. This selinoenzyme converts the prohormone T_4 to the active hormone T_3 which is important in some metabolic activities of the foetus, neonate and child. Selenium deficiency also leads to a reduction of the Se-bearing enzyme glutathione peroxidase which detoxifies H_2O_2 present in the thyroid gland. Reduced detoxification is known to lead to thyroid cell death.

Selenium geochemistry is therefore closely linked to the medical geochemistry of iodine and many investigations are now being carried out on the influence of selenium on IDD. It is worthy of note however, that while selenium deficiency many have a bearing on IDD, the reverse is not necessarily true. Experiments on the sorption of iodine on other minerals such as illite, goethite, clinochlore, calcite, limonite, biotite, pyrite, magnetite and hematite were carried out by Fuhrmann et al. (1998). Figure 5.12 shows the percentage of ^{125}I removed from solution over a period of

15 days in contact with powdered minerals. Pyrite and illite showed major uptake of the tracer. The pyrite removed almost all the ^{125}I from solution over 15 days, while 82% sorbed in less than 1 day. The illite (in shale) sorbed at a slower rate, with about 70% sorption after 15 days.

Table 5.8. Correlation matrix (Pearson correlation, n = 38): relation between (a) transfer factor and parameters of cereal grain and soil and (b) iodine in soil and parameters of soil (Shinonaga et al., 2001)

Parameter	**Transfer Factor of Iodine**	**P**
(a)		
Iodine content in cereal grain	0.703	<0.001
Iodine content in soil	-0.677	<0.001
Clay content in soil	-0.781	<0.001
Organic-carbon content in soil	-0.415	<0.01
pH value of soil	-0.372	<0.03
(b) Iodine in soil		
Clay content in soil	0.750	<0.001
Organic-carbon content in soil	0.520	<0.001
pH of soil	0.377	<0.02

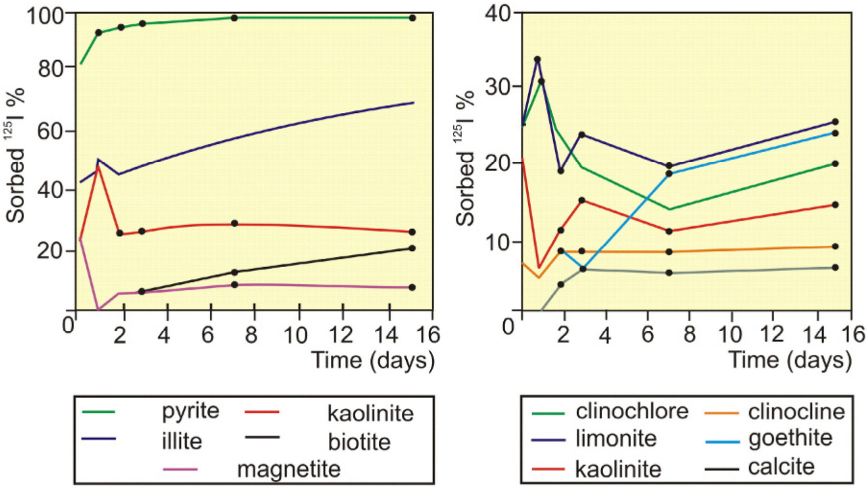

Fig. 5.12. Sorption kinetics results for ^{125}I tracer on a set of minerals (Fuhrmann et al., 1998)

Endemic Goitre in Sri Lanka

Sri Lanka located close to the equator is a typical humid tropical country and is an ideal case study for medical geology. About 75% of the 20 million population of Sri Lanka live in rural areas and depend on the immediate physical environment for their food, water and other basic amenities. The geochemistry of soil and water therefore has a marked effect on the health of the population and significant correlations exist between certain diseases and the geochemistry of some elements (e.g. F and dental diseases).

Endemic goitre is a major national health problem in Sri Lanka and a salt iodization programme is now being carried out. It has been roughly estimated that nearly 10 million people are at risk from IDD. Endemic goitre has been reported in the wet zone of Southwest Sri Lanka for the past 50 years but rarely occurs in the more northern dry zone (Fig. 5.13). The IDD prevalence in the districts of Sri Lanka is shown in Table 5.9.

