

Review

Nickel in soils: A review of its distribution and impacts

Yahaya Ahmed Iyaka

Department of Chemistry, Federal University of Technology, P. M. B. 65, Minna. E-mail: iyaka7@yahoo.com.

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Nickel is generally uniformly distributed in the soil profile and typical soil nickel contents vary widely based on the parent rock, with elevated levels at surface soils been associated with soil- forming processes and anthropogenic contamination principally ascribed to agricultural and industrial activities. Major concern for the impact and distribution of nickel in soils arises apparently from the role of soil as an ultimate sink for heavy metals and the consequence transfer through the food- chain to crops, fruits and vegetables grown in contaminated soils and their possible consumption by animals or humans. Furthermore, in this review the role of nickel as a nutritional trace element for some animals, micro- organisms and plants, and its implicative deficiency or toxicity symptoms that may arise from the presence of too little or too much nickel is also of interest.

Key words: Nickel, heavy metal, soil, nutritional element.

INTRODUCTION

Nickel was first isolated from the mineral niccolite by a Swedish Chemist Axel Crostedt in 1751. The name "Nickel" was derived from the term 'Kupfenickel' which means 'Old Nick's Copper' that the German miners gave to niccolite because of its emission of toxic fumes when heated (Kotov and Nikitina, 1996). Naturally, nickel occurs widely in the environment, being released through both natural and anthropogenic sources, but seldom in its elemental form (DEPA, 2005a; Cempel and Nickel, 2006). Nickel's natural source to the environment include forest fires and vegetation, volcanic emissions and wind - blown dust, while, the anthropogenic activities resulted in atmospheric accumulation of nickel from combustion of coal, diesel oil and fuel oil, the incineration of waste and sludge as well as, from miscellaneous sources (HC, 1991; Clayton and Clayton, 1994; McGrath, 1995; Von, 1997). Application of some phosphate fertilizers are also important sources of nickel into environment as pollutants (Kabata- Pendias and Pendias, 1992). Nriagu (1990) reported that industrial emissions of nickel amount to more than 100 times that from natural sources.

Nickel is the 24th most abundant metal in the earth's crust and 5th most abundant element by weight after iron, oxygen, magnesium and silicon, constituting about 3% of the earth composition. It is a member of 1st row transition series and belongs to group 10 of the periodic table with other group members that include palladium, platinum

and darmstadtium. In its elemental form, nickel is silver-white in colour, hard and lustrous, but in powdery form, it is reactive in air and ignites spontaneously (ATSDR, 2005). It has a density of 8.9 gcm⁻³, a melting point of about 1455°C and a boiling point of 2732°C. Its relative atomic mass is 58.71 and atomic number of 28. Nickel usually exists in the 0 and +2 oxidation states, but less frequently in the -1, +1, +3 and +4 oxidation states. Nickel possesses high electrical and thermal conductivities; hence, it is resistant to electrical erosion, oxidation and corrosion at temperatures of -20 to +30°C (Coogan et al., 1989; WHO, 1991, Chau and Kulikovskyy- Cordeiro, 1995; Higgins, 1995).

APPLICATIONS AND USES

Nickel has many industrial uses such as coinage manufacture, electroplating, nickel alloy production, spark plug and other ignition devices, as well as, electrical resistance heaters and batteries (Kabata- Pendias and Mukherjee, 2007; Kotov and Nikitina, 1996; WHO, 1991). Table 1 shows the occupational sources associated with nickel exposure. Nickel alloys and nickel plated objects have been widely used in the production of bathroom fittings, kitchen and tableware, consumer white goods and in food processing, as well as in the manufacture of

Table 1. Occupational sources associated with Nickel exposure.

Chemical and catalysts production
Cement manufacturing
Ceramics production
Disinfectants manufacture
Electroplating industry
Ink and dyes making
Jewelry industry
Magnets production
Mining industry
Nickel alloys
Paint making
Refining and petroleum industries
Smelting industry
Stainless steel
Varnish

Source: USPHS, 1977

cables and wires, fasteners, motor vehicles, jet turbines, ship building, surgical implants and textiles (Kasprzak, 1987; USPHS, 1993; DEPA, 2005a).

