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Heavy metals – a silent threat to health

Metale ciężkie – zagrożenie, którego nie widać

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Summary

Progressing environmental pollution is a threat for modern human – especially when it comes to toxic influence of heavy metals on human body. Increasing the awareness about the problem of negative influence of those metals is an important aspect of preventive treatment. This thesis describes the negative influence of heavy metals on human body. Most often, these metals enter the body by ingestion but also by inhalation or through the skin. Accumulation of toxins in the body is limited by biological barriers. However, excessive amounts of such toxins are still a threat to human health. They can cause acute intoxication and chronic toxicity which might result in digestive and neural problems and even internal organs damage.

This thesis describes chosen heavy metals which are toxic for human body, characteristic symptoms of chosen metal intoxication types and prevention methods. The examples are: the influence of lead on central nervous system, on anomalies in fetal nervous system development and the influence of tobacco smoke toxins on fetal development during pregnancy.

Environmental pollution makes it impossible to produce goods and food from products completely free from heavy metals contamination. That is why we should focus on reducing the amount of heavy metals to the minimum when it comes to the world around us.

Keywords: heavy metals, toxicity, environmental pollution, risk to health.

Introduction

Of all currently known chemical elements ¾ are metals. These elements have been separated to two groups by their density. Metals which have density lower than 5g/cm^3 are light metals and metals which have density higher than 5g/cm3 are heavy metals. However, 'heavy metals' have broader meaning now than they used to in the past. Currently, all metals which can be a risk to human health are treated as heavy metals regardless of their density. This change results mainly from economic growth, especially energy industry, municipal services, chemistry industry, mining and metallurgy and also from creating new waste dumps and increased use of fertilizers [2]. Each of those factors contributes to environmental pollution.

Human activity is not the only source of heavy metals. Heavy metals are also the products of many natural processes such as: volcanic activity, wildfires, erosion of rocks and pedogenesis.

Heavy metals are very common in human's everyday life and work. The most common are: copper, chromium, cadmium, iron, mercury, manganese, nickel, lead and zinc. It should be mentioned that there are also heavy metals which are necessary for proper functioning of human body (microelements) such as: zinc, copper, iron and metals which are not necessary for biological processes – for example cadmium, mercury, lead, arsenic and aluminum.

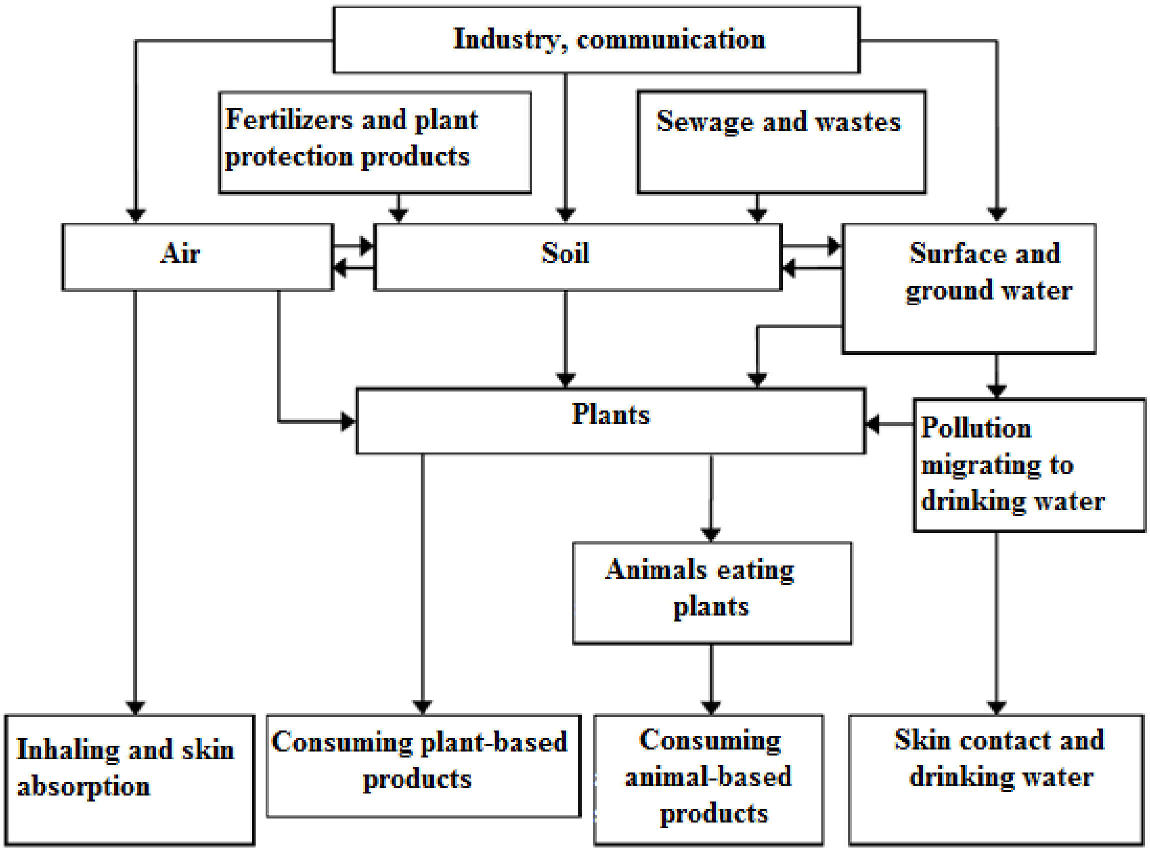
Metals required for proper functioning of human body should be correctly administered because both insufficient and excess amounts of those are detrimental to health. Metals which are completely unnecessary for human body such as cadmium, mercury and lead can cause a serious threat to human health. This risk results from toxic properties of those elements and also from the ability to accumulate in human body [3].