Early reports on endemic goitre include Wilson (1954), Mahadeva et al. (1968), Gembicki et al. (1973), Piyasena (1979) and Fernando et al. (1987, 1989). In these studies there was very little emphasis on the geochemical aspects of the endemicity of goitre. Dissanayake and Chandrajith (1993) considered for the first time, geochemical factors that may have a bearing on the prevalence of goitre in Sri Lanka. Table 5.10 shows some geochemical data on the water and soil in areas of Sri Lanka as studied by these authors. Cluster analysis of the geochemical data showed that the endemic goitre region lies in the group with lowest I, alkali earths, Cl^-, NO_3^-, Fe and Mn. Sri Lanka, being a small island, is expected to receive a higher iodine input from the sea and it is both interesting and surprising to note that the Kalutara district (located in a coastal area) has a 44% rate of endemic goitre. This study clearly showed the importance of geochemical goitrogens in the aetiology of IDD. Dissanayake and Chandrajith (1993) suggested that elements such as Co, Mn, Se, F, As, Zn, Ca, Mg, Cu and Mo may also have an influence in the aetiology of IDD.

Balasuriya et al. (1992) studied 609 sample of drinking water collected from scattered sources from the eight districts of Kandy, Matale, Kalutara, Anuradhapura, Polonnaruwa, Colombo, Puttalam and Gampaha for the iodine contents using the electrode method. Table 5.11 shows the data obtained and their rank orders.

Table 5.9. Prevalence of iodine deficiency disorders in different districts of Sri Lanka (Fernando et al., 1989)

	Male	**Female**	**Both sexes**	**≥13-18 yrs.**	**N**
Kalutara	39.7	49.5	44.9	24.1	13373
Kegalle	18.7	34.1	26.4	11.1	2549
Monaragala	18.5	31.0	25.0	11.1	1178
Kandy	15.4	27.8	22.2	8.0	7840
Ratnapura	14.0	28.3	20.5	5.3	2070
Hambantota	15.5	23.9	19.7	4.2	2474
Galle	11.0	21.9	17.9	8.8	1926
inBadulla	14.5	20.5	17.6	7.6	856
Puttalam	10.3	13.4	12.3	2.5	2625
Kurunegala	8.3	14.1	11.1	3.5	3445
Colombo	6.7	8.2	7.6	1.8	1373
Anuradhapura	4.6	10.1	7.3	1.1	1081
Matale	3.7	8.9	6.5	2.1	1513
Chilaw	4.1	8.1	6.3	1.0	1208

In general, these authors observed that the iodine levels in the water in Sri Lanka are higher than the levels reported from other countries and only 20% of the samples had values below 10 μg/L. Their important findings were:

- There is a geographic variation in the iodide content of drinking water.
- The iodide content is related to the depth of the source (deep wells had the higher iodide levels).
- The difference in iodide contents of drinking water in cases of goitre and controls is minimal.

The Spearman Rank order correlation between water iodide and goitre prevalence among school children by district was -0.64 indicating that only about 40% of the variability of goitre prevalence between districts can be explained in terms of water iodide content.

This study also confirms the view that there are other geochemical factors that need detailed study in relation to IDD in tropical countries. Fordyce et al. (2000a) pursued the search for these geochemical goitrogens in Sri Lanka further and studied the selenium and iodine content in soil, rice and drinking water in relation to endemic goitre in Sri Lanka. They observed that the soil iodine concentrations in the Sri Lankan environment are average to marginal compared to soils elsewhere. This does not support the long-held theory that considers the soil in the wet zone to be depleted in iodine while the dry zone soils are enriched in iodine.

Table 5.10. Geochemical data on the water and soil in the Angunawala-Daulagala area in Sri Lanka (*Sample size 11) (Dissanayake and Chandrajith, 1993)

Parameter	Water (n = 60)		
	minimum	maximum	mean
pH	5.85	8.2	7.7
Alkalinity (mg/L)	30	420	138
F (µg/L)	44	700	297
Cl (mg/L)	6	108	35
I (µg/L)	15	150	55
NO_3 (mg/L)	1.5	15	8.5
Na (mg/L)	27	1016	512
K (mg/L)	0.55	9.4	7.3
Ca (mg/L)	1.35	1616	50
Mg (mg/L)	0.23	16.64	5.9
Mn (µg/L)	1	208	53
Fe (µg/L)	520	2430	1166
Hardness (mg/L)	7	341	82
Co (µg/L)*	1	23	11
	Soil (n = 60)		
pH	3.8	6.8	5.16
F (mg/kg)	0.4	45	8.4
Cl (mg/kg)	8.0	432	155
I (mg/kg)	0.007	6.5	2.0

