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REVIEW PAPER

Soils and geomedicine

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Abstract Geomedicine is the science dealing with the influence of natural factors on the geographical distribution of problems in human and veterinary medicine. Discussions on potential harmful impacts on human and animal health related to soil chemistry are frequently focused on soil pollution. However, problems related to natural excess or deficiency of chemical substances may be even more important in a global perspective. Particularly problems related to trace element deficiencies in soils have been frequently reported in agricultural crops as well as in livestock. Deficiencies in plants are often observed for boron, copper, manganese, molybdenum, and zinc. In animals deficiency problems related to cobalt, copper, iodine, manganese, and selenium are well known. Toxicity problems in animals exposed to excess intake have also been reported, e.g., for copper, fluorine, and selenium. Humans are similar to mammals in their relations to trace elements and thus likely to develop corresponding problems as observed in domestic animals if their supply of food is local and dependent on soils providing trace element imbalances in food crops. In large parts of Africa, Asia, and Latin America, people depend on locally grown food, and geomedical problems are common in these parts of the world. Well-known examples are Keshan disease in China associated with selenium deficiency, large-scale arsenic poisoning in Bangladesh and adjacent parts of India, and iodine deficiency disorders in many countries. Not all essential elements are derived only from the soil minerals. Some trace elements such as boron, iodine, and selenium are supplied in significant amounts to soils by atmospheric transport from the marine environment, and deficiency problems associated with these elements are therefore generally less common in coastal areas than farther inland. For example, iodine deficiency disorders in humans are most common in areas situated far from the ocean. There is still a great need for further research on geomedical problems.

Keywords Geomedicine · Human health · Soil · Trace elements · Deficiency · Toxicity

Introduction

In the basic textbook by Låg (1990) geomedicine is defined as the “influence of ordinary natural processes on the health of humans and animals.” In addition to influence from geological processes, this definition also encompasses the influence on health of factors such as incoming radiation from the sun and the interstellar space, climatic conditions, and atmospheric transport of chemical substances. In this paper such

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factors will be discussed only to the extent that they may affect health through interfering with the elemental composition of the soils, which is the focus of this review.

In spite of the fact that numerous reports have occurred over the centuries linking some human diseases to particular geographical areas (Låg 1990), it is surprising to note the limited attention that has been paid to the relation between soils and human health by soil scientists as well as medical professionals (Deckers and Steinnes 2004). In fact the veterinary profession has been much more aware of this kind of relationship. An extensive literature exists on the problems of deficiency and excess of trace elements in animal nutrition (Lewis and Anderson 1983; Mills 1983; Frøslie 1990), and balancing of micronutrient intake has long been an essential concern in the feeding of agricultural livestock.

The general interest in connections between the natural environment and human health has been stimulated recently through the book "Essentials of Medical Geology" (Selinus et al. 2005), and this book can be recommended for a more extensive treatise of some of the problems discussed in this paper. Other reviews dealing with soils and geomedicine are papers by Oliver (1997; 2004) and Deckers and Steinnes (2004).

A great majority of the literature on geomedicine deals with trace elements, i.e., elements present in living organisms at very low concentrations, but still affecting human health because they may be supplied to the organism in deficient or excessive amounts relative to a normal level. This paper, therefore, concentrates on the impact of trace elements on human and animal health under natural conditions.

Trace elements in the soil/plant system

Trace elements in soil are generally derived from the mineral material present in the soil, and become plant available by weathering of soil minerals. Some metals are more mobile in the soil than others and may be depleted in the root zone by leaching to deeper layers. On the other hand, root uptake in plants and return to the soil surface by decaying plant material ("plant pumping") may serve to concentrate some elements in the surface soil relative to deeper layers (Goldschmidt 1937; Steinnes and Njåstad 1995). This is particularly evident for plant nutrients such as potassium, calcium, manganese, and zinc, but may also explain surface enrichment of other elements readily absorbed by some plants such as rubidium, cesium, barium, and cadmium.

In some cases supply from the marine environment in the form of sea salt aerosols or volatile organic compounds, or from volcanic activity, may significantly affect the concentrations of elements in the surface soil, such as the atmospheric supply of iodine and selenium to coastal areas from processes in the ocean (Låg and Steinnes 1974; 1976) and the contamination of agricultural land in Iceland by fluorine from eruptions of the Hekla volcano (Låg 1990).