Heavy metals entry routes

When it comes to heavy metals, the source of danger is whole surrounding environment – polluted water, air and soil. Inhaling air and drinking water are the main sources of heavy metals. Heavy metals can also enter human body from the soil. This mainly results from heavy metals transferring through soil-plant-human or soil-plant-animal-human routes (chart 1). The transfer of heavy metals from soil to human and animal bodies occurs mainly through plants.

The most important sources of human-based soil pollution are mining and metallurgy of non-ferrous metals, metallurgy and chemical industry, waste dumps, excess use of phosphorus-based fertilizers, using waste lime for soil deacidification, using plant protection products, sewage sludge fertilization and also surface runoff from high-traffic roads [11].

Chart 1. Heavy metals entry routes



Source: A. Ociepa-Kubicka, E. Ociepa, 'Toksyczne oddziaływanie metali ciężkich na rośliny, zwierzęta i ludzi [in:] 'Inżynieria i ochrona środowiska', t. 15, 2012, p. 170

PTWI (Provisional tolerable weekly intake) value

The key factor for human's health and safety is estimating the amount of heavy metals which enter the human body. To solve this problem the Joint FAO/WHO Expert Committee on Food Additives created a PTWI value. This value describes weekly amount of heavy metals ingested through all the sources which do not cause any reaction from the body [8]. Very low PTWI values mean that chosen metal is highly toxic for human body [2].

For four most toxic metals the PTWI values are as following: mercury – 0.005 mg/kg BW, cadmium – 0.007 mg/kg BW, lead – 0.025 mg/kg BW, arsenic – 0.025 mg/kg BW [8]. This means that mercury is the most toxic metal for human body. Even the slight dose of mercury can be harmful for health.

This research paper describes the influence of these four heavy metals on human body and the main environmental sources of those metals.

The toxicity of heavy metals

Lead

Lead occurs naturally in the environment but it is only 0.0013% of Earth's crust. The average amount of this element in ground is about 15 mg/kg. The average amount of lead which naturally occurs in surface waters is 0.2 mg/kg. The amount of lead in surface and ground water does not exceed 10 pg/l in most cases.

Lead occurrence is also a result of human activity. The main sources of lead emission measured globally are:

- burning fuel for road transportation;
- lead, copper, zinc and iron metallurgy;
- coal burning;
- concrete production.

Most lead from these sources is accumulated in soil closest to the surface which is directly connected to surrounding environment. In most cases lead does not penetrate deeper than 20cm which is a result of its low activity in soil.

