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Role of Soils and Its Trace Element Concentration on Human Dental Health: An Overview

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Abstract: Recognition of the relationship between soils and human health dates back to ancient times and soil degradation has certainly been an important issue for human civilization. The intake of food quality and its nutrition value depends to a large extent on the health of soils, in which it is grown. Moreover, the quality of drinking water depends upon the mineral-bearing rocks forming the aquifers, the soils through which it passes and the related geo-hydrological parameters. The present study specifically addresses the dental health problems caused due to the in-situ ground condition of the locality and the soil contamination. This kind of study has become more vital considering the fact that the burden of oral diseases is increasing in many developing countries, especially among the rural masses. However, the possible connections between soils or ground conditions and dental problems are yet to be established properly. Mechanism of the incorporation of trace elements into soils and further into human teeth need more understanding. The present appraisal of the works related to soils and human health can be considered as thought-provoking for future research in this field, especially in view of the effects of rapid climate change and industrialisation on soils and human health in recent times.

Key words: Soil, contamination, trace elements, groundwater, dental caries, fluorosis.

Soils and Human Health

The relationship between soils and human health is recognized since ancient times (Brevik and Hartemink, 2010, Brevik and Sauer, 2015). In the 13th century BCE, Moses who was then a renowned Hebrew prophet, teacher, and leader, preached that fertile soil was essential to the well-being of his people. In 400 BCE, the Greek philosopher Hippocrates defined health based on an equilibrium achieved between environmental forces including soils or ground on the one hand and individual habits on the other (Pournaropoulos, 1938). Although most of the people in the ancient world used to view illness as a punishment from the gods, many of them believed that the natural world including soils plays a role in human health (Queijo, 2010).

Gradually, the relationship between soils and human health has been established scientifically. Investigations have dealt with a possible connection between trace elements in soil and dental caries, cardiovascular disease and multiple sclerosis as mentioned in the literature (Armstrong 1964; Healy et al., 1961). A possible connection between cancer and soils is sought by some of the researchers (Haviland, 1892; Underwood, 1962). In the 1900s, large numbers of investigations have been done establishing the possible relationships between human diseases and soil, especially the fertility of soils and the nutrition value of food crops being grown on

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it (Albrecht, 1947, 1951; McCarrison, 1921). Albrecht (1947) has pointed out the loss of soil health due to high rainfall and highly naturally weathering conditions and thus affecting the protein content of foods obtained from the crops grown in these soils. The proteins and carbohydrates produced in plants by the biosynthesis and photosynthesis process mainly depend upon the quantity and availability of different soil minerals. For example, calcium is associated with the synthesis of protein whereas potassium is for carbohydrates. Hence, the loss of calcium even in the fertile soils can make it unfit for growing protein-rich legumes like alfalfa, clover, beans, peas, chickpeas, lentils, lupins, mesquite, carob, soybeans, peanuts, etc. Hamidov et al. (2018) have highlighted the soil process change in organic carbon transformations and nutrient cycling through altered moisture and temperature regimes, altered rainfall patterns in the soils.

Further, the application of fertilisers and pesticides in huge quantities in current agricultural practice, use of inorganic chemicals in construction and infrastructure development projects, and the uncontrolled release of effluents from industries pollute the soils and thus incorporating heavy metals and toxic elements into our food chain. Incorporation of the toxic and harmful elements into our food chain is affected by many of the soil parameters like soil permeability and its drainage quality, soil capillary action, soil mineralogy, geo-hydrological properties of the soil and rocks, etc.

Soils and Teeth

Soil plays a major role in the dental health of human beings. Mainly, soil affects the dental conditions through foods obtained from crops grown on the soils and through water that passes through the soils. Consumption of food and water flourished in contaminated soil may cause dental diseases like the formation of cavities and tooth decay (dental caries), dental fluorosis, periodontal problems, and even tooth loss. Moreover, the treatments needed to grow even carbonaceous vegetation on soils in most of the countries are lime (calcium) and superphosphate (phosphorus), which are the chemical composition of our teeth i.e. calcium phosphate. Hence, there is a good reason that the poor dental condition of the people in these areas should relate to the low fertility of the soils (Schlack and Birren, 1946). It cannot be denied that significant technological development in dental treatment has taken place over time i.e., starting from the use of a silver paste as an amalgam to maintain oral health in 700 AD to the introduction of synthetic enamel in the current decade. However, considering the large dental care market all over the world, it becomes essential to establish the relations between human teeth and various affecting factors including soil or ground conditions.

