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Review

Chemical Element Circulation in the Trophic Chains of Different Urban Environments

P. Kamiński

University of Warsaw, Branch Białystok, Institute of Biology, Świerkowa 20 B, 15-950 Białystok, Poland.

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Abstract

Studies on element concentration in soils, plants, invertebrates and food, and body parts of synanthropic bird nestlings in polluted and unpolluted urban environments have been reviewed. Different ways of intake of elements by nestlings living in urban environments are presented. This required the determination of differences in element concentration in soils, plants, invertebrates and nestlings' food. It was considered that knowledge of these differences would allow establishment of the relationship between the element concentration in birds' bodies and the environment.

Homeostatic mechanisms ensured Fe, Mg, Zn, Mn and Co accumulation in definite amounts in nestling tissues. Copper is mainly stored in soft tissues. These mechanisms made it possible for nestlings to accumulate Cd and Pb in soft tissues in small amounts compared with concentration of these elements in the environment. The majority of Cd and Pb taken in by nestlings was accumulated in bones and feathers. Higher concentrations of toxic heavy metals decreases the accumulation of physiological elements in the bodies of nestlings.

Keywords: trophic chain, urban birds, chemical elements, soils, plants, invertebrates, environmental pollution, homeostatic mechanisms.

Introduction

The trophic chain is of great importance for understanding the processes of chemical element circulation in the environment and their role in the particular trophic levels. Metals whose concentration is higher than 6 g cm^{-3} are called heavy metals. Some of them are essential for vital functions (Fe,Zn,Cu, Mn,Co,Mo), and some of them play an unexplained role (Cd,Pb,Hg). But all of them are in higher concentrations dangerous for animals and plants [77]. Most elements are released to the environment in the form of compounds as a result of human activity and biogeochemical processes. When these compounds reach a soil, they start to accumulate there and are available for plants. The degree of intensity of processes of chemical element circulation in the environment depends on their bioavailability, i.e. their chemical form and their ability to pass from one trophic level to another. This bioavailability is expressed as a relationship between the concentration of an element in two different trophic levels (the concentration ratio); Little & Martin [70], Kabata-Pendias & Pendias [57], Wolf et al. [109]. The higher is this ratio for particular element the higher is its accessibility on the given trophic level [21,70]. Correlations between the concentration of elements in soil and plants are dependent on the processes which occur during their passing from one trophic level to another, e.g. transfer of an element from the soil to a plant is conditioned by physiological processes such as transpiration ability and growth intensity [32,41,57].

Soils are characterized by high activity of microorganisms, fungi and animals of different taxonomic groups. They are dependent on organic matter constantly supplied by plants. Basic food demands of soil fauna are covered by plant roots and other plant dead parts present in the soil. However, these resources can exist only due to constant photosynthetic activity which

is dependent on water and mineral resources absorbed by the plant roots. Therefore, biological activity and elements circulating in the soil, plants, fauna living in soil and plants zone are interdependent [109].

The danger of toxic metals and other pollutant accumulation and their constant influence on ecosystem elements is significant in the soil. As a result of different elements' accumulation, the soil as an important compartment of the environment determines the type of plant and animal existence in a given area, which is of great importance for humans [109]. This is why it is important to find natural indicators of environmental pollution which are simultaneously links of the trophic chain. Both plants and animals are able to absorb elements depending on their chemical form in the soil. The intensity of the intake of metals by plants is additionally dependent on transpiration ability, soil properties, organic and mineral compounds [53,54] and for higher links of the trophic chains (birds, mammals) it is dependent on the intensity of ciliary cuticle mechanisms, efficiency of trachea-bronchus system and intestine absorption [76,77]. Furthermore, the transportation of metals from soil to plants and animals is dependent on interactions between elements in the environment [57,76]. Absorption and distribution of metals depends mainly on solubility of lipids of particular metal compounds. A consequence of the ability to penetrate lipid membranes by organic compounds is that they penetrate and accumulate in an organism more frequently and easily than inorganic compounds [35].

The inflow of the elements is higher than their outflow in most trophic chains which start in the soil. Thus their accumulation takes place. The further circulation of elements is dependent on different factors; water circulation, water and chemical soil properties, pH [6,72,86,102]. Most reviews referring to element circulation in the trophic chain deal with relationship between the soil and plants [1,4,6,21,23,33,57,3,67,86]. Some reviews refer to elements circulating in the trophic chain: soil-plants-soil fauna-epigeic fauna [13,14,70,71,72,110,111]. Some reviews concern the influence of heavy metals on soils of different contamination [17,84,105], and reaction of plants to heavy metals [21,39,88,89,90].

There are not many reviews referring to the concentration of elements and their circulation in the trophic chain starting from the soil and ending with vertebrates (small passerine birds and small mammals). It is worth mentioning the works by Dmowski & Karolewski [24]. They investigated the concentration of Zn, Cd and Pb in the soil, plants, invertebrates, amphibia and birds from areas of different contamination. Weyers et al. [107] investigated the concentration of Pb,Cd and Zn in the soil, in food of adult and 12-day-old Blackbirds (*Turdus merula*) living in the polluted and controlled environment and in their livers, kidneys and feathers. Cloutier et al. [16] analyzed the concentration of Cu, Ni, Fe, Co, Zn, Pb and Ra-226 in different organs of Pennsylvanian Field Vole (*Microtus pennsylvanicus*) living in polluted (metallurgical factory vicinity) and unpolluted areas. Andrews et al. [7,8] investigated zinc and lead concentration in the soil, plants, invertebrates and small mammals (Field Vole, *Microtus agrestis* and Common Shrew, *Sorex araneus*) in ecosystems of different contamination.