Micronutrient deficiency in plants may limit agricultural production and either directly or indirectly affect human nutrition (Alloway 2005; Andersen 2007). There are eight recognized essential plant micronutrients: boron, chlorine, manganese, iron, nickel, copper, zinc, and molybdenum (Gupta and Gupta 2005). With the exception of nickel, and possibly boron, these elements are also essential to humans and higher animals. The plant uptake of these elements as well as other elements discussed in this chapter, such as cobalt, nickel, arsenic, selenium, cadmium, and iodine, depends first of all on their chemical form in the soil, which may be influenced by a number of factors. The soil pH is particularly important in this respect. Elements such as molybdenum and selenium may be strongly bound in the intermediate pH range (5.5–7.5), but readily plant available in more alkaline soils. On the other hand, iron, aluminium, manganese, and toxic metals, such as cadmium and lead, are more available the more acid the soil. Sometimes competition between different metals may prevent optimal uptake of a particular nutrient, such as the decreased zinc availability induced by the presence of relatively high concentrations of other metals such as copper, iron and calcium (Kiekens 1995). Under equal conditions, different plant species may take up the same metal from the soil at very different rates (Alloway 2005).

Trace elements and health

Most of the 90 elements present on Earth occur in the human body at concentrations of 100 mg kg^{-1} or less. Only a few of these elements are known to have essential functions in the body. Among the elements present in trace concentrations in the human body, only chromium, manganese, iron, cobalt, copper, zinc, selenium, and molybdenum, and possibly fluorine, are confirmed to have some essential function. For some other elements, clinical symptoms have been observed with low concentrations in the diet, but the possible essential function is not known. The great majority of elements are not known to possess any specific biological function. Most, if not all, elements are toxic to the human organism if they occur in the food in specific chemical forms and above certain concentration levels. This means that for essential elements there exists a certain concentration range representing a safe and adequate intake. Concentrations above or below this range may cause health problems due to deficiency or toxicity. For elements not possessing any biological function, there is probably no such range, but just a concentration threshold above which the element becomes toxic.

In the following, the geomedical aspects of some key elements are discussed. The data listed for mean concentrations in the upper continental crust and median levels in surface soils are Wedepohl (1995) and Bowen (1979), respectively.

Aluminium

Although aluminium is the most abundant metal in the Earth's crust (8.0%), it is present at trace levels in most biota. Studies suggest that less than 1% of dietary aluminium is absorbed in humans—factors affecting absorption may include vitamin D, fluoride, and presence of complexing agents (WHO 1996). Aluminium is known to be neurotoxic at high exposure levels. Some epidemiological studies found a statistically significant association of aluminium in drinking water with the incidence of dementia (Martyn et al. 1989; Flaten 1990). Some more recent studies did not confirm this association, and a recent authoritative review (Krewski et al. 2007) states that further studies are needed to settle the debate over the link between aluminium in drinking water and neurological disorders.

Aluminium from drinking water usually contributes only a very small proportion of daily human intake. The major part of a typical 20 mg/day daily intake comes from food (e.g., tea) and food additives containing aluminium, such as preservatives, fillers, coloring agents, etc. Aluminium may also leach from cooking utensils if exposure is long enough. However, evidence surrounding the relationship between aluminium in food and neurological disorders is at present very minimal (Krewski et al. 2007).

Arsenic

The crustal mean concentration of arsenic is 2 mg kg^{-1}, and the median concentration in soils is 6 mg kg^{-1}. Arsenic is a toxic metal, especially if present in oxidation state III. In most cases the arsenic content in soils does not represent a health problem as such, but under specific circumstances naturally occurring arsenic can create very substantial health impacts. In many areas of the world traditional surface water sources for drinking have been replaced by groundwater because of high contents of infectious organisms. This has caused severe problems in some regions because of the naturally high content of arsenic in the groundwater. The most well known case is the Bengal delta (Bangladesh and adjacent areas of India) where millions of people are exposed to high levels of arsenic. According to Smedley and Kinniburgh (2002) around 35 million people in Bangladesh and 6 million people in West Bengal were estimated to be at risk from arsenic in drinking water at concentrations above 50 µg l^{-1}. The most obvious health problems related to chronic exposure to arsenic are skin disorders, notably pigmentation changes and keratosis, although skin cancer has also been identified (Smedley and Kinniburgh 2005). Karim et al. (2007) compared the nutritional status of children in arsenic-exposed and non-exposed areas in Bangladesh and found that children in the exposed area had a significantly lower body mass index, were more underweight, and more stunted than those in the control group. Health problems related to naturally high arsenic in drinking water have also been reported from Taiwan and northern Chile (Oliver 1997). Concentrations in groundwater sufficiently high to cause health problems have also been reported from numerous other areas, including northern China, Vietnam, Hungary, north central Mexico, Argentina, and southwest USA (Smedley and Kinniburgh 2005).

