# CHAPTER 1

# INTRODUCTION

## HISTORICAL PERSPECTIVES

At the launch of the journal "Chemical Geology" in 1966, Manten (1966) traced the historical foundations of chemical geology and geochemistry. The first use of the word "geochemistry" was attributed to the Swiss chemist C.F. Schönbein in 1838. He had discovered ozone and worked as a Professor at the University of Basel. Geochemistry at this period of time emphasized the need to investigate the chemical and physical properties of geological materials and their age relationships.

W. J. Vernadsky, a Russian geochemist developed the subject of geochemistry further by studying the concentration of chemical elements in relation to the crust of the earth and the earth as a whole. Vernadsky's contributions to geochemistry are well acknowledged and it is mainly due to his early work that geochemistry in Russia received international recognition. His influence on the younger colleagues was also marked and research on geochemistry intensified with the publication of a large number of research papers.

V.I. Verndasky, another Russian scientist, made major contributions to geochemistry and published the book "La Geochemie" in 1924. Other Russian scientists such as A.E. Fersman and A.P. Vinogradov developed the science of geochemistry still further and their research findings opened up whole new disciplines related to geochemistry, such as space chemistry, biogeochemistry and chemistry of the interior of the earth.

Modern Geochemistry had its foundations in the outstanding work of F.W. Clarke and V.M.Goldschmidt. Clarke`s studies on rocks as chemical systems, the nature of chemical changes caused by external agencies and the establishment of equilibrium were indeed most significant. His publication

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"The Data of Geochemistry" which appeared in several editions from 1908 to 1924 was a landmark contribution.

V.M. Goldschmidt, referred to as the father of modern geochemistry by many, classified the elements geochemically and laid the theoretical foundations for the understanding of the affinities of different chemical elements to the different units of the earth. He established the rules governing the distribution of the elements in minerals and rocks. He studied the geochemistry of the rare-earth elements (REE) and recognized the lanthanide contraction. The importance of ionic size, ionic charge and the nature of chemical bonding in minerals was well recognized by Goldschmidt and his understanding of the geochemical cycles and pathways was truly remarkable.

Moreover, Goldschmidt's studies on meteorites and their importance in the partitioning of elements in the crust, mantle and core of the earth led to further studies of the chemistry of meteorites. It is now recognized that plate tectonics and planetology with their far reaching transformation of geological concepts had their roots in the basic discoveries of physics and chemistry made between 1900 and 1930 (Wedepohl, 1996). A special publication of the Geochemical Society, paid tribute to Viktor Moritz Goldschmidt-the truly outstanding geochemist of the century (Mason, 1992). His book "Geochemistry" (Goldschmidt, 1954) remains a classic work in the field of geochemistry.

Subsequent workers of the modern era such as N.L. Bowen, S.S. Goldich, K. Rankama and T. Sahama, H.L. Barnes, H.C. Helgeson, H.D. Holland, K. Krauskopf, B. Mason, W.S. Fyfe, K.H. Wedepohl, I.M. Garrels and C. Christ among many others, made invaluable contributions to the different aspects of the major discipline of geochemistry. With the availability of extremely powerful and accurate analytical tools, the science of geochemistry is now probing into the chemical compositions of materials in planets as far as Mars and Jupiter as well as microbial matter from the interior of the earth. With the development of the science of geochemistry, our understanding of the various earth processes has improved vastly. The knowledge of the geochemical cycles and their pathways transcending the different spheres namely atmosphere, hydrosphere, biosphere and lithosphere enabled scientists to discover the intricate processes which influence the distribution of the chemical elements. The significance of the interactions between the different spheres is of special interest to geoscientists. From among these, the geosphere-biosphere interactions have aroused the curiosity of many and the role of geology on biological processes is beginning to be increasingly investigated.

With the establishment of a relationship leading to rock-soil-water-plant-animal interactions, the influence of geology on animal and human health soon became apparent. As far back as the $11^{th}$ Century AD, the Chinese recognized this influence. Regional variations in the prevalence of human diseases were observed, indicating a geological association with the incidence of some of these diseases. The science of Medical Geology was thus established. The importance of the influence of the composition of the geological materials such as rocks, minerals, soils and water on the aetiology of a localised disease is better appreciated when man and animal are considered as only a part of a system in a total environment. The geochemical cycles and element pathways also involve man and hence the influence of the chemical composition on human and animal health becomes clearer.

Terms such as Geomedicine, Medical Geology, and Medical Geochemistry with their subtle differences in definitions, broadly deal with the geographical distributions of diseases with geological materials playing a very significant part. As in many other scientific disciplines, the birth of a new discipline is a gradual process with early examples arising from ancient chronicles, reports and hear-say accounts.