Investigations of urban polluted areas show that the concentration of heavy metals in soils, plants, invertebrates, food and organs of tree sparrow nestlings (*Passer montanus*) are higher than in unpolluted areas. It was found that homeostasis mechanisms decide Fe, Mg, Zn, Mn and Co accumulation in nestlings' tissues in specific amounts. Cu is accumulated mainly in soft tissues. Cd and Pb is accumulated by nestlings in soft tissues in small amounts compared with their concentration in the environment; higher amounts accumulate in bones and feathers [59].

Chemical Element Circulation in the Trophic Chains

Calcium and Magnesium

Magnesium and calcium are those macroelements which are important for physiological functions [2,29,57] and their influence on plants and animals is connected mainly with interactions with other elements, which determine intake of different metals from the soil [18,25,76]. Magnesium and calcium compounds are practically atoxic and their surplus is expelled. But when there is a high amount of Mg and deficiency of Ca in the environment, hypermagnesemia may occur, for which calcium compounds are active antagonists. Intestine absorption of magnesium is 12-40% and regulation of magnesium in the body depends on kidney activity. Magnesium and calcium are also activators of many enzymatic systems [2,57]. Intake of these elements by invertebrates living on the soil surface is strictly dependent on their body mass and age. It is also dependent on the heavy metals (Cd,Pb,Zn) concentration in the soil, which inhibit Mg and Ca intake and may disturb metabolism of these elements [12,18,37,76]. The last mentioned authors found that invertebrates living on the soil surface (mainly *Oligochaeta* and *Arthropoda*) intake Mg and Ca in specific, constant doses regardless of the concentration of these elements in the environment (even when there is a deficiency or surplus of these elements). Studies conducted by Kamiński [59] confirm these results. Beardsley et al. [11] obtained similar results for *Microtus agrestis* in unpolluted, polluted and laboratory environments.

Iron

Iron in soil occurs mainly in oxides and hydroxides or is bound within the mineral surface. Solubility of iron compounds in the soil increases with the degree of soil acidity. Mineral and organic iron compounds are easily transformed in the soil. Organic matter influences the process of iron oxide creation [40,57]. Microorganisms play a significant role in iron compounds transforming. They may cause Fe accumulation on cell surfaces [9,40]. Concentration of iron compounds in the soil influences the accessibility of some macroelements and many trace elements for plants and animals. Also heavy metals in certain concentrations decide on bioavailability of iron [40,57]. Iron minerals, especially its amorphous hydroxides, show significant sorption capacity compared with other heavy metals and influence their accessibility and arrangement in the soil [30]. Fe concentration in soil surface layers in urban polluted areas investigated by Kamiński [59] (1700 ppm dw on average) was over two times higher than in unpolluted areas and in the underlying layer even three times higher.

Concentration of iron in soils investigated by Kabata-Pendias [55] was 500 ppm on average. Data for polluted areas, which were some distance from a contamination source, were much higher: 15,000 ppm on average [39].

Uptake and transportation of iron in plant organs are exactly connected with soil pH, Ca and P concentration, other metals (Mg,Zn,Cu,Co,Cd) content and a stage of plant growth. Plants may absorb high amounts of iron (up to 3600 ppm dw) when iron is easily soluble [52]. Uptake of Fe by plants is metabolically controlled. This element may be absorbed as Fe^{3+} (rarely), Fe^{2+} or in a form of chelate compounds. Root ability to reduce Fe^{3+} to Fe^{2+} is of greatest importance for this metal absorption by most plants [15]. When there is a deficiency of iron in the soil plant roots show higher ability to absorb iron from mineral and chelate compounds [57]. Fe concentration in terrestrial plants is different and it varies widely. It depends on physical-chemical soil content, other elements, stage of plant growth and plant species. It may range from 130 to 1200 ppm dw and for marine plants even up to 3500 ppm [56]. Physiological concentration of iron in grasses ranges from 40 to 300 ppm dw [88]. Concentration of Fe may reach several thousand ppm dw in polluted areas [34]. Sawicka-Kapusta [88] found that the level of iron concentration in washed Rye-grass (*Lolium multiflorum*) sprouts in steel mill protective zone was 124-7739 ppm dw and in the region of aluminium metallurgical center (South Poland) it was 80-1760 ppm dw for grasses and 38-795 for root crop plants (beetroots, potatoes); Sawicka-Kapusta et al. [90]. Henriques & Fernandes [39] found similar values for Common Rush (*Juncus conglomeratus*) in polluted areas (228-1050 ppm dw) and in unpolluted areas only 154-220 ppm dw. Fe concentration in plants investigated by Kamiński [59] was 600 ppm dw on average in unpolluted urban areas and 1800 ppm dw in polluted ones. These values seem to be high compared with above-mentioned data.