Boron

The crustal mean concentration of boron is 17 mg kg^{-1}, and the level in soils is similar. The presence of boron in the environment originates mainly from marine salts, volcanic activity, and industrial pollution. In foodstuffs boron occurs in plant tissues, of which legumes contain the highest levels, followed by fruits and vegetables (WHO 1996). Boron is essential for plant growth and is probably essential for human health, but this has not been established conclusively. Excessive boron intake may cause symptoms of boron poisoning, such as: gastrointestinal disturbances, erythematous skin eruptions, and signs of central nervous system stimulation followed by depression (WHO 1996). Boron is an issue of concern in irrigated agriculture, as high boron levels in irrigation water may cause boron levels in the soil to rise to such an extent that crop levels become toxic.

Cadmium

The crustal mean concentration of cadmium is as low as 0.10 mg kg^{-1}, but the median concentration in soils is considerably higher (0.35 mg kg^{-1}), partly due to "plant pumping." Human activities however are the main reason for high cadmium contents in soils. Phosphate fertilizers are the most widespread cause of cadmium contamination, but activities such as zinc mining, emissions from smelters, and application of sewage sludge to soils have caused significant local problems in some places. Cadmium is one of the most toxic metals known to humans and is present in relatively high concentrations in black shales. The major health hazard of cadmium appears to be chronic accumulation in the renal cortex, which may cause age-related decline in the renal function at moderate intakes (Roels et al. 1981).

Chromium

The crustal mean concentration of chromium is 35 mg kg^{-1}, and the median value in soils is 70 mg kg^{-1}. Trivalent chromium is essential to man and animals, and it plays a role in carbohydrate metabolism as a glucose tolerance factor. The function of chromium in the human body seems to be closely associated with that of insulin, and most chromium-stimulated reactions depend on insulin (Anderson 1981). It plays a role in carbohydrate and lipid metabolism, and for the utilization of amino acids. At normal soil pH chromium is present as Cr(III), which is fairly insoluble and immobile. It is only under very acid soil conditions that chromium may be released in sizeable quantities from the exchange complex. Chromium is necessary in the human body as a co-factor for insulin and henceforth plays a role in sugar metabolism. Chromium deficiencies may lead to arteriosclerosis. Excessive intake of chromium is associated with renal dysfunction. It should be noted that toxicity of chromium depends on oxidation status—Cr(VI) is mutagenic, whereas Cr(III) is not (WHO 1996). In epidemiological studies an association is found between occupational exposure through inhalation to Cr(VI) and mortality due to lung cancer, but no problems in human health connected to naturally high levels of chromium in soils seem to have been reported.

Cobalt

The mean crustal concentration is 12 mg kg^{-1}, and the median in soils is similar. Among the trace elements essential to humans and animals, cobalt is unique in that the requirement is not for the element per se, but for a preformed cobalt compound, Cobalamin (vitamin B_{12}) produced by microorganisms. Higher plants and animals are not able to produce cobalamin. Sometimes however there is an indirect symbiotic relationship between bacteria and animals, such as in ruminants where cobalamin produced by rumen microorganisms is absorbed further down the gastrointestinal tract of the animal. Cobalt deficiency is frequently observed in sheep, and also sometimes in cattle. The symptoms were known already at the end of the nineteenth century, but the problem was long thought to be iron deficiency, until Underwood and Filmer (1935) were able to link it to cobalt. Cobalt deficiency is widespread in New Zealand, Australia, and Great Britain, and also occurs frequently in parts of Scandinavia (Frøslie 1990). Endemic problems in humans related to cobalt are not known, with the exception of a proposed relationship between the cobalt status in the environment and incidence of goiter in Russia, which deserves to be further examined (Smith 1987).