Diseases such as the iodine deficiency disorders (IDD) and their relationship to the geochemistry and geographical distribution of iodine in soil and water had been recognized as far back as 1851 by Chatin (1852), a French Chemist. Likewise, several other geographically related diseases, as exemplified by dental and skeletal fluorosis were shown to be closely related to the geological environment.

The term “Medical Geochemistry”, though not as commonly used as Medical Geology, could perhaps be broadly described as the science dealing with the chemistry of the elements in geological materials in relation to health in man and animals. An understanding of the chemical species, their pathways, toxicities and bioavailabilities in human and animal health and their impact comprise the main subject matter of the discipline of Medical Geochemistry. Unlike the much broader discipline of Medical Geology, the subject of Medical Geochemistry emphasizes the geochemistry of the chemical species concerned and their pathways. It also overlaps with other fields such as biochemistry and molecular biology. The mechanisms of the entry of the trace elements from the geosphere into the human and animal tissues is of particular scientific interest and has aroused the curiosity of scientists in a variety of disciplines. Medical geochemistry therefore deals essentially with the geochemistry of those trace elements which originate in the geological environment and which has a profound impact on the human and animal life living in close proximity. It is thus closely related to the geographical distribution of the diseases concerned, in view of the fact that the geology and hence the geochemistry of a terrain concerned is unique to that terrain. The excesses and deficiencies of the trace elements in the rocks and minerals of the terrain are shown by their geochemistry and a thorough understanding of the chemical speciation and the geochemical cycles is clearly warranted.

The field of medical geochemistry has benefited immensely from the pioneering work of Russian, Scandinavian and the British geochemists. The Russian geochemists (Vinogradov, 1938; Kovalsky, 1979) in particular had recognized "biogeochemical provinces" in the former USSR where they established relationships between geochemistry and health in both humans and animals. Also of importance is the early work of Låg (1980, 1983), in the general area of "geomedicine" which was explored fully in two symposia under the Norwegian Academy of Science and Letters.

In Canada, Warren et al. (1972) made important contributions to the field of medical geology, where they recognized the importance of the geological distribution of trace elements and their impact on health. British geochemists also made major contributions to this field as evidenced by the work of the Royal Society of London (1983) and Bowie and Thornton (1985). The publication of the National Academy of Sciences (1974, 1978) on "geochemistry and the environment" was a result of the workshops undertaken by its sub-committee on geochemical environment in relation to health and disease. More recently, The British Geological Survey has made extremely valuable contributions to the field of Medical Geology through their detailed studies in different terrains of the world. The work of Jane Plant and her team deserves special mention.

Recently, however, with the development of fast and accurate analytical techniques such as X-ray fluorescence (XRF) and Inductively Coupled Plasma-Mass spectroscopy (ICP-MS) and also with concurrent improvements in computer technology, geochemists are now able to geochemically map vast areas fairly rapidly and superimpose geographic information data. This has led to the better understanding of the geochemical pathways through the various spheres, notably the biosphere. The science of "Medical Geology" can now be considered as a well established discipline in its own right.

## WE ARE WHAT WE EAT AND DRINK

From a purely geochemical point of view, this old adage has a scientific basis. Even though there are complicating factors; such as life style, sex, age, migrations and food habits; deficiencies, excesses or imbalances in the supply of inorganic elements do exert a marked influence on human and animal health and also on the susceptibility to disease. As shown by Mills (1996), these in turn, are frequently attributable to the composition of the geochemical environment as modified by the influence of soil composition and botanical or cultural variables upon the inorganic composition of the diet. Trace element anomalies have a significant impact on the composition of food chains.

Figure 1.1 illustrates the geochemical pathways which enable the trace elements to enter the human body. The general geochemical principles govern the processes of element distribution, accumulation and depletion of trace elements in specific environments and this leads to situations where humans and animals encounter mineral excesses, deficiencies or imbalances. Such scenarios are somewhat clearer in developing countries where large populations live in close contact with the soil and immediate environment and whose food chains and trace element inputs are heavily dependent on the geochemistry of the habitat. Marked geochemical variations and anomalies therefore clearly influence the health of the population.

The importance of medical geology on the application to human and animal health can be emphasized by the following examples as summed up by Dissanayake and Chandrajith (1999).

i. More than 30 million people in China alone suffer from dental fluorosis caused by the excess of fluoride in drinking water. This is clearly related to the geochemistry of the groundwater among some other factors. Many countries, such as South India, Sri Lanka, Ghana, Tanzania among others also have very high incidences of dental (and in some cases) skeletal fluorosis.

ii. Nearly 1 billion people (notably in developing countries) suffer from Iodine Deficiency Disorders (IDD) caused by the lack of iodine in the diet. These diseases include endemic goitre, cretinism, foetal abnormalities among others. The relationship between the geochemistry of iodine in the rocks, soil, water, sea and atmosphere on the incidence of IDD is one of the most interesting research studies that is now creating global interest among scientists.

