**BABEȘ-BOLYAI UNIVERSITY**
**FACULTY OF ENVIRONMENTAL SCIENCE AND ENGINEERING**
**DOCTORAL SCHOOL OF ENVIRONMENTAL SCIENCE**

# DOCTORAL THESIS

# SUMMARY

## THE USE OF VEGETATION AS A BIOINDICATOR OF AIR AND SOIL QUALITY

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# KEYWORDS

Metal pollution biomonitoring

Soil-to-plant transfer of metals

Metal bioaccumulation

PM10 in ambient air

Moss-bag biomonitoring

Human health risk

# 1. INTRODUCTION

The quality of the environment (water, air, soil) indicates the quality of life as the human body is in a permanent exchange of substances with the environment. Exposure to pollution increases human health risks and may lead to an increased incidence of chronic pathologies (Roba et al., 2016; Miclean et al., 2018; Miclean et al., 2019).

Soil is considered a finite natural resource, an essential component in the food, fiber, and fuel production chains, as well as the provider of an important number of ecosystem services. At the same time, the soil may act as a source and sink for many pollutants. Air is also a vital component of life as well as an important link in the cycle of carbon, water, nitrogen, and a large number of pollutants.

Metals are persistent pollutants widespread in the environment, with toxic potential even at low concentrations (Drava et al., 2016). The pollution with metals can be assessed directly by measuring the metal content and comparing it with legislated thresholds or reference values for a particular area or indirectly using biomonitoring approaches (Pavlovic et al., 2017). The measurement of physico-chemical parameters provides quantitative data on the pollutant's presence in the environment at a certain point and time (Ajtai et al., 2020). In contrast, biomonitoring acts as an integrator of pollution and provides information on the effects of pollutants on living organisms and the long-term evolution trend of ecosystems (Rai, 2016).

In this context, the PhD thesis presents different biomonitoring approaches for air and soil pollution in urban and industrial areas and the human health risk assessment by exposure to contaminated food and air. Herbaceous, deciduous, and coniferous plant species suitable for active biomonitoring of the air and soil quality were identified and tested; the metal content in soil, air, and biomonitors was determined; and the soil-to-biomonitor and air-to-biomonitor transfer of metals was studied. Air pollution was also biomonitored using the moss bag method, and the human health risk of vegetables, fruits, and milk produced in polluted areas and of air polluted with suspended particles and metals was assessed.

# 2. THEORETICAL CONSIDERATIONS ON METAL POLLUTION BIOMONITORING

Biomonitoring is an alternative approach to environmental pollution monitoring by physico-chemical analysis and uses living organisms or their response to determine the quality or changes in the environment under the influence of anthropogenic pressures. Passive biomonitoring uses organisms naturally occurring in the study area, whereas active biomonitoring uses organisms transplanted from their natural habitat into the study area (Levei et al., 2020a; Swislowski et al., 2021; Wolterbeek, 2002; Conti & Cecchetti, 2001; Asgari & Amini, 2011; Schreck et al., 2016).

Different mechanisms govern metal uptake by the leaf surface and root. Root uptake is influenced by the plant species, metal chemistry, soil type, soil grain size, microbial activity, cation exchange capacity, organic matter content, and soil pH. Metal chemistry, leaf surface characteristics, cuticle composition, and leaf maturity govern metal accumulation by leaves (Levei et al., 2021). Airborne pollutants deposition on leaf surfaces depends on canopy shape (branch and leaf density), leaf surface electromagnetic charge, leaf structure (shape, area, morphology, wax thickness), and density of stomata (Levei et al., 2020c; Wroblewska & Jeong, 2021; Rodriguez-Santamaria et al., 2022; Shahid et al., 2017). Thus, the needle-like leaves of conifers can capture airborne particles more efficiently than the leaves of deciduous tree species. The roughness and thickness of young leaves differ from those of senescent leaves. Young leaves have a thin and permeable cuticle as well as a thin epicuticular wax layer; therefore can accumulate higher amounts of metals than mature leaves (Shahid et al., 2017). Metals uptaken by the roots are stored locally or in the cell vacuoles by precipitation of metals into insoluble salts. Generally, except for hyperaccumulating plants, the translocation of metals from roots to the aboveground parts is limited (Levei et al., 2017).