Table 5.11. Rank order of goitre prevalence, mean and median iodine content of water in different districts of Sri Lanka (Balasuriya et al., 1992)

District	Mean (µg/L)	Median (µg/L)	Rank order of median water iodine	Rank order of goitre prevalence
Kandy	30.96	19.1	5	7
Matale	16.91	11.1	2	5
Kalutara	15.50	12.2	4	8
Anuradhapura	118.03	101.6	8	1
Polonnaruwa	47.21	33.0	7	2
Colombo	16.86	11.4	3	4
Puttalam	34.68	21.6	6	3
Gampaha	11.90	5.0	1	6

Fordyce et al. (2000a) studied 15 villages with different levels of IDD (Figure 5.14) selected from both the dry and wet zones of Sri Lanka. The results showed that concentrations of soil total Se and I are highest in the HIDD (high goitre incidence) villages. The soil clay and organic matter appeared however, to inhibit the bioavailability of these elements.

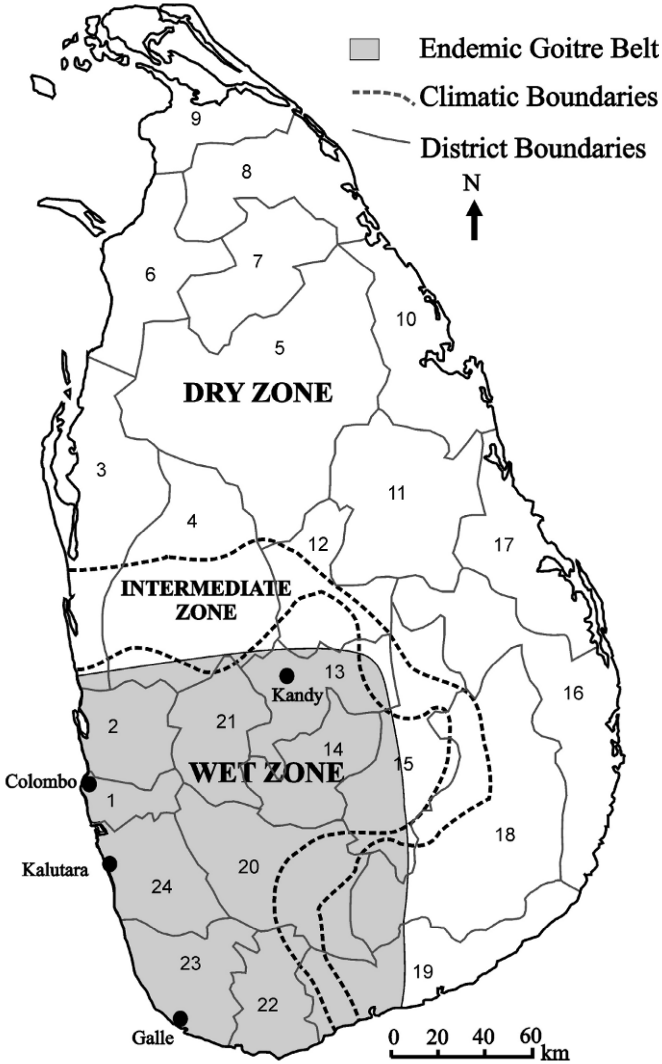

Fig. 5.13. Endemic goitre region of Sri Lanka (Districts:- 1- Colombo; 2- Gampaha; 3- Puttalam; 4- Kurunegala; 5- Anuradhapura; 6- Mannar; 7-Vavuniya; 8- Mullaitivu; 9- Jaffna; 10- Trincomalee; 11- Polonnaruwa; 12- Matale; 13- Kandy; 14- Nuwara Eliya; 15- Badulla; 16- Batticaloa; 17- Ampara; 18- Monaragala; 19- Hambantota; 20- Ratnapura; 21- Kegalle; 22- Matara; 23- Galle; 24- Kalutara)