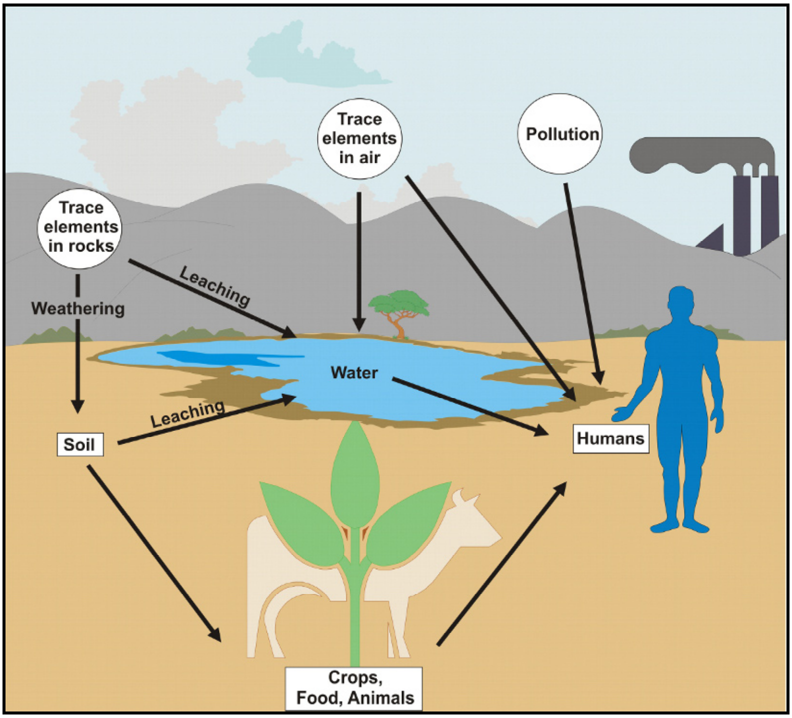


**Fig. 1.1.** Geochemical pathways of trace elements entering the human body

iii. Arsenic is a toxic and carcinogenic element present in many rock-forming minerals including iron oxides, clays and in particular sulphide minerals. When this arsenic gets into the groundwater through oxidation and subsequently into the human body through drinking water, serious health hazards can occur. Well documented cases of chronic arsenic poisoning are known in southern Bangladesh, West Bengal (India), Vietnam, China, Taiwan, Chile, Argentina, and Mexico. Skin diseases are the most typical symptoms of chronic exposure to arsenic in drinking water, including pigmentation disorders; hyperkeratosis and skin cancer, but other renal, gastrointestinal, neurological, haematological, cardiovascular and respiratory symptoms can also result. The study of the medical geochemistry of arsenic is now being recognised by several governments as a priority area of study.

iv. Recent evidence indicates that cancer, after heart diseases, is the leading killer in many industrialized societies and is largely due to environmental factors. A large number of causative factors which have been isolated are in one way or other environmental. Historically research into the causes of cancer was often based on the hypothesis that all cancers are environmentally caused until the contrary was proved. Geochemistry therefore plays an important role in the aetiology of cancer. A good example from developing countries that affects millions of poor people is the contamination of drinking water by nitrogenous matter such as human and animal wastes, nitrogen containing fertilizers etc. The common diseases caused by this are stomach and oesophageal cancer and methaemoglobinaemia ('blue baby' syndrome), caused by excess nitrates. The passage of these chemical species from the environment into the food chain and into the human body is mostly geochemical and the medical geochemistry of cancer has developed into an intriguing field of research (Dissanayake and Weerasooriya, 1987).

v. Podoconiosis or non-filarial elephantitis, named and characterised by Price (1988) affects large populations in Ethiopia, Kenya, Tanzania, Rwanda, Burundi, Cameroon and the Cape Verde Islands. The most interesting feature observed was that the affected areas were consistently associated with red clay soils. Analysis of lymph nodes from diseased tissues showed the presence of microparticles consisting predominantly of aluminium, silicon, and titanium. It was suggested that the pathological agent is a mineral from volcanic bedrocks, probably the amphibole eckermanite (Harvey et al., 1996). In this case too, the importance of research into medical geology is obvious.