The sensitivity level and type of response to metal pollution differ from specie to specie. Pollutant-sensitive plants that present phytotoxic concentrations of metals show visible symptoms such are leaf chlorosis, leaf fall, and biomass decrease and may be used as bioindicators, while plants that tolerate high amounts of pollutants can be used as biomonitors. To select a biomonitor, its presence in the polluted area and its specificity must be considered. Herbaceous plants may accumulate metals predominantly from the soil, while trees and mosses accumulate metals predominantly from the air (Wolterbeek, 2002; Levei et al., 2018). Other factors that influence the accumulation of metals in plants are the macro and micro climate of the study area, acidity, altitude, presence of nutrients, humidity, etc.

The most applied method of active biomonitoring of pollution is the moss bag method (Stefanut et al., 2019; Ares et al., 2014). The moss bag method is based on moss species transplanted from unpolluted areas into the study area for a certain period. The method is a simple, cheap, facile alternative for every geographical area regardless of the anthropization degree and allows the collection of data on air pollution at different time intervals (Anicic et al., 2009; Hu et al. al., 2018; Stefanut et al., 2019). Unlike instrumental methods that measure the concentration of metals in suspended particles of various sizes over short time intervals (from minutes to 24 hours) and provide snapshots of instantaneous or daily metal concentrations, the moss bag method provides data on the average concentration of metals over long time intervals (Levei et al., 2020b; Vukovic et al., 2016). The amount of metals retained in the moss bags depends on the bag preparation method (type of moss specie, the vitality of the moss, shape of the bag, the ratio between the amount of moss and the surface of the bag, the mesh size of the bag material, etc.), the bag exposure parameters (height, duration, degrees of bag mobility) but also the characteristics of the study area. Due to their high capacity to accumulate metals, the Sphagnum moss species are most frequently used for moss bags. However, due to their endemic presence, it is recommended to use other moss genera or species for the large-scale application of this method (Milicevic et al., 2017). Possible alternatives for *Sphagnum* are *Hypnum cupressiforme* (Milicevic et al., 2017) or *Hylocomium splendens* (Ștefănuț et al., 2019).

## 3. OBJECTIVES

The general objective of the thesis is the biomonitoring of soil and air quality in urban and industrial areas using herbaceous, coniferous, deciduous, and moss species. In this sense, the ability of some herbaceous and woody plants to accumulate metals from soil and air was studied. Also, the moss bag method was applied for the biomonitoring of air quality in urban areas where vegetation is scarce.

The specific objectives of the thesis are:

1. ***Passive biomonitoring of soil pollution with metals using herbaceous plant species.*** To achieve this objective, the concentrations of potentially toxic metals in the soil were correlated with

those in plantain, dandelion, coltsfoot, and ryegrass leaves collected from urban and industrial areas with different degrees of pollution.

2. ***Passive biomonitoring of air pollution with metals and airborne particulate matter using coniferous and deciduous tree species***. To achieve this objective, the concentration of suspended particles and metals in the air was correlated with the metal content in thuja and poplar leaves in urban areas.

3. ***Active biomonitoring of air pollution with metals and suspended particles using moss bags with vital and devitalized moss.*** To achieve this objective, the optimal parameters of the moss bags were studied, and the differences between metal accumulation in vital and devitalized muscles were studied. Furthermore, the air pollution with suspended particles and metals was biomonitored for six months, the biomonitoring results being correlated with the intensity of road traffic.

4. ***Health risk assessment by consumption of food contaminated with metals and inhalation of air with high concentrations of suspended particles.*** To achieve this objective, the carcinogenic and non-carcinogenic health risk by consumption of plant (vegetables and fruits) and animal (milk) food products contaminated with metals and by exposure to air polluted with suspended particles (PM10) was assessed for different population groups.