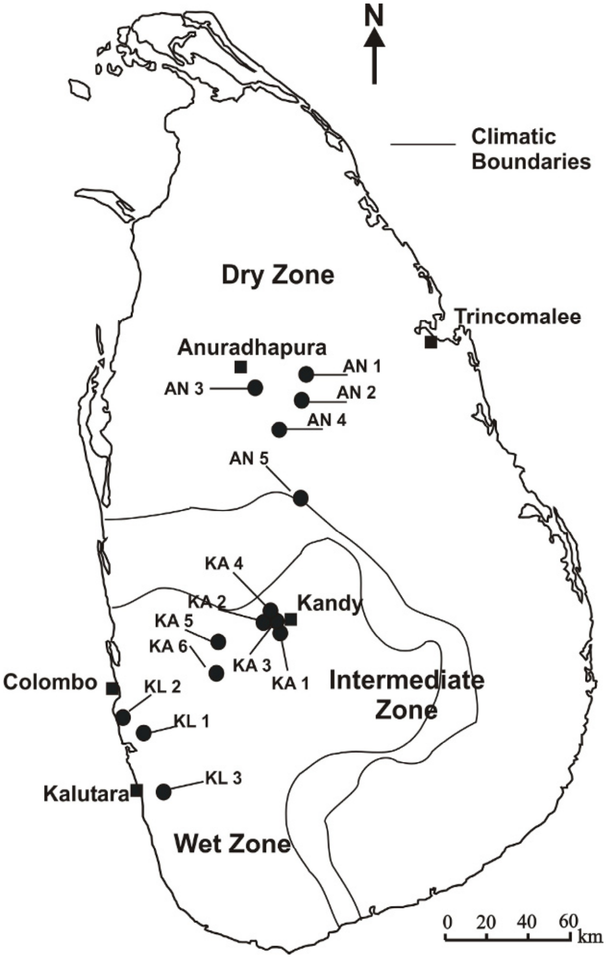

Fig. 5.14. Sketch map showing the location of the 15 study villages. NIDD- No/low goitre incidence (<25%); MIDD- Moderate goitre incidence (10-25%) and HIDD- High goitre incidence (>25%) (Modified after Fordyce et al., 2000a)

Concentrations of iodine in rice were low (≤58 ng/g) (Table 5.12) and rice is therefore not a significant source of iodine in the Sri Lankan diet. However the iodine levels in Sri Lankan rice was comparable to those in rice from other parts of the world. High concentrations of iodine (up to 84 µg/L) in drinking water in the dry zone was considered to be one of the sources of iodine. Although selenium-deficiency was not restricted to areas where goitre was prevalent, a combination of iodine- and Se-deficiency was considered to be involved in the pathogenesis of goitre in Sri Lanka.

Table 5.12. Summary of iodine and Se determinations in all sample types in each goitre incidence village group (Abbreviations: NIDD, no/low goitre incidence; MIDD, moderate goitre incidence; HIDD, high goitre incidence; nd, no data) (Fordyce et al., 2000a)

Group	Sample Type	Min. Se	Max. Se	Mean Se	No.	Min. I	Max. I	Mean I	No.
NIDD	Soil (ng/g)	113	663	226	25	130	10000	2260	25
	Rice (ng/g)	6.8	150	42	25	45	58	51	5
	Water(µg/L)	0.06	0.24	0.11	5	53	84	66.5	5
	Hair (ng/g)	104	765	294	25	nd	nd	nd	
MIDD	Soil (ng/g)	310	5238	875	24	130	6600	2008	25
	Rice (ng/g)	0.1	776	55	25	<38	<38	<38	5
	Water(µg/L)	0.06	0.09	0.07	5	3	23.5	5.5	5
	Hair (ng/g)	118	2652	389	25	nd	nd	nd	
HIDD	Soil (ng/g)	276	3947	1124	25	1000	9600	3914	25
	Rice (ng/g)	0.1	127	25	25	<38	<38	<38	5
	Water(µg/L)	0.06	0.09	0.07	5	3.3	20.2	7.02	5
	Hair (ng/g)	111	984	302	25	nd	nd	nd	

The Endemic Goitre Belt of India and Maldives

Among the nutritional disorders in India, IDD is widely prevalent with an estimated 120 million people affected (ICMR, 1989; Pandav and Kochupilai, 1982). The northern and northeastern parts of India have high endemic goitre incidence (range 25-54%) and these regions belong to the great arc of the Himalayas from West Pakistan across India and Nepal, into northern Thailand, Vietnam and Indonesia which forms one of the most highly endemic regions of the world.