Dental Problems due to Trace Elements

As mentioned earlier, dental problems through the soil are mainly due to the presence of trace elements in it. Among different trace elements, fluoride is given much importance by doctors and researchers from a dental point of view. The World Health Organization (WHO) has recommended a fluoride content of 0.6 to 1.5 mg/L in drinking water for human consumption. The minimum prescribed value is required for the sound health of teeth and bones, whereas fluoride content >1.5mg/L results in dental fluorosis. However, the prescribed limits are slightly varied by some countries. It is worth mentioning that the fluoride content in natural drinking water mainly depends upon the surface and subsurface soil/rock properties. Many literatures (Brudevold and Soremark, 1967; Shahab et al., 2017) are available on dental fluorosis. Fluoride may affect tooth dentin as well as enamel. For easy reference, the teeth structure is presented in Figure 1.

The tooth enamel is principally made up of hydroxyapatite (87%) which is crystalline calcium phosphate. Since fluoride is more stable than hydroxyapatite, it displaces the hydroxide ions from hydroxyapatite to form fluorapatite resulting in hard and brittle teeth if continued for a long time. This is called dental fluorosis (Brudevold and Soremark, 1967).

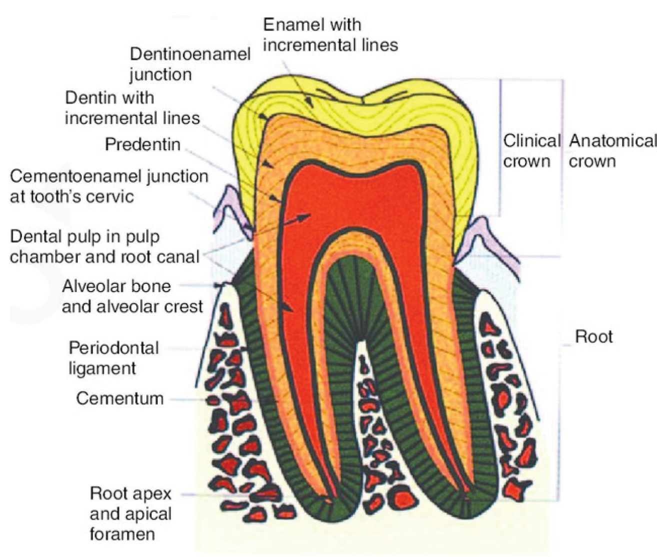

Figure 1: Teeth structure (Papagerakis and Mitsiadis, 2013).

In dental fluorosis, glistening white teeth become dull, lose their shine, and become coloured from yellow to brown. Discolouration, streaking, and even structural damages like cracking of teeth, pitting and chipping are reported to be the consequences of dental fluorosis. Mottled enamel due to the poisoning of the enamel forming cells i.e., ameloblasts is a characteristics feature of dental fluorosis. Moreover, fluoride exposure during this enamel development process disrupts the enamel (i.e., hard outer surface layer of *teeth)* mineralisation and thus resulting in anomalously large gaps in its crystalline structure, excessive retention of enamel proteins, and increased porosity.

From the literature review, it was found that the trace elements other than fluoride are not considered seriously from a dental point of view. Some of the researchers (Bhaskar et al., 2018) have even stated that dental researchers have been almost mesmerised by the element fluorine only. They are of the opinion that Pb, Sr, Mg and carbon are other elements influencing chemical, crystallographic and biologic characteristics of teeth by consolidating them into the enamel. The metal traces result in roughening of the tooth surface and thus making it more susceptible to decay from bacteria further. In addition, large ulcerations (i.e., sore on the skin or a mucous membrane, accompanied by the disintegration of tissue), ecchymoses (i.e., discolouration due to bleeding underneath), gingivitis (i.e., a gum disease which results in bleeding or swollen gum due to plaque formation on teeth causing inflammation of the surrounding gum tissue), periodontitis (inflammation of the gums and supporting structures of the teeth), and subsequent tooth loss are the severe consequences of heavy metal concentrations in teeth.