# 4. MATERIALS AND METHODS

Five study areas located in the western and northwestern parts of Romania were selected for the study: Cluj-Napoca and Copșa Mică towns and Baia-Mare, Aries, and Certej mining areas.

The metal concentration in soil, air, plant, and food samples was determined by inductively coupled plasma optical emission spectrometry (ICP-OES) using the 5300 Optima DV spectrometer (Perkin Elmer, Waltham, MA, USA) and by inductively coupled plasma mass spectrometry (ICP-MS) using ELAN DRC II spectrometer (Perkin Elmer, Waltham, MA, USA), depending on the metal concentration.

Airborne particulate matter, PM10, PM2.5, and PM1 were measured using the 831 Aerocet portable optical particle counter (Met One Instruments, Washington, US).

Daily PM10 concentration was determined gravimetrically by collecting PM10 particles for 24h on 150 mm diameter glass fiber filters (MG227/1/60, Sartorius, Gottingen, Germany) preconditioned at constant mass using a DHA-80 sampler (Digitel Elektronik GmbH, Burs, Austria) with a flow rate of 500 L/min. After sampling, the filters were conditioned, and the PM10 concentration was determined gravimetrically using the analytical balance.

# PERSONAL CONTRIBUTIONS

## 5. EXPERIMENTAL RESULTS ON BIOMONITORING OF SOIL POLLUTION WITH METALS USING HERBACEOUS PLANTS

Soil pollution in mining and urban areas was biomonitored using the leaves of plantain (*Plantago major*), perennial ryegrass (*Lolium perenne*), dandelion (*Taraxacum officinale*), and coltsfoot (*Tussilago farfara*) (Figure 1).

|  |  |  |  |
|---|---|---|---|
| Plantain (*Plantago major*) | Perennial ryegrass (*Lolium perenne*) | Common dandelion (*Taraxacum officinale*) | Coltsfoot (*Tussilago farfara)* |

**Figure 1.** Herbaceous plant species used in soil pollution biomonitoring (source: ISA, 2023)

Plantain is widespread in urban and industrial areas, grows in nutrient-poor environments, and is easily recognizable, making it a potential biomonitor of soil pollution with metals. The obtained results showed the moderate ability of plantain to accumulate Zn, Cu, Cd, Ni, Cr, and Pb from the soil (TF <0.5). The relatively linear dependence of the Pb and Zn concentration in plants on the Pb and Zn concentration is soil recommends using plantain for biomonitoring of moderate soil pollution with Pb and Zn.

Ryegrass is a widespread herb, especially in peri-urban areas and hayfields, but it is also found in heavily polluted industrial areas. Although it accumulates substantial amounts of metals, especially Pb, the transfer factor rarely exceeds 0.5. The linear dependence between the concentration of metals in ryegrass and soil was observed only for Zn for the whole concentration range studied and for Cu and Pb for concentrations below 1000 and 2000 mg/kg, respectively. This fact suggests that ryegrass can be used for biomonitoring of heavily polluted soils with Zn and moderately contaminated soils with Cu and Pb.

Dandelion does not hyperaccumulate any of the studied metals, but it can be used as a biomonitor of Zn, Pb, and Ni pollution in urban areas, where the concentration of these elements is moderate to high. A linear correlation between the concentration of metals in dandelion leaves and soil was found for moderate concentrations, as at higher metal concentrations in the soil, the physiological mechanisms, such as exclusion, limit the metal uptake to protect the plant and reduce the toxic effects.

The coltsfoot tolerates high concentrations of toxic metals by limiting the metal uptake from the soil, the metal transfer factor being generally below 0.5 regardless of the metal content in the soil. The concentration of Cu, Pb, and Zn in coltsfoots varies linearly with the concentration of these metals in moderately polluted soils, suggesting that it can be used as a bioindicator of moderate soil pollution with Cu, Pb, and Zn.