Longvah and Deosthale (1998) analysed food and groundwater samples collected from the North Eastern states of Nagaland, Manipur, Mizoram, Meghalaya, Arunchal Pradesh, Assam and Sikkim for iodine. Figure 5.15 and Table 5.13 show the districts studied and their water-iodine contents. The mean iodine content in water samples from the goitre-endemic states of northeast India ranged from 6.65 µg/L in Sikkim to 8.89 µg/L in Assam. The iodine values groundwaters of northeast India ranged from 3.0 to 31.5 µg/L, and this was much lower than the range 30-50 µg/L observed in the non-endemic areas of Gujarat, Maharashtra, Mysore and Madhya Pradesh as reported by Tulpule (1969). The state of Sikkim, which had the lowest water- iodine content, has an incidence of goitre of 54% (Pulgar et al., 1992).

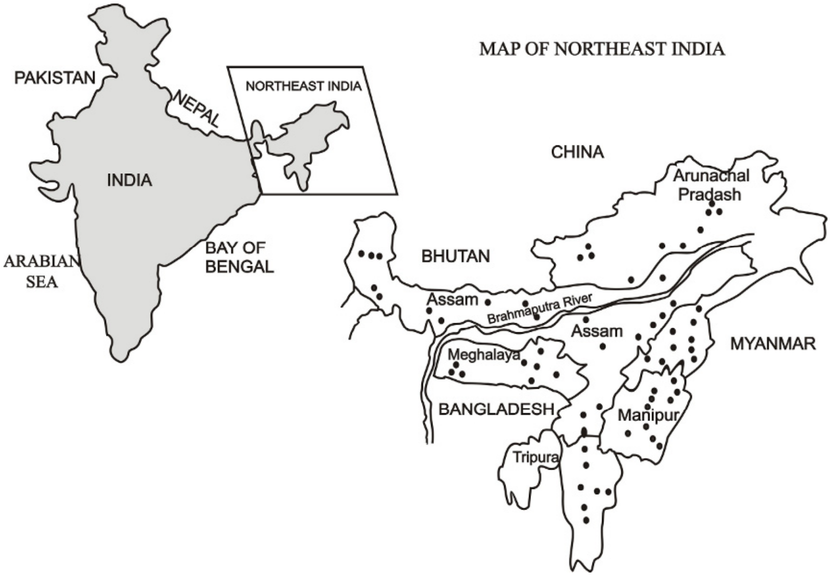

Fig. 5.15. Map of India and the location of groundwater sampling sites for iodine contents (Table 5.12) (Longvah and Deosthale, 1998)

In the case of food, the mean iodine content of rice from the goitre-endemic states of northeast India was, lowest in Sikkim (8.8 µg/100g) and highest in Assam (12.9 µg/100g). In non-endemic areas such as Hyderabad, the iodine in rice had an average of 40 µg/100µg. Other foods such as maize were also found to contain only about 25% of the iodine values observed in non-endemic areas.

Table 5.13. Iodine content in groundwater (µg/L) samples from northeast India (after Longvah and Deosthale, 1998) and Hyderabad (Mahesh, 1993)

State	No. of Samples	Range (µg/L)	Mean (µg/L)±SD
Arunachal Pradesh	24	3.2-14.5	6.98 ±2.1
Assam	44	4.3-31.5	8.89±4.9
Manipur	51	3.8-22.0	7.80±2.8
Meghalaya	35	4.3-14.7	7.68±1.84
Mizoram	48	4.0-13.9	6.92±1.7
Nagaland	54	3.2-11.9	6.57±1.5
Sikkim	31	3.0-12.6	6.65±1.8
Pooled data	287	3.0-31.5	7.38±2.7
Hyderabad	50	5.0-63.7	36.5±4.8

Even though the main endemic-goitre belt lies in the north and northeast of India, it has been found that based on results of sample surveys conducted by different agencies in 275 districts of 25 states and 4 union territories, 235 districts have been identified as endemic for IDD (Tiwari et al., 1998; ICMR, 1989).