vi. The main causes of low production rates among grazing livestock in many developing countries are probably linked to under nutrition. However, mineral deficiencies and imbalances in forages also have a negative effect. The assessment of areas with trace element deficiency or toxicity problems in grazing livestock has traditionally been executed by mapping spatial variations in soil, forage, animal tissue or fluid compositions. Regional stream sediment geochemical data sets collected principally for mineral exploration already exist in many developing countries (Agget et al., 1980; Plant and Thornton, 1986). The application of these data sets for animal health studies in tropical regimes is now being developed (Fordyce et al., 1996).

vii. One of the most intriguing yet, not very well defined aspects is the geochemical correlation between the incidence of cardiovascular diseases and the water hardness in the areas concerned. In several countries and areas, a negative correlation has been observed between water hardness of the country or region and its death rate due to heart diseases (Masironi, 1979). Even though a causal effect still cannot be ascribed to this geochemical correlation, the effect of trace elements in drinking water on heart diseases is worthy of serious study. It is of interest to note that such a negative association between water hardness and cardiovascular pathology is evident in both industrialized and developing nations.

## DEFICIENCIES, EXCESSES AND IMBALANCES OF TRACE ELEMENTS

Geochemically, elements are often classified as major, minor and trace elements depending on their relative abundance in geological materials, even though a precise definition has not been ascribed. Elements are broadly classified as essential or toxic depending on their impact on human and animal health. With new research and discoveries, the optimum and danger levels often change as exemplified by mercury and arsenic when their extreme health hazards were realized. As against this, with advances in analytical techniques as well as our understanding of the physiological importance of the different elements, new elements hitherto thought of as not being physiological important, have recently been classified as essential.

Such a classification of elements essential to human health and those considered to be toxic or undesirable is shown in Figure 1.2. What is of great importance is the fact that, whatever the element, it is the dosage that is critical. Elements, which are considered as being truly beneficial to human and animal health, may also lead to debilitating diseases if ingested in large doses.

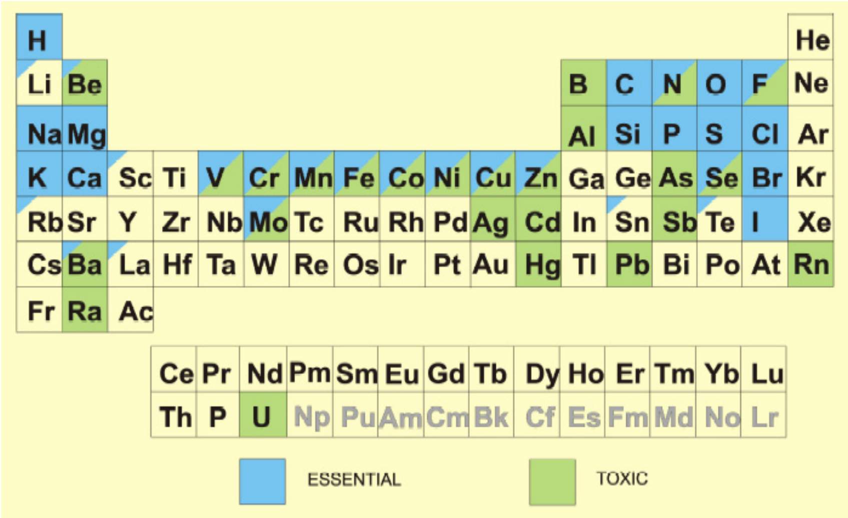


**Fig. 1.2.** The periodic table of elements showing those elements essential to human health and those considered or known to be toxic or undesirable. Note that some elements fall in both categories, others are possibly essential for living organisms (Source: Groundwater Geochemistry and Health, 1996; reproduced with kind permission of the British Geological Survey)

It is of interest to note that Paracelsus (1493–1541) defined the basic law of toxicology, namely ***"All substances are poisons; there is no element which is not a poison. The right dose differentiates a poison and a remedy"***. This basic law can be put in its perspective as shown in Figure 1.3. The effects of deficiency and excess of essential and non- essential trace elements on the growth and health of organisms are highlighted. It should be noted that it is the optimal range of the essential elements that one needs to keep intact in the ideal situation. Diseases such as hyperkalemia (excess K), hypercalcaemia (excess Ca) and hyper-phosphatemia (excess P) are known.