# 6. EXPERIMENTAL RESULTS ON AIR POLLUTION BIOMONITORING USING CONIFEROUS AND DECIDUOUS TREES

## 6.1. Thuja

White cedar (*Thuja occidentalis*), commonly named thuja, is a coniferous specie from *the Cupressaceae* family, have a small or medium size, and is frequently used as an ornamental tree or hedge. To evaluate the potential of thuja leaves to be used for biomonitoring of air pollution with metals, the concentration of metals in thuja leaves and airborne particle matter from different areas of Cluj-Napoca and Copșa Mică were measured and compared with the traffic intensity.

The concentration of metals in thuja leaves increased in the order Pb<Cr<Ni<Cu<Zn both in Cluj-Napoca and in Copșa Mică. The concentration of Pb and Cr in thuja leaves from low-traffic and high-traffic areas was comparable, but the concentration of Cu, Zn, and Ni was double in high-traffic areas compared to low-traffic areas, suggesting that thuja leaves are good bioindicators of Cu, Zn and Ni pollution. Particulate matter (PM) of 2.5–10 μm diameter was the major fraction of total suspended particles (TSP), followed by PM1 and PM2.5 in both high-traffic and low-traffic areas. In Cluj-Napoca, the concentration of TSP in the air was below the legislated threshold, but

the PM10 was higher in areas with heavy traffic than in those with low traffic, suggesting that traffic is an important source of suspended particles and metals.

### 6.2. Poplar

Poplar (*Populus spp*.) is a deciduous tree specie belonging to the *Salicaceae* family, suitable for air pollution biomonitoring due to the high sensitivity of its leaves to metal pollution (Yalaltdinova et al., 2018). Poplar is a fast-growing tree, has an extensive root system, is resistant to drought, storms, and cold weather, produces high quantities of biomass, thrives in nutrient-poor areas, and tolerates high amounts of metals (Chandra & Kang, 2016; He et al., 2012). Poplar accumulates metals through the root system and leaves, translocating metals from roots to shoots and storing metals in the leaves (Lepp & Madejon, 2007; Unterbrunner et al., 2007).

In the Cluj-Napoca town, the enrichment factor of Co, Mn, Ni, and Fe in PM10 was less than 10, indicating no enrichment, the presence of these metals being most likely related to the Earth's crust and not to anthropogenic sources. However, the enrichment factor of Cu, Pb, and Zn was <100, indicating moderate enrichment, these metals being of both natural and anthropogenic origin, whereas the enrichment factor of Cd was 230, indicating high enrichment and its anthropic origin. The concentration of metals in poplar leaves varied from metal to metal, but the phytotoxic level was not reached for any of the analyzed metals. In all studied areas, the concentration of Cu was low, and that of Cd was high, in agreement with the content of metals in PM10. The Pb concentration in poplar leaves was low (<3 mg/kg), being well below the toxic level (>20 mg/kg) (Hajar et al., 2014). A possible cause of the low Pb concentration in the poplar leaves could be attributed to the preferential uptake of Pb through the root system and not through the leaves, as well as to the low translocation of Pb from roots to leaves (Madejon et al., 2004). The metal concentration in poplar leaves consists mainly of Zn (46%), Fe (23%), Mn (14%), and Al (12%). Although metals emitted by various pollution sources can easily bind to airborne particles and then is settled on the leaf surface, their accumulation in poplar leaves depends on both meteorological conditions and the physiology of each tree. The high concentrations of Zn determined in poplar leaves can be explained by the fact that poplar is a good Zn accumulator, which recommends its use not only for biomonitoring but also as a natural barrier for Zn abatement.

The moderate values of the enrichment factor for Cu, Pb, and Zn in PM10 as well as the high values for the enrichment factor for Cd in PM10, show that Cd is most likely of anthropogenic origin, while the other metals are of mixed origin. Traffic and waste burning were identified as the main source of Cu and Zn, dust is the source of Fe, Pb, Mn, Co, and soil pollution is the source of Pb, Cu, Ni in poplar leaves and air.