The Kottayam district, in Kerala state, South of India, was studied for its iodine deficiency by Kapil et al. (2002). A total of 1872 children in the age group 6-12 years were studied and clinically examined. The total goitre prevalence was found to be 7.05% and this indicated that the population is in a transitional phase from iodine deficient, as related by the goitre rate, to iodine sufficiency, as revealed by the mean urinary iodine excretion level of 175 μg/L.

The importance of natural goitrogens in IDD is clearly seen in the case of Maldives, a country of islands. Being under the major influence of the sea, the main iodine reservoir, one expects a very low IDD rate in Maldives. Pandav et al. (1999), who studied IDD in the Maldives, observed that the total goitre rate was 23.6%, with grade I goitre contributing 22.5% to this figure.

Goitre in Vietnam

Vietnam is another country in South Asia which has been affected by iodine deficiency disorders. In 1992, Vietnam had 40 provinces with IDD at a rate of 43.2%. It was estimated that a million people were affected (Binh et al., 1992). As shown in Figure 5.16, the most affected areas were Ham Yen, Bach Thong, Cho Don, Sapa, Ngugen Binh and Cumngat. However, Vietnam has embarked on a successful salt iodisation programme and the IDD rate in Vietnam has dropped sharply.

Iodine Deficiency in China

In some parts of China, iodine deficiency disorders are common and have affected millions of people, bearing in mind that China is the most populous country of the world. Fordyce et al. (2002) studied the environmental controls in IDD in Xinjiang Province of China, known to be an area badly affected by IDD. According to the 1995 National lDD Survey, the goitre prevalence rate among school children aged 8 to 10 was 43.3%, the highest in China (Shaohua and De Long, 2000). This area has a semi-arid climate with an annual rainfall of less than 100 mm.

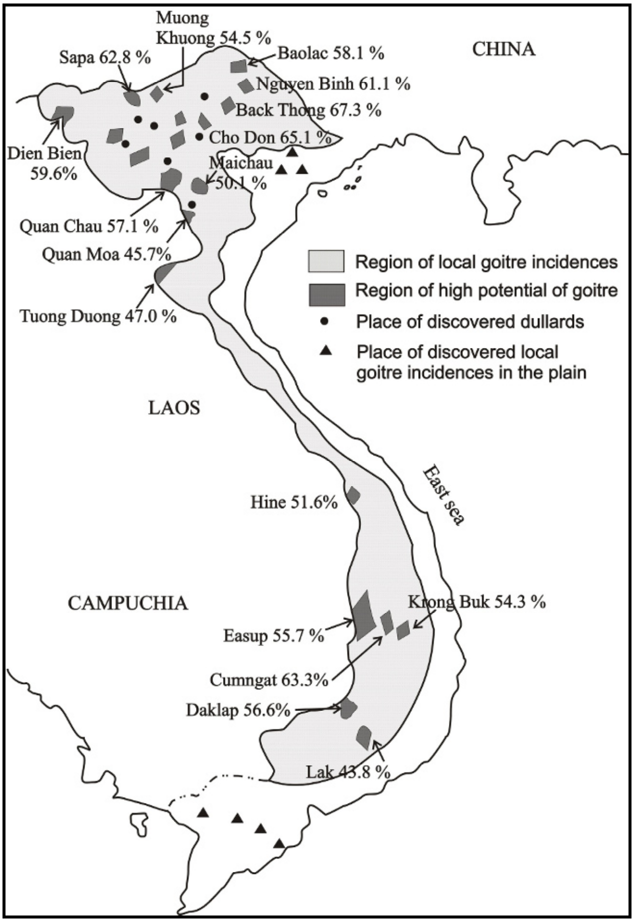

Fig. 5.16. Regional map of goitre incidences in Vietnam (Binh et al., 1992)

Some previous workers carried out a new project based on adding iodine (iodine dripping) to irrigation water and Fordyce et al. (2002) examined the environmental iodine and impact on health in three contrasting areas.

Area 1 -	AC 148 low (3.5%) recent goitre prevalence (20% historic rate). no iodine irrigation. Iodized salt available
Area 2 -	Kuqu District >30% goitre rate. No iodine irrigation. Iodized oil programme implemented.
Area 3 -	Wushi District 40-60% goitre rates. Iodine irrigation. iodized oil programme implemented.