Potassium for example, is a major ion of the body, 98% of which is intracellular. The concentration gradient is maintained by the sodium and potassium-activated adenosine triphosphatase ($Na^+/K^+$-ATP ase) pump. The ratio of intracellular to extra-cellular potassium is important in determining the cellular membrane potential. Small changes in the extra-cellular potassium level can have profound effects on the function of the cardiovascular and neuromuscular systems. It has been shown that in serum the normal potassium level is 3.5-5.0 meq/L and the total body potassium stores are approximately 50 meq/kg (3500 meq in a 70 kg person). Hyperkalemia is therefore defined as a serum potassium level greater than 5.5 meq/L, bearing in mind that a level of 7.0 meq/L and greater is classified as a severe condition, with a mortality rate as high as 67% if not treated rapidly (Garth, 2001).

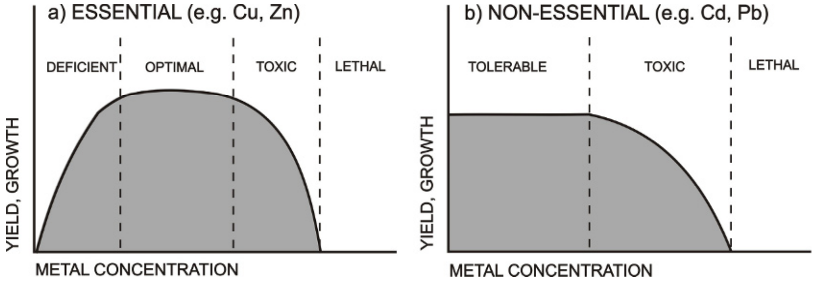


**Fig. 1.3.** Deficiency and oversupply of essential and non-essential trace elements (Förstner and Wittman, 1981)

Similarly calcium, another essential element, could cause the disease hypercalcemia (Carrol and Schode, 2003). The reference range of serum calcium levels is 8.7-10.4 mg/dl, with somewhat higher levels present in children. Approximately 40% of the calcium is bound to protein, primarily albumin, while 50% is ionized and is in physiologically active form. The remaining 10% is complexed to anions.

For hypercalcemia to develop, the normal calcium regulation system must be overwhelmed by an excess of parathyroid hormone (PTH), calcitriol, some other serum factor that can mimic these hormones or a huge calcium load (Fukagawa and Kurokawa, 2002).

Iron, another essential and important nutrient, can cause significant damage to the endothelium, the inner lining of blood vessels, if present in excessive levels in the body. Table 1.1 shows examples of effects of mineral deficiencies and excesses in human beings and Table 1.2, examples in plants.

While food is a major source of the trace elements needed by the body, some other elements, notably fluorine, is mainly ingested through water as fluoride.  Figure 1.4 illustrates the levels of trace elements, both essential and toxic, in groundwater. Their significance in terms of health and environmental protection is of particular importance in that provision of safe drinking water is a dire need in developing countries.