# 7. EXPERIMENTAL RESULTS ON ACTIVE BIOMONITORING OF AIR POLLUTION USING MOSS BAGS

For the biomonitoring of air pollution with metals (Cu, Pb, Zn, Cd, Co, Ni, Cr) in Cluj-Napoca, the concentration of metals was determined in moss bags exposed for 7 months in different city areas. The concentration of metals in moss bags was correlated with that of PM10 and metals as well as with the level of traffic in the biomonitored areas. The results obtained using both vital and devitalized moss-containing moss bags were also compared. Except for one biomonitoring site located in a low-traffic residential area, the relative bioaccumulation factor (RAF) was above 1 for Cu in vital muscles indicating considerable Cu accumulation. For the other elements, the values of the relative bioaccumulation factor differed from sample to sample, both for vital and devitalized muscles, but for each of the studied metals, RAF > 0.5 were found in at least one samples (Figure 2), and the cumulative RAF was above 1 in all samples, indicating the metal accumulation.

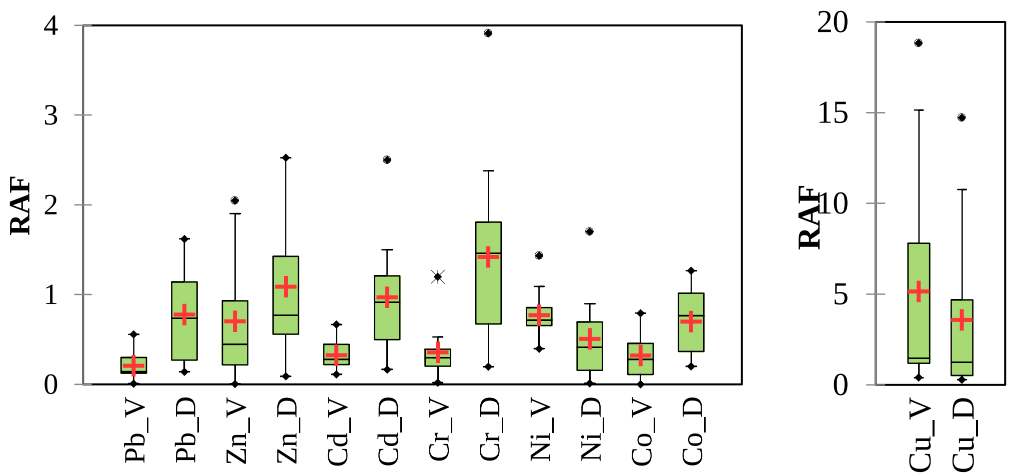


**Figure 2.** Relative accumulation factor (RAF) for moss bags with vital (V) and devitalized (D) moss (•Minimum/Maximum, +Average, —Median, ⁎ Extreme)

Copper and Zn represent 75% of the total metals bioaccumulated in moss bags. High enrichment of Cu, moderate enrichment of Zn, Cd, Ni, and lack of enrichment of Pb, Cr, and Co in moss bags indicated that exhaust gases (Co, Cr, Ni) have a lower share in air pollution than emissions due to tire and brake wear (Cu, Zn). The correlation between the number of vehicles that pass by the biomonitored area and the concentration of TSP, PM10, PM2.5, and PM1 confirmed that traffic is an important source of suspended dust in urban areas. However, there is no linear correlation between the concentration of the metals in moss bags and airborne particulate matter concentration. The primary mechanism of metal accumulation in moss bags is through adsorption, whereas physiological processes have only a secondary role. The preferential absorption of some elements is due to the competition between elements for the cation exchange sites of the moss tissue. The different metal concentrations in exposed moss bags in different areas of the city suggest the existence of local fluctuations in the airborne particle concentration and composition of these particles. The concentration of metals accumulated in the moss bags allowed the differentiation of high-traffic areas from low-traffic areas, thus the moss bag method is suitable for long-term assessment at a high spatial resolution of the distribution of metals in ambient air and is an attractive alternative to instrumental methods of air quality monitoring.