Table 5.14 shows the village median iodine contents in soil, water, wheat and cabbage samples from the three areas studied. The results from 5 soil and wheat, 3 cabbage and 1 drinking water samples collected in 5 villages in each of the three study areas showed that the iodine concentrations in soils are similar in all three areas, and low by world standards. The total iodine content of wheat in the three study areas is broadly similar and comparable to other areas of the world. Cabbage iodine contents also showed little variation in the three study areas, but are slightly lower than results from other areas.

Table 5.14. Village, median iodine contents in soil, water, wheat and cabbage samples (No. = No of Samples; WSol = Water Soluble; DW = Dry Weight) (Fordyce et al., 2002)

Area	Village	Soil Total I, mg/kg	Soil WSol. I mg/kg	Wheat I µg/kg DW	Cabbage I µg/kg DW	Water I µg/L
148	Village 2	1.17	0.012	107.0	106.6	92.25
148	Village 21	1.14	0.012	171.4	103.5	100.00
148	Village 3	1.16	0.020	105.9	118.6	93.00
148	Village 4	0.67	0.020	182.0	94.9	80.00
148	Village 6	0.77	0.012	140.6	155.3	78.00
Kuqa	Qiman	0.99	0.020	132.2	71.7	3.09
Kuqa	Sandaqiao	0.93	0.012	101.2	77.6	3.15
Kuqa	Waqiao	1.16	0.012	80.3	118.4	4.05
Kuqa	Wuzun	1.00	0.012	112.6	178.6	2.40
Kuqa	Yaha	1.65	0.012	162.9	154.5	3.25
Wushi	Aheya	1.37	0.012	156.8	93.5	0.10
Wushi	Autebeixi	0.70	0.012	111.4	106.6	0.40
Wushi	Daqiao	0.62	0.012	121.4	79.6	3.70
Wushi	Wushi Town	0.94	0.014	152.6	81.7	0.95
Wushi	Yimamu	0.98	0.012	121.1	176.9	2.10

It is known that acidic soils favour and alkaline soils inhibit the bioavailability of iodine. The very low iodine status of the study area was explained by their location in an alkaline desert environment.

A feature worthy of note in this study was that the surface and shallow groundwaters used for drinking in Kuqa and Wushi Districts had very low iodine contents (0.1 to 4.05 µg/L) whereas waters taken from deep bore holes in the AC-148 area contained very high quantities of iodine (78-100 µg/L). Drinking water was therefore an important source of iodine in this case. Fordyce et al. (2002) were therefore of the view that the eradication of goitre from the AC 148 region many have been due to development of the area and provision of centralized groundwater supplies, rather than to the use of iodized salt. In subsistence populations consuming low-iodine food, water from iodine-rich deep sources can therefore be an important dietary source.

Iodine Deficiency in East Africa

Many countries of Africa, notably those lying in and around the tropical belt are particularly vulnerable to several diseases linked to nutritional deficiency. The non-availability of essential trace elements, poor diet, poverty, bad sanitary conditions among others, cause a multitude of health-related problems for a large population. Among these, IDD rank very high.

In 1993, Africa ranks third among regions most affected by IDD, after Western Pacific and Southeast Asia. About 220 million people were estimated to be at risk of whom 95 million were goitrous. Each year, about 3 million women who were "at risk" became pregnant resulting in about 15,000 foetal deaths, the birth of 30000 cretins and about 1 million brain-damaged children (WHO/MDIS-1993). At present however, due to salt iodization programmes, this figure has dropped dramatically.

As shown in Figure 5.17 several eastern African countries have high endemic goitre prevalence. In Kenya, goitre rates varying from 15 to 72% have been observed (Davies, 1996) and the highest rates being noted in the Highlands of the Rift Valley, Central Nyanza and western Province. Two possible goitrogens that may have contributed to the low iodine status of Kenya were the complex ions thiocyanate (SCN^-) and fluoroborate (BF_4^-). The BF_4^- ion was considered to be present in natural waters in parts of the Rift Valley (Davies, 1994). The univalent BF_4^- ion is known to have the same ionic size as the iodide ion and its goitrogenic properties have been reported (Langer and Greer, 1977).