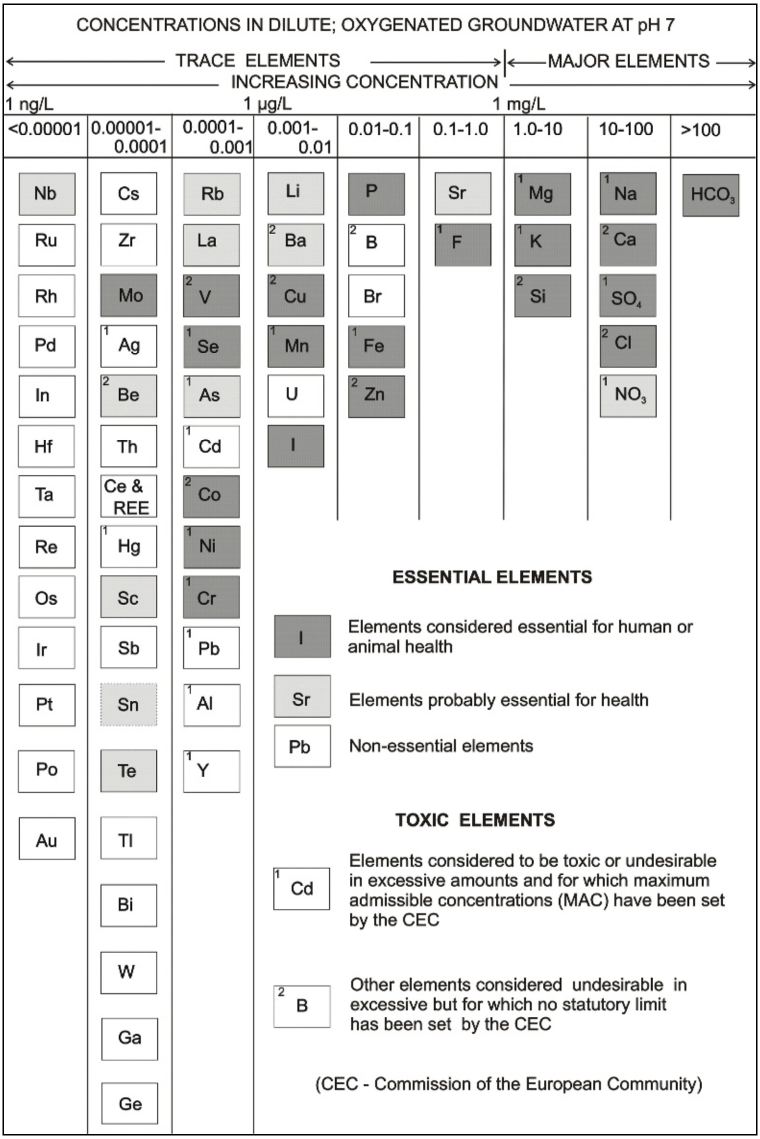


**Fig. 1.4.** Major and trace elements in groundwater and their significance in terms of health. Concentrations shown are those typical of dilute oxygenated groundwater at pH 7 (Edmunds and Smedley, 1996).

The World Health organization (WHO) plays a leading role in providing guidelines for food, drinking water quality and also for trace elements. Table 1.3 shows the guidelines for the different elements and other harmful substances in drinking water. According to the WHO (1996), the traditional criteria for essentiality of trace elements for human health are that absence or deficiency of the element from the diet produces either functional or structural abnormalities and that the abnormalities are related to, or a consequence of, specific biochemical changes that can be reversed by the presence of the essential metal.

As pointed out by the WHO, one of the important aspects of the essentiality of trace elements that the medical geologist must necessarily be aware of, is the margin between individual and population requirements and the tolerable intake (TI). This may turn out to be very small and in some instances may even overlap among individuals and populations. Developing countries with their different life styles and inadequate nutritional requirements coupled with a host of natural and anthropogenically related environmental problems may have markedly different tolerable intakes as compared to those living in developed and temperate countries. Medical geology should therefore necessary link up with toxicology and nutrition science. Terms such as acceptable daily intake (ADI), tolerable intake (TI), tolerable upper intake level (UL) and homeostasis as used by the International Programme on Chemical Safety (IPCS, 1987) need to be incorporated into the terminology of Medical Geology. Table 1.4 shows the Indian water standards which perhaps may be more appropriate for those living in developing countries of the humid tropical belt.

Groundwater quality, drinking water, health and sanitation are of special importance to developing countries in view of the fact that central water purification and proper water disposal techniques may not be available in most areas and the groundwater quality then becomes critically important in locating sites for wells for domestic and community use. In highly populated countries such as India and Sri Lanka lying within the tropical belt, water quality becomes a major factor in urban and sub-urban development.

An interesting case study in this regard is highlighted by Hutton and Lewis (1980) in their study of nitrate pollution of groundwater in Botswana. They observed nitrate levels as high as 603 mg/L in several water supplies providing drinking water to many villages. A lithium chloride tracer injected into a pit latrine was detected in the supply borehole 25 m away after only 235 minutes. The steep hydraulic gradient between the latrine and the borehole had obviously induced the rapid movement of nitrates in open fissures.

**Table 1.1.** Typical geochemical and soil features associated with inorganic element anomalies causing nutritional diseases in man and domesticated livestock (Mills, 1996)

| SYNDROME | ENVIRONMENTAL QUALITY | SPECIES AFFECTED |
|---|---|---|
| **Article I Deficiencies** | | |
| low cobalt | Soils intrinsically low in Co, eg. extensively leached, acid arenaceous soils or with Co immobilized with Fe/Mn hydroxide complexes. | ruminant livestock, specific |
| low phosphorus | High Fe/Al parent materials with low pH and highly organic soils. | ruminant livestock, specific |
| low selenium | Soils intrinsically low in Se, eg: leached arenaceous soils particularly when low in organic and argillaceous fractions. | human subjects, farm livestock, general |
| low zinc | Calcareous parent materials and derived soils especially when adventitious soil present in diets high in cereals and legumes. Arid arenaceous soils. | human subjects farm livestock, general |
| **Article II Toxicities** | | |
| high arsenic | Waters from hydrothermal sources or soils derived from detritus of mineral ore (especially Au) workings. Well waters or irrigation waters from sandstones high in arsenopyrite. | |
| high fluoride | Waters from some aquifers especially from rhyolite-rich rocks, black shales or coals; soils from F-containing residues of mineral or industrial deposits. Aggravated by high evaporative losses. | human subjects farm livestock, general |
| high molybdenum | Mo from molybdeniferous shales or local mineralization especially if drainage is poor and soil pH >6.5 (a significant cause of secondary Cu deficiency). | ruminant livestock, specific |
| high selenium | Bioaccumulation of Se in organic-rich soil horizons; accumulation by high evaporative losses of high pH groundwaters. | human subjects farm livestock, general |