# 8. EXPERIMENTAL RESULTS ON HUMAN HEALTH RISK ASSESSMENT VIA CONSUMPTION OF FOOD CONTAMINATED WITH METALS AND INHALATION OF POLLUTED AIR

## 8.1. Health risk assessment by ingestion of vegetable products polluted with metals

Vegetables and fruits are an important source of carbohydrates, vitamins, fibers and essential elements for the human diet. Vegetables and fruits grown in polluted areas may accumulate toxic elements from the soil and air. By ingestion, these toxic elements may reach the human body and trigger adverse health effects (Demkova et al., 2017). The human health risk caused by ingesting vegetables polluted with metals grown in households in two localities in Maramureș County, located near tailings dumps, was evaluated based on the target hazard coefficient (THQ). The health risk was estimated based on an estimated daily intake of 100 g of potatoes, 250 g of vegetables and 65 g of fruit for a 70 kg person.

The THQ (Figure 3) is higher for vegetables than fruits and potatoes, being below 1 for all metals except Pb in vegetables. Cumulative THQ value decreases in the order Pb>Cd>Cu>Zn, being below 1 for Cd (0.59), Cu (0.36) and Zn (0.18) and above 1 for Pb (1.2). These results revealed the existence of a potential health risk by ingestion of contaminated vegetables. The potatoes and fruits grown in polluted areas do not pose important health risks.

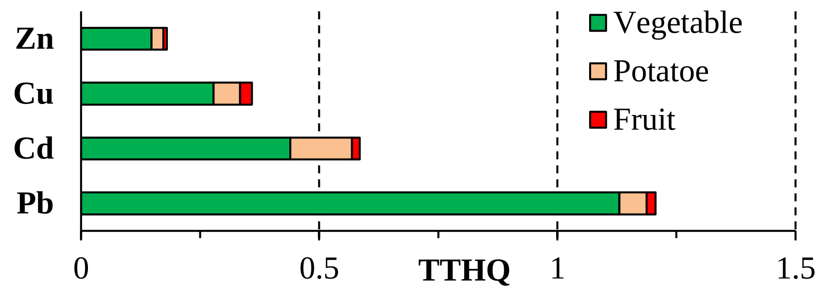


**Figure 3.** Target hazard quotient (THQ) of vegetables and fruits grown in contaminated areas

The total carcinogenic risk index (TCR) was higher than 1 x $10^{-4}$, indicating high carcinogenic risk by long-term consumption of contaminated vegetables. By reducing the daily consumption of contaminated vegetables, the risk does not fall below the risk threshold (HI decreases from 2.33 to 1.33, whereases TCR decreases from 8.71 x $10^{-4}$ to 4 .36 x $10^{-4}$). Considering that the study did not include all classes of foods in the diet, the health risk may be underestimated.

### 8.2. Health risk assessment by ingestion of milk produced in polluted areas

Foods of animal origin, such as dairy products, have an important share in the human diet, especially for children, due to their high content of proteins, vitamins, and minerals (Lucey, 2015). Although milk is an important element in the daily basket, data on the presence of essential and toxic elements in milk produced by small farms is limited. Soil→forage→animal→milk→consumer is an example of a food chain through which toxic metals can be transferred from soil to various types of grass used as animal feed and then into the human body. The potential human health risk by consumption of milk produced in polluted areas was assessed by analyzing the metal content of milk samples from cows raised in family farms in the Baia Mare post-mining area.

Milk produced in the Baia mare mining area contains low concentrations of Cu and Zn and high concentrations of Pb and Cd. The estimated average daily intake and average weekly intake are lower than the tolerable values, whereas the target hazard coefficient (THQ) is below 1 for both adults and children for all studied metals indicating the lack of health risk for milk produced in contaminated areas. The average THQ decreased in the order Zn>Cd≥Cu>Pb for all population groups and does not differ significantly for men and women but is slightly higher for children.

The average carcinogenic risk index of Cd was higher than the acceptable risk limit ($1x10^{-6}$) for both adults and women, whereas that of Pb was lower in adults and slightly higher for children. The total carcinogenic risk index was above the acceptable limit, indicating the risk of developing neoplastic pathologies following long-term milk consumption. Although the human body has excretion mechanisms to limit the accumulation of toxic elements, special attention to food quality is recommended, especially for vulnerable population groups such as children.