Nickel contents, inputs and distribution in soils

The most significant nickel ore are pentlandite; nickel – iron sulphide and garnierite as well as, nickel – magnesium silicate. Nickel is a relatively abundant and naturally occurring metal, widely distributed in the earth's crust. Its status in soils is highly dependent on the nickel concentration of the parent rocks, but in surface soils, its content is also a reflection of soil- forming processes and pollution (Kabata- Pendias and Pendias, 1992; McGrath, 1995). The lowest contents are found in sedimentary rocks that comprise of clays, limestones, sandstones and shales, while the highest concentrations exist in basic igneous rocks (Kabata- Pendias and Mukherjee, 2007).

Nickel content in soils varied widely and have been estimated to range from 3 to 1000 ppm; for the world soils, the brand range is between 0.2 and 450 ppm, while the grand mean is calculated to be 22 ppm (Kabata- Pendias and Pendias, 1992; Cempel and Nickel, 2005; Bencko, 1983; Scott-Fordsmand, 1997). Duke (1980a) also reported an average concentration of 86 ppm for the natural nickel content in the earth's crust. Values representing the contamination level of nickel in rural soils of the world for various countries have been reported by Chen et al., (1999); Australia (60 ppm), Canada (150 ppm), China (20 ppm), France (50 ppm), Germany (200 ppm), Japan (100 ppm) Netherland (210 ppm), South Africa (15 ppm), United kingdom (60 ppm), and United State of America (420 ppm). However, Shacklette and Boerngen (1984) in their soil survey of the

United States reported Nickel concentration range of less than 5 to 700 ppm, with a geometric mean of 13 ± 2.31 ppm.

Industrial waste materials, lime, fertilizer and sewage sludge constitute the major sources of nickel into soils (McIlveen and Negusanti, 1994). Moreover, nickel is apparently a heavy metal of environmental concern only in urban cities, but could become a problem resulting from decreased soil pH, due to reduced use of soil liming in agricultural soils and mobilization arising from increased acid rain in industrialized areas (Bencko, 1983; Cempel and Nickel, 2005). With decreasing pH, the solubility and mobility of nickel increases, hence, soil pH is the major factor controlling nickel solubility, mobility and sorption, while clay content, iron- manganese mineral and soil organic matter being of secondary importance (Anderson and Christensen, 1988; Ge et al., 2000; Suavé et al., 2000; Tye et al., 2004).

Generally, the distribution of nickel in soil profile is uniform, with typical accumulation at the surface soil due to deposition through anthropogenic activities (Cempel and Nickel, 2005). Nickel can also exist in several forms in soils that include; adsorbed or complex on organic cation surfaces or on inorganic cation exchange surfaces, inorganic crystalline minerals or precipitates, water soluble, free-ion or chelated metal complexes in soil solution (EHC, 1991; Bennett, 1982). In the presence of fulvic and humic acids, the complexes are much more mobile, and may be prominent than the hydrated divalent cation in soil solution (ATSDR, 2005).

Transmission through the food chain

Nickel is often mobile in plants, and accumulates readily

in plant leaves and seeds (Welch and Cary, 1975), thus, having a high potential to enter the food chain. Therefore, the uptake of nickel by plants is related to its toxicity, which may have possible implications with respect to humans and animals through the food chain.

Nickel in plants

Generally, nickel is not an important element for plant growth and development, but it is an essential micronutrient required for the growth of higher plants (Brown et al., 1987). The phytoavailability of nickel has been correlated with free nickel ion activity in soil solution; hence, plant uptake is also dependent on soil pH, organic matter content and iron- manganese oxide (Massoura et al., 2006; Rooney et al., 2007; Ge et al., 2000). Environment Agency (2009e) documented that nickel from anthropogenic sources is more readily taken up by plants than that from natural occurring sources, and that plant species also differ in their tolerance and ability to take up nickel from soils.