Copper

The mean crustal concentration is 14 mg kg^{-1}, somewhat lower than the median of 30 mg kg^{-1} reported for soils. Copper deficiency is widespread all over the world. Copper deficiency in plants is common with high soil pH, high organic carbon content, and excessive drainage conditions. Copper plays an essential role in the human body as part of metalloproteins, e.g., hemoglobin. Main sources of copper in food are meat, mainly liver followed by fish, nuts, and seeds. Zinc and iron are strong antagonists to copper, and a large intake of them can lead to copper deficiency (Oliver 1997). Copper deficiency in humans may lead to typical disease symptoms such as anemia, deformations of the skeleton, neural disorders, color change of hair, degeneration of the hearing muscle, reduced elasticity of arteries, and loss of pigment in the skin. Copper deficiency however is relatively rare in adults, but is involved in several diseases in children, particularly in situations of malnutrition. Geo-medical correlations with copper in human medicine, however, remain inconclusive so far.

In animals both copper deficiency and copper poisoning problems related to natural pastures are quite common, in particular in sheep (Frøslie 1990). In both cases the condition may be influenced by the antagonistic effect on copper exerted by molybdenum. Thus, the copper/molybdenum ratio in the feed is important, in particular with ruminants. Excess of molybdenum can cause copper deficiency at otherwise sufficient copper levels (molybdenosis), whereas poisoning may occur at relatively moderate copper levels if the molybdenum intake is too low.

Interestingly, copper deficiency and/or molybdenosis may have been the reason for a complex disease observed in moose in a region of Sweden affected by acidic precipitation (Frank 1998). The clinical signs of this disease were multiple, including sudden heart failure and osteoporosis, and the reason was thought to be increased pH in soil and water in the moose environment and corresponding changes in plant availability of copper and molybdenum.

Fluorine

Fluorine occurs in nature as the fluoride ion. The mean crustal concentration is 610 mg kg^{-1}, whereas the median in soils is only 200 mg kg^{-1}, presumably because fluoride is easily leached from the topsoil. Correlation between fluorine content in the human diet and the soil type was established for the first time in New Zealand (Ludwig et al. 1962). Drinking water constitutes an important source of fluoride, and wherever concentrations are high, drinking water is likely to constitute the main source of fluoride to humans and livestock.

The natural fluorine content shows large geographical variations (Havell et al. 1989), which has a great impact on human and animal health. Moderate amounts of fluorine are beneficial to dental structure, whereas chronic intake of high amounts may lead to development of dental fluorosis, and in extreme cases skeletal fluorosis. Deficiency in fluorine has long been linked to dental caries, and fluoride addition to drinking water to augment naturally low fluoride concentrations has been undertaken in some countries (Edmunds and Smedley 2005). The range of safe and adequate fluoride, however, appears to be very narrow. Fluoride concentrations in drinking water of around 1 mgl^{-1} are thought to be optimal. However, chronic use of drinking water exceeding 1.5 mgl^{-1}, the WHO (2004) guideline for fluoride in drinking water, may already be detrimental to health. More than 200 million people worldwide are thought to be drinking water with fluoride in excess of this value, including about 70 million in India and 45 million in China (Edmunds and Smedley 2005). In Sri Lanka, where the incidence of dental fluorosis among children is high, it is apparent that the fluoride exposure may depend not only on the natural fluoride content of the bedrock, but also on the climate (Dissanayake 1991). In spite of the fact that rocks containing fluoride-rich minerals are underlying most of the country, areas in the west with mean annual precipitation above 2,000 mm experience few fluoride problems, whereas they are abundant in the eastern and north central regions of the country where the climate is dryer. This difference is apparently due to more extensive leaching of fluoride in the areas of high rainfall.

Iodine

The mean crustal concentration of iodine is 1.4 mg kg^{-1}. The median in soils worldwide is 5 mg kg^{-1}, but the span between low and high iodine soils is very large. The highest values are found in organic-rich soils near the coast. It has long been obvious that iodine must be released from the ocean in another form than just as sea-salt aerosols. Whereas the chlorine/iodine ratio in ocean water is about $3 \cdot 10^5$, it is generally 100–1,000 times lower in precipitation samples collected in marine air (Seto and Duce 1972) and another factor of 10 lower in natural surface soils (Låg and Steinnes 1976). The major mechanism of iodine transfer from ocean to land must reflect preferential volatilization of seawater iodine into the atmosphere (Fuge 2005), and the most likely source seems to be the release of volatile methyl iodide by marine organisms (Yoshida and Muramatsu 1995). The relative role of wet and dry deposition of iodine on land surfaces is not clear (Fuge 2005), and little is known with regard to the quantities of marine iodine carried to areas remote from the sea.