Armstrong (1964) found that higher contents of Mo, Al, and Ti, and lower contents of Ba, Co, Mn, and Sr are associated with a lower incidence of dental caries. Similarly, Bhaskar et al. (2018) have reported that a high level of Ba, Li, Mo, Sr, and V is significantly correlated with lower caries prevalence and a positive correlation exists between Co and Pb levels and high caries. Dogan (2018) has reported that Cu, Se, Mn, Cd, and Pb are increasingly correlated to dental caries or tooth decay. On the other hand, Mo has been associated with reduced caries prevalence (Davies and Anderson, 1987). However, as per the information available in the literature (Curzon and Bibby, 1970), Mo along with Se, V, and a variety of other elements may influence the prevalence of caries in men. Low caries are associated, in order of importance, with higher levels of phosphorus P, Cu, Mo, Ca, Mg, Ba, Sr, and Al (Losse and Ludwig, 1970). Also, the concentration of heavy metal and calculus formation (hardening of plaque which is the sticky, colourless film that constantly forms on teeth), are known to be correlated to each other. It is reported (Cenić-Milosević et al., 2013) that a higher concentration of Pb could be a possible reason for tooth loss and hard dental tissue damage in that regions. Not only the higher concentration of trace elements but also the alteration of the density of some of these elements makes the teeth more susceptible to caries (Dogan, 2018).

The deposition of trace elements in human teeth is age and gender-dependent (Dogan, 2018). For example, Co can be higher in women, while lead can be higher in men. In addition, the accumulation of heavy metals also depends upon the diet habits of a person (WHO, 1996). A diet low in calcium promotes significant increases in the absorption and retention of both lead and cadmium. Similarly, iron deficiency promotes cadmium retention.

Role of In-Situ Ground Conditions

In-situ ground conditions including soil/rock properties and geologic boundary conditions play a major role in determining the concentration of trace elements that we take through our diets and drinking water. Considering the importance of trace elements on human health, many of the researchers have tried to understand the role of subsurface geology and the geotechnical and geo-hydrological mechanism behind the release of trace elements into soil and ground water. However, with relevance to the title of this paper, most of the previous works (Bhattacharya and Samal, 2018; Pickering, 1985; Shahab et al., 2017) are focusses on fluoride content in soil and drinking water. Fluorides are also commonly present in various igneous and volcanic rocks like granites, muscovite, pegmatites, amphibolites, etc. Minerals like apatite, fluorite (also known as fluorspar), topaz and mica get weathered naturally and provide fluoride to soils (Bhattacharya and Samal, 2018). It is reported that in most of the rocks, fluorine is present normally in the range of 100-1300 mg/kg. But, in soils, fluoride contents generally vary in the range of 20-500 mg/kg (Shahab et al., 2017). After its dissolution from weathered rock, it mixes with the ground water and soil and subsequently enters into our body through food and drinking water. Sandy soil is relatively humid environments, contains a lower concentration of F, while the higher concentrations of F are found in soil from weathered mafic rocks and in heavy clays. The pH of the soil and the clay and organic carbon content are reported to be the primary factors in deciding soil F content. Patel et al. (2014) have highlighted that the release of F is a function of several factors including rock mineralogy, hydrogeological condition, groundwater chemistry, interaction period of groundwater with aquifer material, and the dissolution kinetics of bearing minerals. Further, the sorption capacity of the soil, types of sorbents present in the soil, and soil salinity largely regulate the mobility of fluoride in soils (Bhattacharya and Samal, 2018). Hossain et al. (2015) have established the correlations between soil salinity and its physico-chemical properties as presented in Table 1. It is worth mentioning here that the nutrition value of the crops grown in soils majorly depends upon these parameters and total P, exchangeable Ca and K, which also plays a vital role in due consideration of dental health. Yadav et al. (2018) have mentioned that F is not readily released from soil because of its strong association with the soil components (except in coarse clay and Fe/Al oxide-poor soils)and factors like chemical speciation, soil chemistry and climatic conditions influence the fluoride release from soils. They have further reported that the mobility of fluoride in soils depends on soil pH, exchangeable sodium percentage, type of clay and the presence of $CaCO_3$ in natural soil solution. In calcareous soils (soils having high levels of $CaCO_3$), the formation of slightly soluble CaF_2 and F complexes with Al, Fe, and Si is responsible for the low migration fluoride. On the other hand, high levels of exchangeable Na results in increased solubility of F in sodic soils (i.e., soils containing an exchangeable sodium percentage usually >15%).