In Uganda IDD, mainly goitre was a major surgical problem in the national hospitals in the 1960s (Kajubi, 1971). In 1991, a local survey was carried out in four mountainous districts and five lower altitude districts reported a high total goitre rate among school children 6 to 12 years old and which ranged from 63 to 76%. The mountainous districts had higher goitre rates (Bachou, 2002). In 1999, as a result of a successful salt iodisation programme there was a significant reduction in the overall total goitre rate to 16%.

Zaire is another tropical country that has been severely affected by IDD and a large scale eradication programme was required. Several regions of northern Zaire have been documented as areas with severe endemic goitre (Thilly, 1992). About 4 million people were affected and the rate of goitre exceeded 60% in adult women and cretinism was diagnosed at 1-10% of the population. The goitrogen role of thiocyanate in food containing cassava has been established.

Ngo et al. (1997) studied the selenium status in pregnant women of a rural population in Zaire and its relationship to iodine deficiency. They determined serum selenium and thyroid function parameters including urinary iodide in 30 prenatal clinics of rural villages distributed throughout the country. In all cases except one, biochemical maternal hypothyroidism (serum TSH >5 mlU/L) was present, with a frequency ranging from 3% to 12%. Hypothyroidism is caused by insufficient production of thyroid hormones by the thyroid gland.

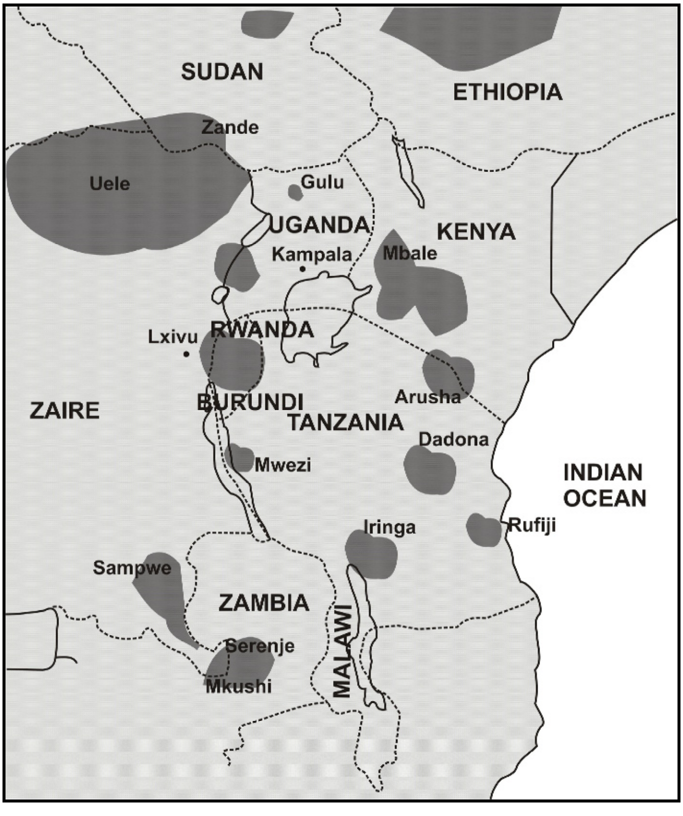

Fig. 5.17. Distribution of reported goitre areas in Eastern Africa (Davies, 1996)

In Nigeria, IDD was a major health concern about 3 decades ago (Ekpechi, 1967). The total goitre rate for Nigeria was placed at 20%. Nigeria has a well-demarcated goitre belt where almost all the inhabitants within the belt live on cassava–based food. At least 60 million Nigerians (from a population of about 120 million) were at risk of IDD. This rate has now dropped and Nigeria appears to have gained success in IDD eradication.

In 1988, a National Goitre Survey carried out in Zimbabwe highlighted goitre as a major health problem (WHO/MDIS, 1993). The National Visible Goitre Rate (VGR) was 3.7% while the Total Goitre Rate (TGR) reached 42.3%. From the 53 districts surveyed, 20 had severe endemia and 21 moderate endemia. Most of the regions with severe endemia were in the north-eastern mountainous region with a very high rainfall. By 1966, however, after a successful salt iodization programme, IDD was virtually eliminated. However, thyrotoxicosis, caused by excess intake of iodine had been recorded.