### 8.3. Health risk assessment associated with PM10 exposure in urban areas

Air pollution negatively affects human health by increasing the incidence of respiratory and cardiovascular pathologies as well as the mortality and morbidity of the exposed population (Levei et al., 2020; Chalvatzaki et al., 2019). In recent years, air pollution episodes with fine and ultrafine particles are increasingly frequent, with exceedances of the maximum allowed concentrations reported mainly in large cities (Gruszecka-Kosowska, 2018). Metals are adsorbed on the surface of suspended particles and may cause inflammation of the respiratory tract and DNA alteration (Gruszecka-Kosowska, 2018).

The hazard quotient (HQ) calculated using the average daily PM10 concentration (best-case scenario) in Cluj-Napoca during 2009-2019 reported by the Environmental Protection Agency and the limit concentration established by Directive 2008/50/EC presented values between 0.2 and 1.1, indicating a potential risk in 2009-2010 and no risk in the other years. For the worst-case scenario, the HQ calculated based on the 90th percentile of the daily PM10 concentrations varied between 0.2 and 1.6 and showed the exceedance of the threshold value several months in each year, especially in the cold season. The HQ calculated using the reference value established by the WHO varies between 0.4-2.1 for the best-case scenario and 0.5-3.2 for the worst-case scenario, indicating potential health risk in the cold months (October-March), respectively health risk almost all year around.

The HQ values higher than the unity benchmark showed that negative health effects are likely to occur even at low PM10 concentrations. Generally, the HQ was higher for urban and suburban monitoring stations than industrial and traffic stations. For the inhabitants of Cluj-Napoca town, the best-case scenario confirmed the reduced probability of developing chronic pathologies associated with PM10, but the worst-case scenario showed a higher probability. Simultaneous exposure to PM10 and other pollutants from the ambient air significantly increases the probability of respiratory and cardiovascular pathologies incidence. The human health risk was estimated based on some assumptions regarding the behavior of the inhabitants and the number of hours spent in the study area, neglecting individual behaviors. Also, the average PM10 concentration from the 4 monitoring stations was considered representative of the entire city. Despite all these limitations, the results can be the basis of pollution abatement measures and public health policies. Possible measures to reduce the negative health impact could be reducing the hours spent in the urban environment in favor of clean areas.

## 9. GENERAL CONCLUSIONS

The PhD thesis presents a series of passive and active biomonitoring studies of metal pollution in different industrial and urban areas using herbaceous plants, coniferous tree leaves, deciduous tree leaves, and moss bags. The chronic and carcinogenic health risk caused by the consumption of contaminated food products in the Baia-Mare mining area and by air pollution with PM10 in the urban area of Cluj-Napoca was assessed.

The first part of the doctoral thesis presents a review of the scientific literature on air and soil pollution with metals, metal pollution biomonitoring and human health risk assessment by ingestion of contaminated food and exposure to polluted air. The literature review allowed the identification of plant species for the biomonitoring of soil and air but also revealed the lack of standardized biomonitoring methods that would allow the comparison of the results of different studies. The low number of biomonitoring studies at a national level as well as the lack of active biomonitoring studies of the air pollution with metals associated with airborne particles were also noticed.

In the second part of the PhD thesis, the original contributions are presented: the objectives of the thesis, the used materials and methods, the study areas, as well as the obtained experimental results. The obtained results showed that the passive biomonitoring of soil pollution with metals using herbaceous plants and of air pollution with airborne particles and metals using thuja and poplar leaves, as well as that the active biomonitoring of air pollution using moss bags are suitable alternatives for instrumental monitoring methods.