Soil Contamination

In addition to the release of trace elements into the soil due to adverse soil/ground conditions, the soil may get contaminated due to some anthropogenic impacts and other reasons as well. Soils may get contaminated from various sources mainly by industries. The total heavy metal contents in soil can be determined as follows:

$$M_{\text{total}} = (M_p + M_a + M_f + M_{\text{ag}} + M_{\text{ow}} + M_{\text{ip}}) - (M_{\text{cr}} + M_l)$$

where "*M*" is the heavy metal, "*p*" is the parent material, "*a*" is the atmospheric deposition, " *f*" is the fertiliser sources, "ag" is the agrochemical sources, "ow" are the organic waste sources, "ip" are other inorganic pollutants, "cr" is crop removal, and "*l*" is the losses by leaching, volatilisation and so (Wuana and Okieimen, 2011). The available trace elements in soils would further depend upon the soil environment. Zhanbin et al., (2013) have shown how the trace elements vary with pH value and presence of organic matter as depicted in Figures 2 and 3, respectively.

Many of the researchers (Brindha and Elango, 2011; Kim et al., 2009; Moon et al., 2015; Zhu et al., 2009) have worked on remediation of contaminated soils. Various methods presented in the literature for contaminated soil remediation are listed in Table 2. However, the objectives of soil treatment are site and project-specific and obviously, all the methods included in Table 2 are not meant for making the soil suitable for agriculture purposes. It is not mentioned clearly whether the treated soil is still safe to use with consideration of human health and if yes, then to what extent. It is still a point of discussion if the treated soil in the actual field with the remaining 23% F content is safe and if the washing solutions are further a threat to the crops grown on the treated soils. Similarly, Kim et al. (2009) have shown the fluorine removal efficiency of electro-kinetic techniques is 75.6%. Zhu et al. (2009) have reported significant F as well as As and Cr removal efficiencies of an appropriate anolyte enhanced electro-kinetic

Table 1: Correlations between soil salinity (EC) and physico-chemical properties of soil (Hossain et al., 2015)

Physico-chemical properties	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Soil pH (1)	-									
Soil temperature (2)	0.783	-								
EC, dS/m (3)	0.917	0.808	-							
Bulk density, g/cc (4)	-.427	-.158	-.326	-						
Organic matter, % (5)	-.775	-.896	-.712	0.251	-					
Total nitrogen, N (6)	-.875	-.809	-.830	0.500	0.853	-				
Total phosphorus, P (7)	0.848	0.624	0.762	-.298	-.480	-.601	-			
Exchangeable K, % (8)	0.808	0.828	0.653	-.291	-.738	-.738	0.833	-		
Exchangeable Ca, % (9)	0.115	0.289	-.101	0.041	-.579	-.244	-.159	0.250	-	
Exchangeable Mg, % (10)	0.884	0.800	0.785	-.510	-.879	-.870	0.597	0.714	0.435	-