Intake of iron by animals depends mainly on its form and the proportion of other metals in the environment. Iron absorption ratio is generally equal to 5-20% of its total amount in food [40,57]. Concentration of iron in animal tissues is very different. This range given by Kabata-Pendias & Pendias [56] is 20-11,000 ppm dw. Many authors say that relations between Fe and other metal concentration in animals and in soil and plants are not explained [44,45,48,76]. In the case of some metals (Cd,Pb) their concentration in invertebrates are strictly dependent on their level in soil and for other metals (e.g. Zn,Cu) these correlations were not found [38]. Studies by Ireland [43,45] showed that Red earthworm (*Dendrobaena rubida*) regulates the level of Fe,Zn and Cu in its tissues depending on the lead and calcium concentration in soil. Intake of iron and many other metals depends on invertebrate body mass [37,78,104]. Iron concentration was comparatively high in invertebrates investigated by Kamiński [59] 3250 ppm dw on average in urban polluted areas and it was about twice higher in unpolluted areas. However some authors give higher Fe concentration in invertebrates from polluted areas. E.g., Martin & Coughtrey [76] and Helmke et al. [38] give average values of Fe concentration in invertebrates (mainly living on soil surface) from polluted areas equal to 480-2500-4200 ppm dw and from unpolluted areas -620 ppm, whereas Fe concentration ranged from 200 to 7000 ppm dw in small mammals (*Microtus pennsylvanicus*) from polluted areas, which were the last link of the food chain investigated by Cloutier et al. [16], and it was 200-1400 ppm in the controlled area. It corresponds with Fe concentration in organs of nestlings investigated by Kamiński [59] in urban areas. Analogical data for birds are not available. Data concerning the Fe concentration in nestlings's food samples have also not been found. The changes of Fe concentration in the food chain investigated by Kamiński [59] lead to conclusion that iron is accumulated in nestlings' tissues in specific amounts.

Zinc

Zinc occurs in a form of minerals in nature. It is released to the environment as dust by zinc works. Zinc is also emitted during coal, oil and its products burning. Burning solid municipal refuse may incorporate 75% of zinc into atmosphere. Also municipal sewage contains a considerable amount of zinc. Application of municipal and industrial waste in agriculture causes zinc accumulation in soil surface layer. Pesticides and

phosphatic fertilizers are also the source of Zn in soil [57,82,106]. Zinc in soil occurs mainly in a form inaccessible to plants, because as a cation of high sorptive energy it is strongly bonded by soil colloids. Thanks to high soils sorptive abilities towards zinc it is mainly accumulated in higher soil layers [68,112]. The range of Zn concentration in soils is very wide and it depends on soil type, humus content, colloids, pH, type of land use practice. Zn concentration in soil surface layer in cultivation areas ranges from 180 to 4500 ppm dw - 1800 ppm on average [84,100]. Average zinc concentration is 110-369 ppm dw when municipal sewage and compost are used as fertilizers [5,17,65]. Zn concentration is much higher in polluted than in unpolluted areas, e.g., Zn concentration in the surface layer of unpolluted soils is equal to 40-992 ppm dw - 10-300 ppm on average [57,80]. This range equals 5 to 362 ppm dw in the surface layer of cultivated soils [55,58] and it is much higher in polluted areas: 1665-5567 ppm dw [28]. It reaches even 34-60 thousand ppm dw - 6090-13,865 ppm on average - in a zinc works vicinity [3,56,99]. The range of zinc concentration given by other authors varies between several hundred and several thousand ppm dw, with a maximum of 37,000 ppm [57,80,81,99,105]. Zinc concentrations in polluted areas investigated by Kamiński [59] were twice higher than in unpolluted ones, but they were not high compared with analogical data given by other authors [28,55,58].

Zinc content in plants is specific for species and depends on the stage of plant growth, zinc accessibility and its concentration in the environment. The highest concentration of Zn occurs mainly in young plants. Plants growing in soils rich in Zn accumulate it mainly in stalks and roots. However, plants are strongly resistant to increases of Zn concentration because it undergoes bounding into biologically inactive forms [36,56,80]. The ratio of plants tolerance to zinc in polluted areas of high Zn concentration in soils is almost ten times higher than in areas of standard (or lower) zinc content [51]. The standard concentration of zinc in plants varies between 15 and 100 ppm dw and values higher than 400 ppm are considered toxic [80]. Concentrations lower than 10-20 ppm dw are considered as harmful for plants [22,57]. But the values considered as deficiency or surplus may differ considerably. They are conditioned by plants' demand, and depend on interactions between Zn and other metals in plants[57].

The range of variation of zinc concentration in plants from polluted and unpolluted areas is considerable, e.g. zinc concentration in above-ground parts of plants from unpolluted areas varies between 47 and 6874 ppm dw (330 ppm on average) and in polluted areas is several times higher (267-12,837 ppm dw; 1900 on average) [69]. Zn concentration in plants is influenced by environmental contamination by zinc. Plants accumulate zinc mainly in roots in the areas where the soil is a source of contamination, and in the areas where contamination comes from the atmosphere zinc is stored mainly on plant tops [76,80]. Zn concentration in plants in industrial areas is equal to 80-460 ppm dw on average [28] and in a zinc works vicinity - 87-937 ppm [101]. Zn concentration in plants from a steel mill protective zone varies between 37 and 841 ppm dw [89] and in grasses from aluminium metallurgical centre (South Poland) between 57 and 783 [90]. These values vary between tens and several thousand ppm in industrial and rural areas investigated by other authors [39,57,84,105]. Zn concentration in plants investigated by Kamiński [59] are within the range given by other authors [28,57,69], though the values for plants from unpolluted areas (140 ppm dw on average) seem to be high compared with the data from references [28,89,101].