Iodine has long been known as an essential element for humans and mammals, where it is a component of the thyroid hormone thyroxene. Insufficient supply of iodine may lead to a series of iodine deficiency disorders (IDD), the most common of which is endemic goiter. Iodine deficiency during pre-natal development and the first year of life can result in endemic cretinism, a disease that causes stunted growth and general development along with brain damage. This brain damage may occur when there is no obvious physical effect, and probably represents the most widespread current geomedical problem on Earth with as many as 1.6 billion people at risk (Dissanayake 2005). The areas of the world currently most affected by IDD are largely located in developing countries (Fuge 2005), with large, continuous territories in continental parts of Africa, Asia, and Latin America. However, even in some affluent countries of Western Europe, it has been suggested that as many as 50–100 million people may be at risk (Delange 1994).

Iron

Iron is the second most abundant metal in the Earth's crust (average concentration 3.1%), and the median in soils is similar. Iron is an important element in man and higher animals, as a key component of hemoglobin, myoglobin, and a number of enzymes. Important sources of total iron in the human diet are meat, fish, eggs, green vegetables, and wholemeal flour and bread, whereas milk and milk products, white flour and bread, polished rice, potatoes, and most fresh fruits are poor in iron. The mobility of iron in soils depends on its oxidation state, Fe(II) being the more mobile form. In the surface soil however iron is normally present as Fe(III), the chemical speciation of which depends on pH and redox conditions. At high pH the soil may be deficient in plant-available iron.

Iron deficiency is a common problem in human populations. In several studies of infants in the USA, the incidence of iron deficiency anemia is reported to vary from less than 5% to as high as 64%. Although some of the variation may be explained by differences in the criteria of anemia employed, differences in socioeconomic status are undoubtedly an important factor (Morris 1987). In the adult population iron deficiency is much more common in women during their fertile years than in men, because of their iron losses in menstruation, pregnancy, parturition, and lactation. In developing countries, where the population relies heavily on vegetable foods and where infections and extensive sweating are common, the incidence of iron deficiency anemia is generally higher than in the more industrialized and temperate climate areas of the world (Morris 1987). No geographical differences in the incidence of iron deficiency related to soil quality seem to have been reported in the literature.

Lead

The mean crustal concentration is 17 mg kg^{-1}, and the median in soils is 35 mg kg^{-1}. This difference is due to the widespread contamination from air pollution; according to Patterson (1965) the pre-industrial value may have been as low as 12 mg kg^{-1}. Lead is an element of high toxicity, but transfer of lead from the soil to the green parts is limited for most plants. According to published literature on adverse health effects of lead, the risk appears to be limited to exposure from lead pollution.

Manganese

The mean crustal concentration is 530 mg kg^{-1}. The median in soil is somewhat higher (1,000 mg kg^{-1}), presumably because of "plant pumping." Manganese is an essential element for humans and higher animals, and is an element of low toxicity. It occurs in some metalloenzymes and is involved in many biochemical processes in the organism. Manganese deficiency is known in several animal species, including sheep, goats, and cattle. It may occur either as a primary condition in certain geographical regions where the soil is poor in manganese or in a secondary form associated with excess calcium and phosphorus, but does not appear to be of any practical importance in livestock farming (Frøslie 1990).

Some epidemiological studies have linked manganese deficiency to human health problems. Marjanen and Soini (1972) found a strong negative linear relationship between soil manganese content and cancer incidence (all types of cancer included) in a study comparing 179 parishes in Finland. Several studies in South Africa and Iran seem to link the incidence of esophageal cancer with manganese deficiency (Deckers and Steinnes 2004). Another health problem located to South Africa, the Mseleni joint disease, has also been associated with manganese deficiency (Fincham et al. 1981).