Nickel toxicity levels vary widely between 25 to 50 ppm (Mishra and Kar, 1974). However, Gregson and Hope (1994) reported that the phytotoxic concentrations of nickel occurred at leaf contents of 10 to 100 ppm depending on the plant species, while, Kabata- Pendias and Pendias (2001) reported phytotoxic range of 40 to 246 ppm DW plant tissue, depending on the plant species and cultivars. The most common plants that have been identified for their tolerance to and hyper accumulation of nickel include cabbage, cauliflower and turnip as well as, leguminosae such as bean and pea (Kabata- Pendias and Mukherjee, 2007). Moreover, Uren (1992) found that besides inhibiting plant growth, other symptoms of nickel toxicity include chlorosis, stunted root growth and brown interveinal necrosis.

Nickel in animals and humans

Nickel is an essential nutritional trace metal based on its deficiency in several animal species, but its functional importance has not yet been clearly documented. In humans, however, nickel's role as a trace element has not been recognized nor its deficiency (Scott-Fordsmand, 1997). Dermal absorption of nickel through human skin is quite very limited, and its uptake from soil is rather fewer. Moody et al. (2009) studied an in vitro dermal absorption of radioactive nickel chloride through human breast skin for a period of 24 h with and without a spiked reference soil; the obtained results revealed a mean dermal absorption of 1% with soil and 23% without soil presence. Further studies showed that most nickel applied as a soluble salt is bound within the skin and does not reach systematic circulation (Hostynek et al., 2001; Turkhall et al., 2008), hence, nickel allergy in the form of contact dermatitis is a very common and well- known reaction in

animals and humans, and is related to nickel induced hypersensitivity and skin disorders (Samitz and Katz, 1976; USEPA, 1986).

Food intake is the major route of nickel exposure for the general population, while inhalation from air, drinking water, oral and dermal routes could serve as secondary sources of nickel exposure. Nickel naturally occur in foodstuffs at a general range of 0.1 to 0.5ppm, but few number of foods usually obtain nickel during the manufacturing process or through food processing methods that may arise from leaching from stainless steel, the milling of flour or through the catalytic hydrogenation of fats and oils (Clarkson,1988; Solomons et al.,1982). Flyvholm et al., (1984) reported increase of nickel intake of up to 900 µg/ person/ day or more on large consumption of rich food sources of nickel that include dark chocolate and soya products, dried beans and peas, as well as oat meal.

The toxic effects of nickel result from its ability to replace other metal ions in enzymes, proteins or bind to cellular compounds (Cempel and Nikel, 2005), and among animals, micro-organisms and plants, nickel is reported by Nielsen (1980a) to interact with at least 13 essential elements namely calcium, chromium, cobalt, copper, iodine, iron, magnesium, manganese, molybdenum, phosphorus, potassium, sodium and zinc. Therefore, prolong exposure to oxides and sulphides of nickel is associated with possible risk to lung and nasal tumours, while systematic effects whose initial symptoms are mild nausea, headache, dyspnoea, and chest pain could be ascribed to nickel carbonyl; these symptoms may disappear or consequently results in severe pulmonary insufficiency. Also, arising from exposure to nickel containing mists and dusts are asthma, pneumoconiosis and irritation of nasal membranes (Kabata- Pendias and Pendias, 1992; El- Hinnawi and Hashmi, 1988; Klein and Snodgrass, 1977).

CONCLUSIONS

Although, nickel is ubiquitous in the environment, but its functional role as a trace element for animals and humans is not yet recognized. Therefore, it becomes trace metal of concern because of its major route of exposure which is either through the dietary intake or ingestion through the food chain which may arise principally from the nickel accumulation in crops, fruits and vegetables grown on contaminated soils and their consequence consumption by animals or man.

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