Zn intake by animals is regulated metabolically [56] and its content increases when concentration in the environment increases [35,76]. Zn concentration in the soil *Oligochaeta* in polluted areas range from 68-914 to 200-1950 ppm dw and is the highest new roads - 800-1950 ppm on average [20,76]. Zn concentration in invertebrates living on the soil surface is equal to 55-160 ppm dw on average in unpolluted areas and 90-800 ppm in polluted ones; e.g., it equals about 1930 ppm in the steel mill vicinity [82]. Roberts & Johnson [86] found similar values for *Formicidae, Coccinellidae, Carabidae, Nabidae, Cantharidae* and *Araneae*. Zn concentrations in the trophic chain investigated by Dmowski & Karolewski [24] were higher in invertebrates from polluted areas and were higher in phytophages (728.4 ppm dw) than in plants (604.4 ppm), and higher in I-order zoophages (1537.8 ppm) than in II-order zoophages (533.5 ppm) and omnivorous invertebrates (526.1 ppm). Zn concentration in the trophic chain investigated by Andrews et al. [8] were higher in the polluted area than in the controlled one (Tab.1). The skeleton served for storing Zn surplus and most likely took part in soft tissues homeostasis in small mammals investigated in this trophic chain [8]. Zn concentration in organs of tree sparrow nestlings investigated by Kamiński [59] at the beginning (1-4 days) and at the end (11-16 days) of their development was similar to the concentration in small mammals investigated by Andrews et al. [8]. Works referring to the concentration of Zn in organs of altricial nestlings, which are the last links in the food chain, are not known. From the analysis of Zn concentration in the food chain investigated by Kamiński [59] it is evident that tree sparrow nestlings accumulate zinc in their tissues in approximately constant amount, and store it mainly in soft tissues.

Copper

Copper in the soil has the ability to interact with mineral and organic components and is a motionless

cation showing small diversity of concentration. Cu is intensively accumulated in the soil [57,92], accumulated mainly in the upper layer. Cu content in the soil depends on pH, different adsorbents and forms, and quantity of organic matter. Fulvic and huminus acids and organic matter play the most important role in Cu bounding. Bioavailibility of soluble copper compounds depends on molecular mass of Cu complexes and their amount in the soil, that is controlled by Cu reaction with active groups on the surface of solid phase. High ability of soil surface layer to accumulate Cu is found in polluted soils [35,57,92]. The extremely high Cu concentration in soils in a vicinity of industrial source of contamination is 3500 ppm dw and in agricultural soils - 1500 ppm. In other polluted areas Cu concentration threshold of 100 ppm dw is often exceeded [17,39,42,57,84]. The constant increase of Cu concentration in soil surface layer in industrial and agricultural areas, urban areas and in the roads vicinity was stated. Cu concentration in soil surface layers in unpolluted areas are lower and vary between 6 and 25 ppm dw on average [55,58] or between 9 and 80 ppm [39,57,92]. Cu concentration in soils investigated by Kamiński [59] was twice lower in polluted areas than above-mentioned data and in unpolluted areas within the similar range.

Particular types of soils influence copper uptake by plant roots differently. Transport of Cu in plants depends on nitrogen, adsorbing copper compounds, as well as on bacteria (*Thiobacillus*) and fungi (*Mycorrhiza*) presence in the soil and pH [92]. Active Cu absorption proceeds in plants, but under conditions of higher Cu concentrations in soils - also passive absorption. Plant roots have a high ability to keep copper, both when there is a deficiency and surplus of this element in soil. The highest Cu concentration in above-ground plant parts occurs at intensive growth stages [57,92]. However, plants have high tolerance to toxic Cu concentration. Cu level in plants raised mainly to about 20 ppm dw, whereas values lower than 5 ppm are harmful [57,92]. In the polluted environment (industrial areas, arterial roads) Cu concentrations in plants are considerably higher and vary between 73 and 274 ppm dw [39,57,84]. However, in plants from metallurgic centre (South Poland) investigated by Sawicka-Kapusta et al. [90] Cu concentration was considerably low (lower than 10 ppm dw). In other regions (steel regions and intensive agricultural areas) these values vary between 75 and 560 ppm dw [39,57,105]. Compared with these data Cu concentration in plants from unpolluted urban areas investigated by Kamiński [59] are within the similar range and values lower than 5 ppm dw were not found. Cu concentration in plants from polluted urban areas [59] were lower than values presented in the references [39,57,84].

Copper intake by animals is most intensive when it occurs in plants in forms of simple neutral or anion compounds [19,56,71]. Contamination of the environment with copper may induce the elimination of some invertebrates (predators) which may cause an increase in the number of other species [76]. Cu concentration in invertebrates living on the soil surface or in low plants zone in the unpolluted environment is diversified from 20 ppm dw [92] to 92-173 ppm [76]. Cu concentration in invertebrates from the plant zone is higher and more diversified in the polluted environment. In the urban area it varies between 187 ppm dw (Sheffield,UK) and 289 ppm (city gardens in Bristol),

Table 1. Concentration of Zn (mg g^{-1} dry weight) in the food chain of Field Vole (*Microtus agrestis*) and Common Shrew (*Sorex araneus*) in polluted (P) and unpolluted (UP) environments investigated by Andrews *et al.* [7]. Average values given in brackets.

Soil					*Microtus agrestis*	*Sorex araneus*
(depht 1-8 cm)	P	1915-2160	**Food:**	P	165-201 (166)	546-587 (583)
	UP	52.2-62.3		UP	18.9-31.9 (24.4)	175-296 (273)
Plans: (*Compositae*)	P	1915-2160	**Liver:**	P	120	180
	UP	52.2-62.3		UP	113	169
Invertebrates: (*Carabidae*)	P	340	**Heart:**	P	108	126
	UP	120		UP	78.9	146
(*Araneae & Opiliones*)	P	657	**Bones:**	P	219-223	438-547
	UP	529		UP	196-249	347-420
(*Diptera*)	P	852	**Whole Body:**	P	121-211 (153)	145-208 (127)
	UP	198		UP	82.9-127 (103)	105-173 (129)
(Detrytophages)	P	1141				
	UP	449				

and within a radius of 2-3 km from steel works - 430-540 ppm dw [76]. Cu concentration in invertebrates investigated by Kamiński [59] in unpolluted areas is within the range presented in the above-mentioned references and in polluted areas is lower. It can be assumed that nestlings accumulate copper mainly in soft tissues.