Mercury

The mean crustal concentration is 0.056 mg kg^{-1}, and the median in soils is similar. Mercury has no known essential function, and all chemical forms are toxic, most severely in the case of methyl mercury. Several cases of intoxication of groups of people have been described, the most severe in Minamata, Japan, where a great number of people died after eating locally caught fish. The reason for the high methyl mercury content in the fish was the release of mercury from a local chlor-alkali plant and subsequent methylation in the sediment of the Minamata Bay. All reported cases of group intoxication due to mercury appear to be associated directly or indirectly with human activities. Epidemic events unquestionably due to naturally high mercury levels have so far not been reported, but some indigenous populations are exposed to high levels of methylmercury due to high consumption of predatory freshwater fish or marine animals. This problem has probably increased during recent times because of a substantially increased atmospheric load of mercury in the Northern hemisphere (Bindler 2003). In some countries the construction of hydroelectric reservoirs, involving flooding of previous land areas, has resulted in methylation of mercury concentrated in the previous topsoil and subsequent accumulation in the aquatic food web. Indigeonus people living mainly from freshwater fish have thus been exposed to high levels of methylmercury (Dumont and Kosatsky 1990).

Molybdenum

The mean crustal concentration is 1.4 mg kg^{-1}, and the median in soil is similar. Molybdenum is an essential element, which is a constituent of several enzymes in human and animal organisms. However, it has a relatively small window of optimal concentration and is involved in several toxicity problems in sheep and cattle (Frøslie 1990). Molybdenum per se appears not to be particularly toxic (Mills and Davis 1987), but when present in excess amounts it may exert an antagonistic effect on copper, causing a secondary copper deficiency in situations when the supply of copper is otherwise adequate. Conversely, a low molybdenum intake may result in copper poisoning at normal copper levels. Corresponding problems in humans have not been reported.

Nickel

The mean crustal concentration is 19 mg kg^{-1}, and the median in soil is 50. The reason for this difference is not obvious; perhaps plant pumping may explain part of its behavior. As yet there is no firmly established biological function in humans or higher animals, but some findings indicate that nickel functions either as a cofactor or structural component in specific metalloenzymes, or as a bio-ligand cofactor facilitating the intestinal absorption of the ferric ion (Nielsen 1987a). The toxicity of nickel is relatively low, but nickel allergy is a significant problem in humans. Nickel deficiency problems seem not to have been reported either for humans or livestock.

Selenium

The mean crustal concentration is 0.083 mg kg^{-1}, and the median in soils is 0.4 mg kg^{-1}. This difference may partly be explained by atmospheric supply of selenium from volcanoes, air pollution, and marine emissions, but it is also conceivable that soils from areas geochemically poor in selenium were underrepresented in the database on which the soil median was based. Selenium concentrations in soils however show extreme geographical variations. This along with the narrow range of safe and adequate intake means that geomedical problems have been identified in humans and livestock both in relation to selenium deficiency and excess. In the USA, there are large areas in the Great Plains where selenium-rich soils are present, and some plants may reach levels toxic to livestock. Wheat from these areas has long been the main source of flour for bread baking in Norway, which is assumed to be one of the main reasons for the good selenium status in the Norwegian population (Meltzer et al. 1993). On the other hand, the selenium-deficiency-related disorder white muscle disease in animals has been commonly observed in several states of the northeast as well as the northwest of the USA (Muth and Allaway 1963).

China is another country where soils show extremely variable selenium contents geographically (Fordyce 2005) and where significant geomedical problems are evident, both in low-selenium and high-selenium districts. Geographically widespread endemic diseases, such as Kashin-Beck disease, an endemic osteoarthropathy resulting in chronic arthritis and deformity of the joints, and Keshan disease, a cardiomyopathy whereby the heart muscle is damaged, have both been shown to be associated with selenium deficiency (Tan and Hou 1989). Keshan disease was most prevalent in eroded hills where regosols and leptosols dominated the soil landscape. Rice seemed to concentrate Se more efficiently from the soil than other local food crops, and people on a rich rice diet showed less selenium deficiency symptoms that people with other eating habits. Selenium supplementation to the affected populations has now reduced these health problems substantially.

There are similarities between Kashin-Beck disease and the iodine-deficiency disorder creatinism (Fordyce 2005). In addition, the recent establishment of the role of a selenium-containing enzyme, iodothyronine deiodonase, in thyroid function means that selenium deficiency is now being examined in relation to iodine deficiency disorders in a more general sense. Concordant selenium and iodine deficiency has been suggested to account for the high incidence of creatinism in some countries of Central Africa (Kohrle 1999). Selenium deficiency has also been demonstrated in populations suffering from iodine deficiency disorders in Sri Lanka (Fordyce et al. 2000).