**Table 1.2.** Signs of deficiency or excess of mineral elements in plants (Wellenstein and Wellenstein, 2000)

| ELEMENT | PRIMARY FUNCTIONS IN PLANT | SIGNS OF DEFICIENCY | SIGNS OF EXCESS |
|---|---|---|---|
| Nitrogen | Growth of green (leaf and stem) portions of plant. | Reduced growth, vigour. Chlorosis of older leaves first, premature leaf drop. | Soft growth, spindly growth, leaf curl, reduced flowering, symptoms of Potassium deficiency. |
| Potassium | Root growth, sugar and starch production, cell membrane integrity. | Dwarfing, chlorosis of older leaves first, leaf curling. | Deficiency symptoms of nitrogen, magnesium, calcium, iron, zinc, copper, manganese. |
| Calcium | Cell wall formation, cell division, enzyme catalyst, neutralization of toxic metabolites. | Poor growth, deformed newer leaves, chlorosis of newer leaves, blackened areas at leaf ends and new growths with a leading yellow edge, stunted, shortened roots, dead root tips. | Symptoms of magnesium deficiency. |
| Magnesium | Chlorophyll and protein production, carbohydrate metabolism, enzyme activation. | Interveinal and marginal chlorosis starting in the older leaves, increase in appearance of anthocyanin in leaves, necrotic spotting. | Symptoms of calcium deficiency. |
| Phosphorus | Constituent of nucleic acids, coenzymes NAD and NADP required for photosynthesis, respiration and many metabolic processes, and the energy compound ATP. Essential for root growth, flowering and seed production. | Older leaves are affected first, an increase in anthocyanin pigment and a dark blue green coloration, sometimes with necrotic areas, and stunting. | Symptoms of nitrogen, zinc, iron deficiencies. |
| Sulfur | Protein formation, photosynthesis, and nitrogen metabolism. | Root stunting, general chlorosis starting with younger leaves. | |

| ELEMENT | PRIMARY FUNCTIONS IN PLANT | SIGNS OF DEFICIENCY | SIGNS OF EXCESS |
|---|---|---|---|
| Boron | Sugar transport, DNA synthesis. | Death of meristematic tissue, root stunting, no flower formation. | Interveinal leaf necrosis. |
| Iron | Component of cytochromes and ferrodoxin, synthesis of chlorophyll. | Interveinal chlorosis of newer leaves. | |
| Manganese | Enzyme activation in respiration and nitrogen metabolism. | Interveinal chlorotic and necrotic spotting. | Stunting, necrotic spotting of leaves. |
| Zinc | Trytophan synthesis, enzyme activation. | Smaller, distorted leaves, stunting, interveinal chlorosis of older leaves, white necrotic spotting, resetting. | Symptoms of magnesium or iron deficiency. |
| Copper | Enzyme component, electron carrier protein in chloroplast. | Stunted, misshapen growth. | Symptoms of magnesium or iron deficiency. |
| Molybdenum | Nitrogen and potassium metabolism. | Chlorotic interveinal mottling, marginal necrosis, folding of the leaf, no flower formation. | |

Such case studies clearly illustrate the overlap between a variety of disciplines such as structural geology, hydrology, community health, town and country planning and medical geology.

As a tool in assessing the state of the environment, geochemical parameters in relation to human health issues have proven to be of immense value, both nationally and internationally. The availability in many parts of the world of sufficient data that show trends over time make such parameters useful indicators in monitoring environmental changes. Trace elements and chemical species that show direct relationships are the most useful as geoindicators of human health (Dissanayake, 1996). Medical geology is therefore rapidly gaining status in monitoring environmental health.