Manganese

Manganese occurs in the soil in numerous minerals in the form of oxides, carbonates and silicates, mainly at deeper levels. The degree of its interaction in particular trophic levels, and its chemical properties in soils depend on soil quality (type), pH, presence of Fe and other metals compounds, mineral and organic matters [57,93]. Organic matter with which manganese forms low-stable bounding, exerts the particular influence on Mn dynamics in soils [83,87]. Manganese is irregularly distributed in the soil. Heavy metals (Zn,Co,Ni,Ba) bounding occurs in places of its accumulation. Iron oxides and silty minerals show the ability of bounding Mn on their surfaces [57,85,93]. The amount of Mn in acid soils is sufficient for plant development, whereas Mn assimilation and solubility are very low in low acid and neutral soils, and they again increase in alkaline soils [93]. Concentration of soluble Mn decreases by over 50% in the period May-December. This element is rinsed out in great amount regardless low solubility of most of manganese compounds [57,93]. Mn concentration in unpolluted soils varies between 100 and 1300 ppm dw and maximum concentration may reach 9000 ppm [57,93]. Mn concentration is within a similar range in soils investigated by Kamiński [59], only the bottom limit is higher (500 ppm dw). Analogical data for polluted soils have not been found. From studies by Kamiński [59] it is evident that Mn concentration in polluted soils was 2-3 times higher than in unpolluted ones and was 1850-2200 ppm dw on average showing high variability.

Manganese is an active element in plants, and is mainly accumulated in young leaves. Mn concentrations are changing in wide range in different parts of plants. Mn accumulation does not depend only on the species but also on its availability which depends on soil properties. Mn concentration in plants shows negative correlation with increase of soil pH and positive with organic matter [57,76,93]. Concentration of Mn shows high variability among plants growing on the same soil with between 20 and 700 ppm dw on average [93]. Values over 1000 ppm were frequently recorded [57,105]. Concentrations lower than 10-20 ppm dw are considered noxious [35,93]. Mn concentrations in plants from polluted urban areas investigated by Kamiński [59] were twice higher (400 ppm dw on average) compared with the unpolluted environment, and did not show high variability as in soils. Mn concentration in plants from urban areas investigated by Kamiński [59] were within the range given in the above-mentioned references but the range of variability was narrower.

Pollution of animals with manganese may occur as a result of plant contamination by anthropogenous factors. Physiological concentration of Mn in invertebrates varies between 0.2 and 5 ppm dw and in the liver - 10 ppm on average [93]. Yet animals are characterized by high tolerance to Mn and only the level of 2000 ppm dw in food may act toxically [35]. Average Mn concentration in invertebrates investigated by Kamiński [59] is considerably higher than physiological standards given by Schiele [93] but is within the range of tolerance [35].

The analysis of Mn concentration in the trophic chain investigated by Kamiński [59] suggests that plants and invertebrates as well as tree sparrow nestlings accumulate this element in specified amounts.

Cobalt

Co distribution in soil is connected with the presence of manganese oxidized phase. In most cases cobalt occurs together with manganese, iron and nickel. It easily undergoes oxidation and migration in water solutions. Yet it is intensively bounded, mainly by iron and manganese oxides and hydroxides, and this is the reason that it is not far transported. Cobalt is absorbed in soils by organic matter, and forms complex compounds. Manganese shows particular sorption properties towards cobalt. The degree of bounding Co by manganese compounds is so high that under unproper proportion of these two metals their solubility may decrease and this may make it impossible for plants to accumulate them. This bounding depends mainly on soil pH and increases rapidly with pH increase [57,94]. Co concentration in surface soils normally varies between 1 and 50 ppm dw - 3-15 ppm on average [57], and values lower than 5 ppm are considered to be deficient [94]. Soil contamination with Co may occur in a vicinity of non-ferrous metals mills and along arterial roads. It can than reach 100-500 ppm dw [42,57]. Co concentration in soils investigated by Kamiński [59] was within the range considered to be standard [57].

Only 6% of total Co concentration in the soil is available for plants. The uptake of cobalt by plants depends on species, the presence of Co in soluble form, and soil pH. Cobalt is accumulated and transported mainly in green parts. The increase of Co concentration in soil results in increase of its concentration in plants [94]. Co deficiencies in plants hardly occur. In most cases its concentration in plants varies between 1 and 3 ppm dw. Plants are resistant to high Co concentrations and many of them can accumulate up to 100 ppm without toxic symptoms [16,57]. Co concentration in plants investigated by Kamiński [59] (1-5 ppm dw on average)

was within the range given in the above-mentioned references.

Cobalt toxic acting on animals was not recorded under standard conditions (unpolluted environment). Cobalt is quickly removed by organisms to the environment. Only when Co concentration in food exceeds 10 ppm dw it may be accumulated in tissues, mainly in liver and kidneys [35]. Animals are characterized by high tolerance to higher Co concentrations and the cases of intoxication do not occur because this element has low toxicity. Co concentration in invertebrates living on soil surface and in plants in urban environment (Sheffield, UK) was 21 ppm dw, and in industrial areas varied between 25 and 237 ppm [76]. Co concentration in invertebrates investigated by Kamiński [59] was 15-30 ppm dw on average, so it was like the analogical data for urban areas [76]. However, Co concentration in food samples of tree sparrow nestlings investigated by Kamiński [59] exceeded 10 ppm dw, and it was most likely that its accumulation by these nestlings in their livers and kidneys will take place [35]. From analysis of Co concentration in the trophic chain investigated by Kamiński [59] it is evident that tree sparrow nestlings accumulate this element in particular amounts.