Big cities agglomerations and high-traffic roads are the most significantly polluted by lead which is connected mainly with road transportation.

The concentration of lead in air before Industrial Revolution is estimated to 0.01–0.1 pg/m^3. In twentieth century lead was commonly used to produce pipes, wires, paints, batteries and fuel. After 1975 when the amount of lead was measured in the place where almost no pollution is present – on South Pole – the result was 0.076 ng/m3.

Currently, the emission of lead is decreasing mainly because it is no longer used in fuel production [2, 15].

The toxicity of lead does not depend on the entry route but rather concerns main biochemical processes. It involves the ability of lead to block or imitate calcium and its interaction with proteins and the most researched effect is impairment of heme synthesis.

After entering the body lead bonds with erythrocytes and is transferred with blood to soft tissues in liver, kidneys, lungs, brain, spleen, muscles and heart. After few weeks most of lead is accumulated in bones and teeth when it can reside for many years.

Even small amount of lead can cause abnormalities in red blood cells biochemistry and delays in physical and psychic development among infants and small babies. Blood pressure and kidney problems may occur among adults. The negative effects of lead occur even when small amounts are ingested.

Lead causes oxidative stress which changes the metabolism of placenta which contributes to increased risk of miscarriage [6, 7].

Mercury

Mercury and its compounds are substances which are common in natural environment. The main natural sources of mercury are volcanic eruptions, underwater eruptions and mercury evaporation from land and water. The erosion of rocks containing mercury, geothermal processes and plants vegetation are also the natural sources of this element.

Natural mercury emission is higher than the emission caused by human activity. However, there are places where human-based mercury emission is the most important factor when it comes to environmental pollution. Coal burning is one of the main processes of polluting the environment with mercury with communal and individual heating being the main source. Industries which use outdated technologies, incorrectly secured wastelands and some waste treatment plants are also the important sources of mercury.

The industrial sources of mercury pollution are also: lime and concrete production, petroleum refining, coking coal, tar and asphalt production. The mercury is also used to produce protective coatings and dental amalgams. Mercury is also a catalyst to produce plastic.

It is estimated that global mercury emission from all sources ranges from about 4400 to 7500 tons annually [4].

Mercury is considered to be the most dangerous and toxic element for human body [2]. Metallic mercury and inorganic mercury compounds are absorbed through skin. It can also enter the body through respiratory tract as gaseous mercury. It crosses pulmonary alveolus membrane to blood and tissues and is then absorbed by central nervous system. The main organs where mercury can be accumulated are: kidneys, liver, spleen and also blood and brain [3]. Of its compounds the methylmercury is one of the most toxic. It can occur in high amounts in tissue of fish from waters which are highly polluted by industrial wastes [14].

The toxic mechanism of mercury compounds is as follows: mercury ions bond with proteins and block important enzymes. This mechanism affects all tissues and organs. Organic mercury compounds cause degenerative changes especially in central nervous system.

Few minutes after human ingests toxic inorganic mercury compounds a severe vomiting occurs. Other symptoms include: burning sensation in mouth and throat, salivating, stomachaches and bloody diarrheas. Severe symptoms are connected with kidney damage which can lead to anuria and heavy uaremia. Ulcer and necrosis might become present in mouth covered by grey residue and also black mercury granules might appear on gums [16].

Cadmium

Cadmium is a very toxic heavy metal. It enters the environment both from natural, industrial and agricultural sources [10].

In nature, this element exists as complex ions and organic chelates. Cadmium, as contamination, can be found in some minerals such as zinc sulfide, sphalerite and in very rarely occurring wurtzite.

Cadmium is also present in fossil fuels such as coal. Average amount of cadmium in earth's crust is around 0.1 mg/kg. It is more common in sedimentary rocks and phosphorites from sea water – around 15 mg/kg.

Secondary cadmium minerals are created as a result of erosion of rocks such as sphalerite. Erosion is a very important source of cadmium which is later taken by rivers to oceans – this is a main circulation route for cadmium in the environment estimated to 15 000 tons per year. Volcanic activity also plays an important role in cadmium emission.

Currently, surface waters which are not polluted contain around 5 ng/l of cadmium. Permitted level of cadmium presence in drinking water is 5 pg/l.