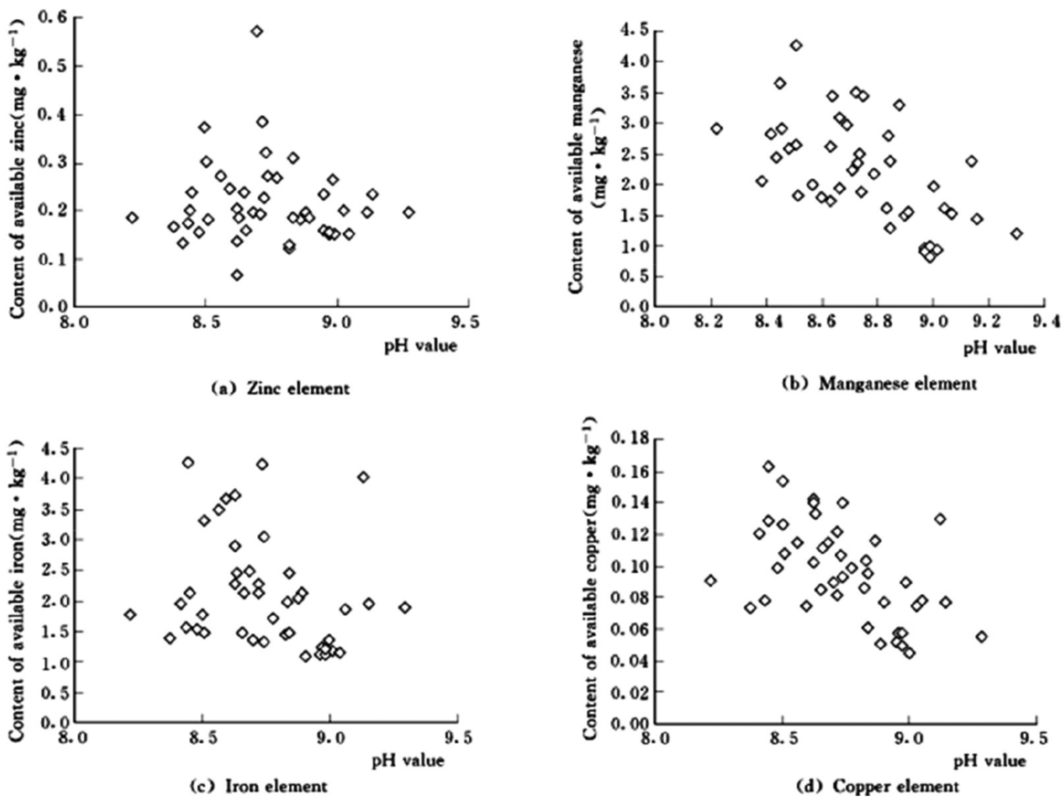

Figure 2: Relationships between available trace elements and soil pH (Zhanbin et al., 2013).