**Table 1.3.** Characteristics of water and waste water. WHO (1993) Drinking water guidelines (mg/L unless specified)

| Parameter | Guide Level | Note |
|---|---|---|
| **Microbiological** | | |
| Total Coliforms/100 ml | 0 | 95% absent over 12 month period |
| *E.coli* | 0 | |
| **Inorganics** | | |
| Antimony | 0.005 | |
| Arsenic | 0.01 | |
| Barium | 0.7 | |
| Boron | 0.3 | |
| Cadmium | 0.003 | |
| Chromium | 0.05 | |
| Copper | 2 | |
| Cyanide | 0.07 | |
| Fluoride | 1.5 | Depends on local conditions |
| Lead | 0.01 | |
| Manganese | 0.5 | |
| Mercury | 0.001 | |
| Molybdenum | 0.07 | |
| Nickel | 0.02 | |
| Nitrate | 50 | Sum of ratio of concentration to GL |
| Nitrite | 3 | should not exceed 1 for both together |
| Selenium | 0.01 | |
| **Organics (Part list only)** | | |
| Carbon tetrachloride | 0.002 | |
| Dichloromethane | 0.020 | |
| Trichloroethene | 0.040 | |
| Benzene | 0.010 | |
| Toluene | 0.700 | |
| Ethylbenzene | 0.300 | |
| Acrylamide | 0.0005 | |
| Nitrilotriacetic acid | 0.200 | |
| Tributyltin oxide | 0.002 | |
| **Pesticides (Part list only)** | | |
| Atrazine | 0.002 | |
| DDT | 0.002 | |
| 2,4-D | 0.030 | |
| Heptachlor | 0.00003 | |
| Pentachlorophenol | 0.009 | |
| Permethrin | 0.020 | |
| Simazine | 0.002 | |
| Mecoprop | 0.010 | |

**Table 1.4.** Indian water standards (Bureau of Indian Standards, 1991)

| Property/ Constituent | Desirable limit | Permissible limit | Undesirable effect outside the desirable limit |
|---|---|---|---|
| | **Physio-chemical Characteristics** | | |
| Turbidity JTU Scale | 2.5 | 10 | Aesthetically undesirable |
| Colour (Pt-Cobalt Scale) | 5.0 | 25 | Aesthetically undesirable |
| Taste and Odour | Unobjectionable | Unobjectionable | Aesthetically undesirable |
| | **Major Chemical Constituents** | | |
| pH | 6.5-8.5 | 6.5-9.2 | Affects taste |
| Total dissolve solids, mg/L | 500 | 1500 | Causes gastrointestinal irritation. |
| Total Hardness, as $CaCO_3$ mg/L | 300 | 600 | May cause urinary concretion, disease of kidney, bladder and stomach disorder. |
| Calcium, mg/L | 75 | 200 | Essential for nervous and muscular system, cardiac function and coagulation of blood. Deficiency causes rickets. Excess concentration causes kidney or bladder stone and irritation in urinary passage. |
| Magnesium, mg/L | <30 if $SO_4$ is 250 mg/L | 100 | Essential as an activator for many enzyme systems. Deficiency results in structural and functional changes. Excess concentration may have laxative effects. Magnesium salts are cathartic and diuretic. |
| Chloride, mg/L | 250 | 1000 | Affects taste and palatability. Causes indigestion may be injurious to people suffering from heart and kidney diseases. |
| Sulphate, mg/L | 200 | 400 | Causes laxative effects in presence of Magnesium. |
| Nitrate, mg/L | 45 | 100 | Causes infant Methemoglobinemia (Blue babies). May cause gastric cancer and affects central nervous system and Cardio-Vascular system. |
| Fluoride, mg/L | 1.0 | 1.5 | Essential for teeth and |

| **Property/ Constituent** | **Desirable limit** | **Permissible limit** | **Undesirable effect outside the desirable limit** |
|---|---|---|---|
| | | | bones, reduces dental caries in concentration range of 0.8 - 1.0 mg/L and at high level teeth mottling, skeletal and crippling fluorosis occurs. |
| Iron, mg/L | 0.3 | 1.0 | Gives bitter sweet astringent taste. |
| Manganese, mg/L | 0.05 | 0.5 | Unpleasant taste |
| Copper mg/L | 0.05 | 1.5 | Astringent taste, deficiency results in nutritional anaemia in infants, high concentration may damage liver and cause central nervous system irritation and depression. |
| Zinc, mg/L | 5.0 | 15 | Very small amount beneficial. Imparts astringent taste at higher concentration. |
| **Toxic Constituents** | | | |
| Arsenic, mg/L | 0.05 | 0.05 | Skin diseases, circulatory system problem, risk of cancer. |
| Cadmium, mg/L | 0.01 | 0.01 | Kidney damage. |
| Chromium(VI), mg/L | 0.05 | 0.10 | Lung tumor, Allergic dermatitis |
| Cyanide, mg/L | 0.05 | 0.05 | Causes nerve damages and thyroid problem. |
| Lead, mg/L | 0.05 | 0.05 | Serious Cumulative body poison |
| Selenium, mg/L | 0.01 | 0.10 | Small amount beneficial, large amount toxic. |
| Mercury, mg/L | 0.001 | 0.001 | Large amount causes brain and kidney damage |
| Polynuclear Aromatic hydrocarbon, mg/L | 0.20 | 0.20 | Toxic |