Increased amounts of cadmium in soil and water occur in places where lead, copper and zinc deposits are found.

Volcanic activity is considered to be the main natural source of cadmium emission to the atmosphere. The annual emission of cadmium from that source is estimated to 100–500 tons. The concentration of cadmium is natural above earth poles where it ranges from 0.003 ng/m to 0.6 ng/m, whereas above big agglomerations the concentration of cadmium might be even 1000 times higher [2,3].

Cadmium presence in the environment can also result from anthropogenic activities such as:

- metallurgy industry (the production of steel, iron and non-ferrous metals) – global emission of cadmium to atmosphere from that source is estimated to 7.5 tons annually;
- the production of phosphorous fertilizers and its extensive use in agriculture;
- municipial solid waste and burning fossil fuels.

Industrial emission of cadmium has been limited in the 70s of the last century. This tendency remains present even in the last decade of 20th century which has been confirmed by measuring the amount of cadmium in moss in Europe (2.5 times less cadmium is present in moss) [2].

Cadmium is most commonly used to produce alloys, covering other metals, dye and pigment production and as a stabilizer for plastics. It is also used in production of nickel-cadmium batteries [3].

The main source of exposure to cadmium for non-smoking people is food. The absorption of cadmium for human is not high and ranges from 3 to 5 per cent. However, cadmium stays in kidneys and liver for a very long time. Its biological half-life ranges from 10 to even 30 years [10]. Smoking cigarettes doubles the daily exposure to cadmium [2].

Cadmium is toxic mainly for liver and also might cause kidneys dysfunctions. It might also cause demineralization of bones directly or as a result of damaging bones by kidneys malfunctioning [10].

Cadmium is an unnecessary and very toxic element for human body. It enters the body from three sources: through gastrointestinal tract, through respiratory tract and through skin. The most vulnerable parts of the body are kidneys, bones and lungs [1,2].

Free cadmium ions are toxic and bond with atoms of biogenic elements (sulfur, oxygen and hydrogen) and this causes changes to protein structures. Cadmium is transported via blood to liver where is detoxified by bonding with metallothioneins. After that, cadmium reaches the main organs where it is accumulated – kidneys. Biological half-time of cadmium in kidneys is longer than 10 years [2].

Arsenic

Similarly to previous elements, arsenic can enter the environment from both natural sources and anthropogenic activity. The main sources are: volcanic activity, wildfire, low temperature evaporation from soil, evaporation from oceans and also erosion and eluviation. However, anthropogenic activity is a much important source of arsenic – burning fossil fuels, metallurgy processes, production of concrete and glass and also wide use in agriculture as plant protection products or as an addition to animal food.

Annual emission of arsenic from metallurgy industry reaches 12 800 tones globally, form burning coal – 6 240 tons which is 60% of emission from anthropogenic sources [9, 13].

Arsenic compounds are used in agriculture and forestry to produce herbicides. Chromated copper arsenate is used as a wood preservative as it creates a protection layer on wood. Compounds of arsenic are also used in the production of glass, dyes, as chemical weapon and to purify industrial gases. Arsenic is also used in alloy production as it increases hardness and improves heatproof properties [12].

Daily intake of arsenic for human ranges from 10 to 370 pg. Absorption of arsenic occurs mainly through gastrointestinal tract and depends on solubility and the amount of arsenic compounds taken. Inorganic compounds of trivalent arsenic have good water solubility (45 to 95 per cent) and are absorbed by gastrointestinal tract. Absorbing arsenic by respiratory tract depends on chemical properties, form and size of particles in air. Absorption of arsenic also depends on its oxidation state. Arsenic is biotransformed in human and animal bodies. Arsenic is excreted via stool, urine and is present in sweat and milk. It can also be found in hair and skin.

Arsenic is a cancerogenic substance. This element and its inorganic compounds can be the cause of respiratory tract cancers and skin tumors but arsenic can also cause cancer in other organs.

Inorganic arsenic compounds also disrupt metabolic processes in liver and kidney cells [13].

Presence of heavy metals in chosen food products.