Cadmium

The trophic chain of active cadmium starts in soil. Soils show different concentrations of cadmium. Concentrations may intensively increase because of the use of phosphatic fertilizer, chemical agricultural agents, composts and in a vicinity of industrial centres [35,36]. Cadmium in the soil is readily soluble and its activity is strongly connected with pH (solubility is high at pH 4.5-5.5). Cadmium is accumulated mainly in the soil surface layer in polluted areas. This process appears mainly in areas of high Pb, Zn and Cu concentration [97]. Cadmium bioavailability and its uptake by plants depends on soil pH, cations exchange capacity, amount of organic matter, humidity, temperature, Ca, Mn, Zn and F concentrations [50]. Most soils from unpolluted areas contain very low amounts of Cd (0.01-4 ppm dw, 1-1.5 ppm on average) [24,69,95,97]. Cd concentration in soil in regions contaminated with this element may be considerably high. It varies between 6 and 40 ppm dw in soil surface layer in the vicinity of metal plants in Poland [28] and is much higher in other countries in similar areas - 100-460 ppm dw [3,57,99]. Cd concentration in soils within the radius of 200 m from arterial roads increases considerably [95,97]. Cd concentration in soils in unpolluted urban environments investigated by Kamiński [59] varies in the range given by other authors for areas of similar pollution degree [24,69,95,97]. However, Cd concentration in soil surface layer in polluted areas is considerably lower [59] compared with data in the references [3,57,99] or is within range bottom limits for these areas [28]. Cd concentration in soils from urban polluted areas investigated by Kamiński [59] was 3-4 times higher compared with unpolluted ones. This could be connected with the vicinity of busy highway and the use of artificial manure and crop protection products in the vicinity, which are significant sources of toxic metals [96,108]. Most plants are characterized by tolerance to high Cd concentration and do not show toxic symptoms even at high Cd content. Ease of Cd uptake by plants is of great importance because of its incorporation into the food chain [50,97]. Plants can accumulate without harm from 0.1 to 1.5 ppm dw of Cd from the soil and 0.5 dw from the atmosphere [97]. Cadmium is absorbed especially by capillary roots zone [64]. But it migrates very slowly to above-ground parts where its concentration is ten times lower. It means that plant roots form a barrier for cadmium [49]. Cd concentration in plants in an unpolluted environment ranges from 0.02 to 2 ppm dw (1 ppm on average) [57,97]. Its concentration in plants in Cd contaminated areas (coal mines, metallurgic industry, city gardens, agricultural areas, municipal sewage) can be several times higher; from several to 45-70 ppm dw [57,84,90,105]. Cd concentration in plants in urban polluted areas investigated by Kamiński [59] was five times higher than in unpolluted ones and was over 2 ppm dw on average. This value is little higher compared with analogical data from references [57,97]. Values for plants from urban polluted areas investigated by Kamiński [97] are within the range given by other authors for similar areas [57,84,90,105].

Cadmium is accumulated in invertebrates proportionally to its concentration in the environment, and in higher animals is accumulated selectively in different organs [95]. Soil invertebrates contain on average 11 times more cadmium than its concentration in the surrounding soil. These proportions are higher closer to highways and they increase together with increase of organic matter in soil and its humidity [95]. The ability to accumulate such high amounts of Cd compared with its concentration in soil makes these animals considerably increase its accumulation in higher trophic chains. Cd concentrations in invertebrates investigated by Kamiński [59] were much higher than in the soil (4.5-5 times higher on average).

Cd concentration in soil invertebrates in the unpolluted environment varies between 3.1 and 9.3 ppm dw [103]. Cd concentration in these animals in polluted areas (near steel mills, busy highways, industrial effluent water) varies between 0.2-35 and 9.3-144 ppm dw [10, 20,31,38,74,75,111]. Cd concentration in invertebrates analyzed by Kamiński [59] are within the range given in the above-mentioned references. These concentrations in invertebrates investigated by Martin & Coughtrey [76] in soil surface and in low level plant zone are higher and vary between 1.2 and 19.2 ppm dw in unpolluted areas

and between 11.5 and 232 ppm in polluted areas.

The main reason of cadmium selective accumulation by vertebrates is the presence of a specific protein which bounds metals: metalothionein, which bounds Cd and other metals (Zn,Cu,Hg). The presence of metalothionein in the liver and kidneys, and the presence of animals in the environment of high concentrations of metals which it bounds, causes high concentrations of these metals in these organs [91]. So Sharma [95] suggests that increasing accumulation of these elements should take place on higher trophic levels. But this is not true in all cases. Mechanisms of relations between metal concentrations in different chain components and factors responsible for the translocations of these elements from one level to another, have not been investigated yet [95]. In tree sparrow nestlings investigated by Kamiński [59] higher Cd concentrations in a liver compared with Cd concentration in lower trophic levels have not been found. Higher Cd concentrations also have not been found in other investigated organs. Significant differences of Cd concentrations in organs of nestlings living in both environments have also not been recorded when these differences occurred in lower levels [59]. It may be evidence that tree sparrow nestlings accumulate cadmium in a certain concentration range. Cd concentration in the food chain investigated by Dmowski & Koralewski [24] was much higher in unpolluted area in I-grade zoophages (2.4 ppm dw) than in soils and plants (0.1 ppm each) and higher than in phytophages (0.8 ppm), omnivorous invertebrates (1.1 ppm) and birds (0.16-0.3 ppm). These proportions were similar in the vicinity of zinc mill investigated by these authors, and Cd concentrations were 15 times higher than in unpolluted areas.