For the passive biomonitoring of soil pollution in Aries, Certej, Baia Mare mining areas and Cluj-Napoca urban area, herbaceous plants known to thrive in nutrient-scarce environments, such as plantain, ryegrass, dandelion, and horsetail were studied. These plants do not hyperaccumulate metals, but the relationship between the metal concentration in soil and plant is specific to each specie and is influenced by the soil properties and the metal chemistry. Plantain (*Plantago major*) is suitable for biomonitoring moderately polluted soils with metals. At higher concentrations, the exclusion processes limit the metal uptake from the soil and impede the translocation from roots to shoots. Ryegrass (*Lolium perenne*) accumulates important amounts of metals from the soil, especially Pb. The linear dependence between the concentration of metals in ryegrass and in soil over a wide concentration range for Zn and at concentrations below 1000 and 2000 mg/kg for Cu and Pb, respectively, allows the use of ryegrass for Zn, Cu, and Pb biomonitoring. Common dandelion (*Taraxacum officinale*) can be used as a biomonitor of Zn, Pb, and Ni pollution because there is a linear correlation between the metal concentration in dandelion leaves and soil. Horsetail (*Tussilago farfara*) accumulates high amounts of Cu, Pb, Zn, Cd, Cr, and Ni, but the dependence is linear only in the case of Cu, Pb, Zn, and Cd.

Air pollution with metals associated with total suspended particles (TSP) and particles of different sizes (PM10, PM2.5, PM1) in the urban area of Cluj-Napoca and the industrial area of Copșa Mică was passively biomonitored using thuja (*Thuja occidentalis*) and poplar (*Populus nigra*) leaves. The concentration of TSP was higher in areas with heavy traffic than in those with low traffic, suggesting that traffic is an important source of particulate matter and metals. Thuja leaves were found to be suitable for biomonitoring of air pollution with Zn, Cu, and Ni, whereas poplar leaves for biomonitoring of Zn, Fe, Mn, Al, Pb, Cu, Ni, Co, and Cd. Thuja leaves sampled from areas with heavy traffic had higher Cu, Zn, and Ni concentrations than those sampled from areas with reduced traffic, but the concentration of Pb and Cr was comparable in the two areas. The results indicated a proportional increase in the concentration of metals in poplar leaves with the increase of PM10 concentration in the ambient air. In Cluj-Napoca, traffic, waste burning, erosion of urban surfaces, and dust resuspension are the most important anthropogenic sources of metals. In Copșa Mică, the main sources of metals are legacy pollution due to the metallurgical industry, which overlaps with the current, much less intense traffic pollution. The metal accumulation index showed the ability of both tree species to accumulate metals, with the preference of poplar for Cu and Cd and of thuja for Cu and Ni being observed. Both species are suitable for biomonitoring industrial areas heavily polluted with metals.

Active biomonitoring of air pollution using moss bags confirmed the air pollution with metals in Cluj-Napoca. The high Cu enrichment, moderate Zn, Cd, Ni enrichment, and the lack of Pb, Cr, and Co enrichment in the moss tissues show that the exhaust gases (Co, Cr, Ni) have a lower contribution to the air pollution than the emissions caused by the tyer and brake wear (Cu, Zn). The correlation between the number of vehicles transiting the biomonitored area and the concentration of TSP, PM10, PM2.5, and PM1 confirmed that traffic is an important source of suspended particles in urban areas. However, no linear relationship between the concentration of metals in moss bags and suspended particulate matter was observed. The moss bag method is suitable for long-term biomonitoring of air pollution with particulate matter in urban areas lacking spontaneous vegetation.

Due to their ability to absorb metals from soil and groundwater, plants grown in metal-polluted areas can uptake and accumulate high amounts of toxic metals. Long-term consumption of plant and animal products contaminated with metals increases the human health risk and favors the occurrence of both chronic and carcinogenic pathologies. Avoiding the long-term consumption of foods containing toxic metals, even below the maximum allowed limits, can decrease health risks and reduce the occurrence of chronic pathologies.

Another factor that may lead to health risks is air pollution with airborne particulate matter, especially PM10. The air quality in Cluj-Napoca has constantly improved in the last decade, with the concentration of PM10 dropping below the permitted limits on most days. The probability of inhabitants of Cluj-Napoca developing chronic pathologies associated with PM10 is reduced. However, cumulative exposure to PM10 and other air pollutants may increase the health risk. Reducing traffic through efficient public transport, using ecological vehicles, rehabilitation of transport infrastructure, stopping waste burning, and using low-emission fuels for residential heating may further reduce air pollution.

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