Also in the developed countries the selenium status varies considerably among different populations, depending on the composition of the diet. Finland was among the countries with low selenium status in the population around 1970. At the same time the incidence of cardiovascular disease in Finland was among the highest in the world, and it was hypothesized that low selenium might be one of the reasons. A large-scale experiment adding selenium to fertilizer was therefore initiated. This led to increased selenium content in bread grain as well as milk, and eventually almost a doubling of serum selenium concentration in the population (Hartikainen 2005).

Låg and Steinnes (1974; 1978) found that selenium in forest soils of Norway decreased regularly with distance from the coast from around 1.0 mg kg^{-1} near the coast to <0.2 mg kg^{-1} in areas shielded from marine influence, suggesting that the ocean may be a significant source of selenium to coastal terrestrial areas. This seemed surprising considering the extremely low content of selenium in seawater (0.1 µg l^{-1}). Cutter and Bruland (1984) however showed that organic selenide made up around 80% of total dissolved selenium in ocean surface waters. Mosher et al. (1987) observed anomalous enrichment of selenium in marine aerosols, and found that the concentration was related to primary productivity in the sea. Cooke and Bruland (1987) studied the speciation of dissolved selenium in surface water and observed the formation of volatile organo-selenium compounds, mainly dimethyl selenide, $(CH_3)_2Se$. On that basis they hypothesized that out-gassing of dimethyl selenide may be an important removal mechanism for dissolved selenium from aquatic systems. Thus, it seems that biologically driven transport from the ocean to continental areas naturally low in selenium may be a significant geomedical factor.

Vanadium

The mean crustal concentration is 53 mg kg^{-1}, lower than the 90 mg kg^{-1} median reported for soils. Vanadium is an essential element for some marine organisms and has long been suspected to have a biological function in humans and domestic animals as well. So far, however, there has been no demonstration that vanadium deficiency reproducibly and consistently impairs a biological function in any higher animal (Nielsen 1987b).

Zinc

The mean crustal concentration is 52 mg kg^{-1}, lower than the 90 mg kg^{-1} median reported for soils. Zinc is one of the most important essential trace elements in human nutrition, being essential for the functioning of a great number of enzymes. Examples of the essential role of zinc are (1) its utmost importance during pregnancy, pregnant women requiring much more zinc in their diet than otherwise (Jameson 1982), (2) its importance for brain growth in infants (Prohaska 1982), and (3) its extreme importance in immunocompetence (Nauss and Newberne 1982). Red meat is a particularly good source of zinc nutrition, and whole grains, pulses, and unpolished rice are also important sources of daily zinc intake (Oliver 1997).

Large areas of the world have soils that are unable to supply staple crops, such as rice, maize, and wheat, with sufficient zinc. According to Alloway (2005), zinc deficiency is the most widespread essential trace element deficiency in the world, perhaps affecting as much as one third of the world's human population. In several countries large proportions of the arable soils are affected by zinc deficiency, such as in India where around 45% of soils are deficient in zinc (Singh 2001). Zinc deficiency was first observed and reported among rural inhabitants of the Middle East in the early 1960s (Nauss and Newberne 1982). Dietary zinc deficiencies are also found in industrialized countries such as USA (Nauss and Newberne 1982) and Sweden (Abdulla et al. 1982). Moderate zinc deficiency has been cited as a major etiological factor in the adolescent nutritional dwarfism syndrome in the Middle East, the cardinal features of which are severe delay of sexual maturation and dwarfism (Hambidge et al. 1987). Phytate intake is assumed to adversely affect zinc metabolism, and consumption of phytate-rich bread has been suggested as a reason for the above problem (Reinhold et al. 1973). Other studies however have failed to demonstrate a significant inhibitory effect of phytate on zinc uptake (Hambidge et al. 1987). Recently it was suggested that fetal Zn deficiency contributes to the pathogenesis in adults (Maret and Sandstead 2008).

Radioactive elements

Radiation from natural sources is the major source of radiation exposure to humans (Steinnes 1990). Natural radiation sources are classified into external and internal sources. External radiation sources consist of two components: an extraterrestrial one in the form of cosmic rays and a terrestrial one from radioactive nuclides present in the geological environment, in building materials, and in air. The internal sources comprise the naturally occurring radionuclides that are taken into the human body. In areas with normal geochemical background, the internal sources contribute about two thirds of the effective radiation exposure to humans (UNSCEAR 1982).