Lead

Lead concentration in soil surface layer is under great influence of pollution, mainly of anthropogenic origin. Even soils far from influence of industry show higher Pb concentration in a top layer. Lead undergoes strong sorption in soils (mainly by organic matter and silty minerals or hydrated iron and manganese oxides). Soil biological activity decreases as a result of Pb accumulation in soil. Accumulated humin acid increase lead solubility and cause its migration [27,57]. Lead is the least active element among heavy metals. Its solubility in soil decreases as Ca increases. Surface Pb location in soils is connected not only with sources of pollution from the atmosphere but also with surface accumulation of organic matter. Pb accumulation in the top soil layer is ecologically important because this element has a significant influence on soils biological activity [27,57]. Natural Pb content in the soil is not known because of long-term and different soil contamination by this element. Most of the authors consider lead concentrations of 10-40 ppm dw as natural [27]. Kabata-Pendias & Pendias [57] say that the top limit of lead concentration in normal soils may even reach 70 ppm dw. Pb concentrations in unpolluted soils are 20 ppm dw on average [27,39]. But it may vary between 1000 and 2000 ppm dw in busy parts of cities, along busy roads, in protective zones of metallurgic plants and steel mills (and even at a 50 km radius from them), in regions of industrial waste influence and in agricultural areas [26,27,39,84,99] and maximum values are much higher and may reach 10,000-50,000 ppm [27,66]. Pb concentration was 4-6 times higher (60-85 ppm dw) in urban polluted soils investigated by Kamiński [59] than in unpolluted ones (10-20 ppm dw). Pb concentrations in urban unpolluted soils investigated by Kamiński [59] are within the range of natural Pb contents in soil [27] and even below them [57]. However, Pb concentration in polluted urban areas investigated by Kamiński [59] was comparatively low compared with the above-quoted data from analogical areas [26,84,99].

Plants absorb lead only in trace amounts from soils unpolluted with Pb. Absorbed amount increases with an increase of Pb concentration in soil or when soil ability to bound lead decreases (low amount of organic fraction and low pH). Lead is not directly transported to above-ground parts but at the beginning is accumulated in roots [27]. Roots take up great amounts of Pb when it is present in soil in soluble forms. Degree of lead accessibility for plants is strictly conditioned by environmental factors (soil type and reaction, redox potential, humidity, mineral contents, amount of organic matter). Lead compounds of atmospheric origin are partially bound on leaf surfaces and partially penetrate further to tissues and are transported to roots [57]. Natural Pb content in plants from unpolluted areas ranges from 0.1 to 10 ppm dw - 2.3 ppm on average [35,39,57]. Industry and motor traffic increase Pb concentration in plants in great deal [35,62,73]. Its value is then of the order of 100-1000 ppm dw [35,90,105]. Pb concentration in plants in polluted urban areas investigated by Kamiński [59] was 5 times higher than in unpolluted areas and equalled 45 ppm dw on average. Therefore this value is lower than the bottom limit of Pb concentration in plants from polluted areas investigated by other authors [35,90,105]. But Pb concentration in plants from unpolluted urban areas investigated by Kamiński [59] was slightly higher than analogical data given in references [35,57].

Animals take in lead not only from air but also from lower links of trophic chains. The higher level of trophic chain the higher Pb concentration in it. In animals lead taken in from the environment gets into blood. Part of it is expelled by kidneys and part is accumulated in soft tissues and then in bones and feathers [27,35]. The speed of intestinal absorption is different in animals and changes from 2 to 20%. It depends on food composition,

mainly Ca, P and S content [35]. Pb concentration in soil invertebrates in the contaminated environment range widely: 9-7,593 ppm dw [20,31,46,47]. They are much lower in unpolluted areas (4-5.5 ppm) [103]. Pb concentration in invertebrates from the lowest level plant zone varies between 200 and 600 ppm dw in polluted areas and between 3 and 60 ppm in unpolluted ones [76]. Pb concentrations in invertebrates from unpolluted urban areas investigated by Kamiński [59] are 35 ppm dw on average and are within the range given by Martin & Coughtrey [76] for analogical areas but are higher than values given by Van Hook [103] for unpolluted areas. The highest Pb concentrations were found in plants and soil (3-3.6 ppm dw) and in birds-zoophages (3.4 ppm dw) in the food chain investigated by Dmowski & Karolewski [24] in the unpolluted area. They were lower in omnivarous invertebrates and birds-zoophytophages (2.3-2.5 ppm dw) and in I-grade invertebrates-zoophages there were no Pb at all. Pb concentrations in the vicinity of zinc mill in all invertebrates trophic groups were almost the same (435-498 ppm dw), in plants only 34 ppm dw, and in soil 1379 ppm dw. These authors also found that Cd and Pb were stored mainly in bird feathers in areas of considerable emission of these elements and were accumulated there in relatively constant proportions. Pb concentrations in the trophic chain investigated by Andrews *et al.* [7] were much higher in contaminated environments than in controlled ones (Tab.2.).