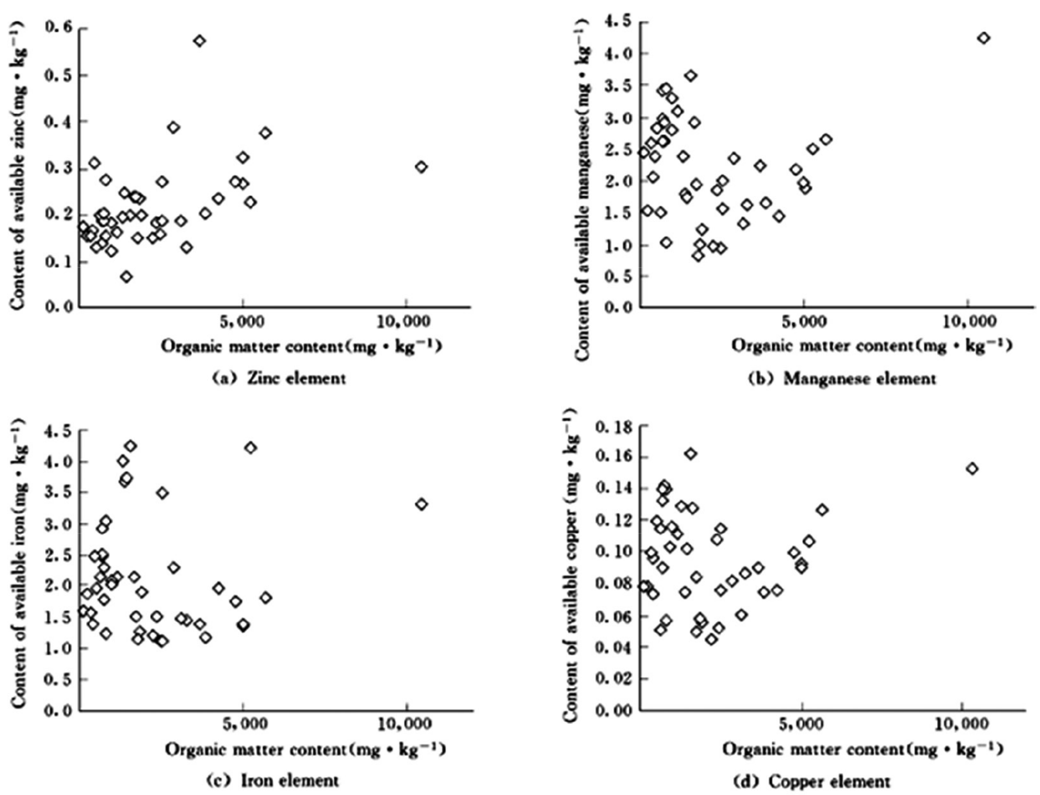

Figure 3: Relationships between trace elements and total organic carbon content (Zhanbin et al., 2013).

Table 2: Remediation techniques for contaminated soils

Category	*Methods*
Isolation	Capping, subsurface barriers
Immobilisation	Solidification or stabilisation, vitrification, chemical treatment
Toxicity and/or mobility reduction	Chemical treatment, permeable treatment walls, biological treatment bioaccumulation, phytoremediation (phytoextraction, phytostabilisation, and rhizofiltration), bioleaching, biochemical processes
Physical separation Extraction	Soil washing, pyrometallurgical extraction, in- situ soil flushing, electrokinetic treatment

method from contaminated field soil. Compared to the other methods, phytoremediation is economical, less disruptive to the environment and avoids excavation and transport of polluted media thus reducing the risk of spreading the contamination. Moreover, it has the potential to treat sites polluted with more than one type of trace element. However, the determination of the exact time required to treat a specific contaminated soil may be a bigger challenge as it depends upon many factors such as climatic condition, soil properties and topography, chemical properties of the contamination and its concentration, etc. Kumar et al. (2017) have mentioned different types of plants for the removal of different heavy metals like Cd (*Jatropha curcas*, peanut, sunflower, etc.), Pb (Canola, oat, wheat, king grasses like *Pennisetum* and *Americanum*, sweet potato, *Mscanthus* spp. and giant reed, sunflower, willow), Zn (energy grasses like *Arundodonax* and *Miscanthus*, *Mscanthus* spp. and giant reed, sunflower, willow), Cr (*Mscanthus* spp. and giant reed, willow) and so on. Keeping in view the overall literature available, it is realized that future research should also be focussed on the post-remediation utility of in-situ contaminated soils considering human health including dental problems. Moreover, further agricultural research establishing the different heavy metals intake capacity of the crops under different soil and climatic conditions and establishment of suitable crop rotation patterns are expected to be very helpful in tackling the problems.

Conclusions

Based on the review of literature, it is deeply realised that there is a strong connection between soil and human teeth. The following points are concluded from the present study:

- The dental research has not seriously considered trace elements other than fluoride. Based upon the known facts from limited literature available, it is stated that more research is required to establish the effects of trace elements like arsenic, lead, molybdenum, selenium, vanadium, strontium, magnesium, etc. on human teeth.
- The effect of climate change on soil environment/ ecosystem, and in turn, its effects on dental health are pointed out by some of the researchers. This issue needs to be addressed widely, keeping in view the rapid climate change in the present scenario. Considering the strong connection between soil health, crops nutrition, and human teeth, future research can also be focused on modified hybrid seeds to tackle the problem.

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