The radioactive nuclides responsible for more than 99% of the radiation exposure from terrestrial sources are ^{238}U and its radioactive decay products (61%), ^{232}Th and its radioactive decay products (19%), and ^{40}K (18%). When it comes to internal exposure, the ^{238}U chain is even more important because one of its members, ^{222}Rn, is a gas. This isotope of radon has a half-life of 3.82 days and is supplied to the human body by inhalation. The radiation dose provided by ^{222}Rn and its decay products is about 40% of the total exposure for the average population, but can be much greater for people living in areas with high uranium in the ground. The ^{232}Th chain also has a radon isotope, ^{220}Rn, but its contribution to the internal radiation dose is less than 20% of that from the ^{238}U series, in spite of the fact that thorium is four times as abundant as uranium in the Earth's crust. One reason for this is the shorter half-life of ^{220}Rn (55 s) compared to that of ^{222}Rn.

In a recent review paper (Appleton 2005) the sources and human health impact of radon were discussed in detail, with examples mainly from the USA and UK. The radon problem is closely associated with rocks high in uranium, such as uraniferous granites, marine black shales, and phosphate rock. Most of the exposure to radon results from living indoors. Radon in indoor air comes from gas derived from soils and rocks beneath the building, with smaller amounts from degassing of domestic water into the indoor air and from building materials.

Contribution from domestic water is normally small except where ground water is the source of water supply. The main health effect of radon is lung cancer. In the USA radon in the indoor air contributes to about 20,000 lung cancer deaths each year. Only smoking causes more lung cancer deaths. These estimates are based on case-control studies considering individual radon exposure and smoking histories.

Considerable efforts have been made in many countries to map the natural background radiation, and occurrences of anomalously high levels have been identified in a great number of cases, sometimes extending over considerable areas. The most well-known cases appear to be the monazite-bearing areas in Kerala on the southwest coast of India, where thorium is the main radioactive element, and similar areas in Brazil (Cullen and Franca 1977). In a nationwide geochemical reconnaissance study in Canada, several examples of a broad regional nature of uranium anomalies were demonstrated (Painter et al. 1994). It is not yet known however to what extent human health may be associated with the regional distribution of natural radioactivity. Cohen (1997) reported a negative correlation between radon and lung cancer rates in counties of the USA, but the results of this study are controversial (Lubin 1998, Smith et al. 1998). Epidemiological studies were also conducted in high background areas of India and Brazil, but the output appeared to be somewhat limited, e.g., because of small exposed populations and inadequate medical records (Cullen and Franca 1977).

Need for future geomedical studies

Regional differences in chromium, copper, iron, iodine, selenium, and zinc in the human diet and excesses of arsenic, cadmium, fluorine, and selenium do occur in both developed and developing countries, but their effects are usually more evident in the latter, largely because of malnutrition and reliance on local food products (Oliver 1997). The extent of geomedical problems in developing countries is therefore potentially very large, and much work needs to be done in order to solve these problems. As evident from examples in this paper, there is a considerable activity in many developing countries regarding some of the known problems related to soil and health. Very likely, however, the extent of geomedical problems is even greater than so far anticipated, and it therefore remains as an important area of interdisciplinary research for the foreseeable future. Soil scientists should feel responsibility for a significant part of this activity.

As also indicated in the foregoing text, geomedical problems do exist also in developed countries, in spite of the more balanced diet available in these countries. One particular development that may be followed closely in this respect is the rapid development of organic farming (Steinnes 2004). Organic farming is dependent on approaches different from those used in conventional agriculture in order to compensate for deficiencies of essential nutrients in the soil. If the farmers and their advisers have insufficient knowledge about the local geochemical conditions and the demands for micronutrients in plants and animals, they may face diseases in crops and animals, reduced agricultural production, and inferior product quality. The practices accepted for use in organic farming should be able to account for these problems.

At a recent international conference on biogeochemistry of trace elements (Zhu et al. 2007), more than 400 papers were presented, a large part of which related to soils. An overwhelming part of the papers however dealt with potentially toxic trace elements of pollution origin and measures to prevent human exposure to these elements. The papers at that conference dealing with geomedical issues can probably be counted on one hand. This may seem rather disappointing considering the great need for further research related to the natural occurrence of trace elements. Research on soil pollution may be important *per se*, but the problems in the world related to imbalances in the supply of naturally occurring elements to humans and livestock are probably much greater than those related to soil pollution.

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