The highest accumulation of lead in birds takes place in bones. Pb concentration in organs of birds from polluted environments is several times higher than from normal ones. E.g., Pb concentration in bones, feathers and kidneys of Feral Pigeon (*Columba livia*) were 90-475 ppm, 30-250 ppm and 10-220 ppm and in pigeons nesting in rural areas - only 20-95 ppm, 2-5 ppm and 1-30 ppm [98]. Similar differences were found by Ohi et al. [79] in pigeons investigated in the centre of Tokyo and in rural areas. In organs of tree sparrow nestlings investigated by Kamiński [59] the highest concentration of Pb were recorded in bones and feathers at the end of development. Differences in Pb concentration in these organs between urban polluted and unpolluted areas were also recorded (as in lower links of the chain). Pb concentration in other organs were lower and such differences were not recorded. This may be evidence that nestlings accumulate lead in specified concentrations and store it mainly in bones and feathers.

Recapitulation and Conclusions

Investigating how elements circulate in the trophic chain makes it possible to learn different ways that nestlings absorb elements, that is to say of differences of their concentrations in soil, plants, invertebrates and nestling food. Dependence between element concentrations in bird bodies and their concentrations in the environment may be determined thanks to that. The intensity of degree of element circulation depends on a chemical form of elements, therefore on the ability to pass between different components of the environment, thus on their bioavailability. It is expressed as a proportion between element concentration in two, different trophic levels. The higher is this proportion for an element the higher is its bioavailability on the given level [21,70,109]. Interdependencies between elements

Table 2. Concentration of Pb (μg g^{-1} dry weight) in the food chain of Field Vole (*Microtus agrestis*) and Common Shrew (*Sorex araneus*) in polluted (P) and unpolluted (UP) environments investigated by Andrews *et al.* [7]. Average values given in brackets.

Soil		
(depht 1-8 cm)	P	3411-5292
	UP	94.3-130.7
Plans: (*Compositae*)	P	94.8-277
	UP	9-15.3
Invertebrates: (*Carabidae*)	P	106
	UP	5.7
(*Araneae & Opiliones*)	P	462
	UP	22.2
(*Diptera*)	P	549
	UP	28.1
(Detrytophages)	P	1228
	UP	107

		Microtus agrestis	*Sorex araneus*
Food:	P	84-277 (158)	307-555 (391)
	UP	7.7-14.5 (10.8)	11.9-39.9 (25.3)
Liver:	P	12.8	22.3
	UP	6.1	7.1
Heart:	P	10.3	14.8
	UP	5.8	5.1
Bones:	P	129-149	370-698
	UP	17.8-27.8	35.3-79.8
Whole Body:	P	40.3-96.7 (60.1)	86.7-120 (98.6)
	UP	6.3-11.1 (7.7)	7.2-23.1 (11.0)

concentration on different trophic levels are dependent on processes which take place during elements passing from one level to another [32,41].

Investigations of element concentrations in particular links of the trophic chain of tree sparrow in nestlings period in different urban environments [59] showed that homeostasis mechanisms decide Fe,Mg,Zn,Mn and Co accumulation in nestling tissues in specified amounts. Cu is accumulated by nestlings mainly in soft tissues. Cd and Pb are stored by nestlings in soft tissues in small amounts and a bigger part of these elements is accumulated in bones and feathers.

Concentration of different elements in the environment directly influences the number of eggs laid by females and nestling development and mortality [60,61]. Not only are the concentration of elements important during egg production in females, but also toxic heavy metal concentration in eggs (i.e. during the period of their development in females), decide about the number of laid eggs. It is dependent on these metals concentration in the environment. Element concentration in females may decide the number of eggs laid. A high number of laid eggs is connected with higher Fe, Mg, Ca and Zn concentrations in females and lower Cu, Mn, Co, Cd and Pb concentrations. A low number of laid eggs may be a result of too low Fe, Mg, Ca and Zn accumulation in the environment or too high concentrations of other elements, and this may give evidence of the degree of the environmental contamination [61].

Summary

Examinations on the element concentrations (Mg, Ca, Fe, Zn, Cu, Mn, Co, Cd, Pb) in soil, plants, invertebrates and food and body parts of synanthrophic bird nestlings in polluted and unpolluted urban environments were reviewed.

Generally, it was stated that Mg and Ca concentrations in soils and plants were higher in polluted areas than in unpolluted ones. The concentration of Mg and Ca in the remaining components in the polluted areas were either lower than, or not significantly different from, those in the unpolluted areas. Concentrations of heavy metals in soils, plants, invertebrates, and food eaten by nestlings in the polluted areas were higher than those in the corresponding components in the unpolluted ones. Similarly, concentrations in the organs of nestlings were either higher in the polluted areas, or else not different. Concentrations of Mg,Zn,Mn,Co,Cd, and Pb in the organs of nestlings at the beginning and end of development were lower than those in the soil, plants and invertebrates, though exceptions to this rule were noted for Mg, Cd and Pb in bones and feathers, and for Zn in the liver and heart at the end of development. Concentrations of Fe and Cu in the organs were close to those noted in soils and plants from unpolluted areas, though exceptions to this rule referred to Fe in feathers and Cu in liver and heart at the end of development [59].

Homeostatic mechanisms make it possible to accumulate Fe, Mg, Zn, Mn and Co in nestling tissues in amounts lower than those present in soils, plants and invertebrates [59]. Moreover, these mechanisms enable nestlings to accumulate Cd and Pb in soft tissues in small amounts compared with concentrations of these elements in the environment. Most Cd and Pb absorbed by nestlings was stored in bones and feathers.

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