The most important source of exposure to heavy metals is food, mainly plant-based food. This is a result of mineral metabolism of plants when it comes to metals. All plants absorb elements, minerals and chemical compounds necessary for their growth from the soil using a root system which later transports these elements to other parts of a plant – stems, flowers and leaves.

Because of industrial activity of a human, many toxic elements have entered the soil and plants might absorb them.

It is currently believed that there are 17 metals required for plants development in soil: Al, B, Br, Cl, Co, Cu, F, Fe, I, Mn, Mo, Ni, Rb, Si, Ti, V, Zn. Other elements – Pb, Cd, As, Hg, Tl – are considered to be not necessary for plants life. They are still absorbed by plants root system, they reach other parts of the plant and later they become a part of human food. This route causes heavy metals to enter human body.

One of the most serious problem when it comes to metals' toxicity is polluting the soil with heavy metals which become very stable after entering the soil. The amount of time required to remove heavy metals by natural processes is estimated to thousands of years. As a result, after soil is polluted with heavy metals it stays polluted for hundreds of years. As an example, even though lead is not a part of fuel production process for 15 years now, the levels of lead in soil are still very high. The situation is worsened by the fact that heavy metals do not undergo biodegradation and are not decomposed to non-toxic elements [2].

Table 1 and 2 present four most toxic elements in wheat-based food, in vegetable-based products and in sugar confectionery.

Table 1. Lead, cadmium, arsenic and mercury in wheat-based products and vegetable-based products (2004).

Wheat-based products		Lead [mg/kg]	Cadmium [mg/kg]	Arsenic [mg/kg]	Mercury [mg/kg]
Type	**Source**				
Pastry	National	0.043	0.018	0.018	0.003
	EU	0.063	0.019	0.007	0.001
Flour, groats, pastas	National	0.030	0.026	0.015	0.003
	EU	0.028	0.031	0.015	0.003
Vegetable-based products		**Lead [mg/kg]**	**Cadmium [mg/kg]**	**Arsenic [mg/kg]**	**Mercury [mg/kg]**
Type	**Source**				
Containing more than 50% of root or leafy vegetables	National	0.038	0.016	0.018	0.003
	EU	0.043	0.008	0.009	0.002
Other	National	0.037	0.009	0.023	0.002
	EU	0.051	0.009	0.031	0.005

Source: M. Wojciechowska-Mazurek et al.: Monitoring zanieczyszczenia…, Rocznik PZH, Nr 3, 2008, p. 251-266.

Table 2. Lead, cadmium, arsenic and mercury in sugar confectionary (2004).

Sugar confectionary		Lead [mg/kg]	Cadmium [mg/kg]	Arsenic [mg/kg]	Mercury [mg/kg]
Type	**Source**				
Chocolate and chocolate goods	National	0.060	0.013	0.017	0.002
	EU	0.035	0.018	0.025	0.003
Other	National	0.031	0.008	0.019	0.002
	EU	0.034	0.013	0.013	0.002

Source: M. Wojciechowska-Mazurek i in.: Monitoring zanieczyszczenia…, Rocznik PZH, Nr 3, 2008, p. 251-266.

From the tables above it can be assumed that no product is free of heavy metals. Heavy metals appear in small amounts in every presented group of products. However, they are not a threat to human health because of how small the amount is. There is also no significant difference between national products and products coming from other EU members [5].

Conclusions

Heavy metals are elements which can be necessary or unnecessary for human body. Both of these groups have one common characteristic – after exceeding acceptable daily intake they might become toxic. Mercury, cadmium, lead and arsenic are four most toxic elements and they are also absolutely unnecessary for human body. Ingesting even the small amount of any of those elements might result in various types of diseases. The higher the dose and exposition time the higher toxicity of that element.

The most important source of heavy metals is human activity and economic development which takes place in developing countries. Chemical, energetics and communication industries are the most detrimental when it comes to the emission of toxic substances. Creating new waste lands and excessive use of fertilizers is also a part of the problem.

The key factor is the realization that heavy metals have become a permanent part of environment of modern human and therefore have become a new, invisible threat to human health. Expanding knowledge about sources of heavy metals and their negative effects can limit the amount of unwanted substances entering our bodies which will result in decreasing the risk of contracting various illnesses.

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