Journal of Hazardous Materials 197 (2011) 109–118

Contents lists available at SciVerse ScienceDirect

Journal of Hazardous Materials

journal homepage: www.elsevier.com/locate/jhazmat

Comparison of four bioindication methods for assessing the degree of environmental lead and cadmium pollution

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ARTICLE INFO

Article history:
Received 28 February 2011
Received in revised form
14 September 2011
Accepted 16 September 2011
Available online 22 September 2011

Keywords:
Biomonitoring
Heavy metals
Birch
Scots pine
Moss bags

ABSTRACT

The purpose of this study was to assess the application of several bioindication methods for the monitoring of environmental pollution from Pb and Cd. The study area centered on the town of Olkusz, Poland, which is one of the oldest centers for the metallurgical industry in Europe. The assessment of environmental pollution due to metals was performed using four frequently used bioindication methods: moss-bag (*Sphagnum fallax*), determination of metal accumulation in *Pleurozium schreberi*, silver birch foliage, and Scots pine needles. The region of Olkusz, and especially the area surrounding the mining and metallurgical Bolesław complex, was extremely contaminated with Pb and Cd. The results of the investigations are presented as contamination deposition maps. Despite the application of various methods and the resulting diversity of the specific exposure periods for different biomonitors, the spatial distribution of contamination shown on the maps was similar, as confirmed by the statistical analysis of the results.

1. Introduction

Metals, such as Pb and Cd, are much more harmful to people than they are to plants. Pb and Cd belong to the group of elements with a high risk of disturbing chemical equilibrium in the biosphere because they are characterized by a high capacity for accumulation in the environment [1].

The application of bioindication methods provides a significant and intense study of pollution, especially pollution that is due to the trace elements. Generally, biomonitoring can be defined as the use of plants and animals to gain quantitative and qualitative information about certain characteristics of the biosphere [2].

Mosses are among the most frequently used monitors of environmental pollution. Often, their ability to effectively accumulate metals is utilized in this context. The very first studies on the use of mosses to assess metal pollution in air were carried out in Sweden in the 1960s [3]. In parallel to the biomonitoring studies, several methodological projects were conducted to determine the influence exerted by numerous factors on the level of metal accumulation in mosses [4–10].

Determination of the accumulation of pollutants in the living organisms, in spite of its various limitations is still considered to be a very good method of evaluating the condition of the environment. It was found particularly useful when evaluating the degree of pollution with metals. Simultaneous application of various biomonitors allows one to minimize the fundamental limitations of the bioindicative methods. Four bioindicative methods were employed in the research. They encompassed the determination of the accumulation of metals in the following: exposed *Sphagnum fallax* moss (the moss bag method), growing *Pleurozium schreberi* moss, Silver Birch leaves, and Scots Pine needles.

The assessment of atmospheric pollution using naturally growing mosses as biomonitors has been widely implemented as an effective method of evaluation of air contamination with metals. However, similar to other bioindication methods, this method has limitations caused by the difficulties in finding a given biomonitoring species over the entire study area. Such situations are common in significantly polluted or urbanized areas. In such situations, moss bag methods have been employed that involve the physical transfer of mosses from their natural areas to a studied location [11]. This method was based on the collection of moss in a relatively unpolluted area and its placement in nylon hairnets, which were later exposed to the contaminated study areas. The concentration of metals in the moss bags was correlated with atmospheric metal concentrations [12].

Studies involving the chemical analyses of pine needles for the biomonitoring of environmental pollution started in the 1970s. These studies confirmed the advantages of pine as an indicator species, resulting in an elaboration of the monitoring

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0304-3894/$ – see front matter
doi:10.1016/j.jhazmat.2011.09.062

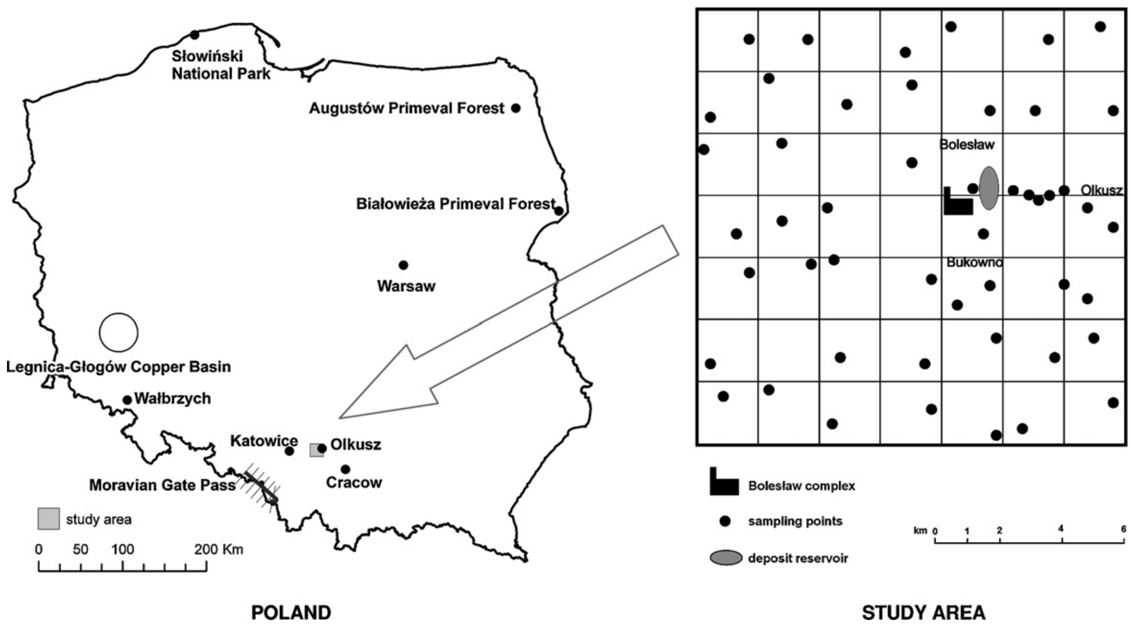

Fig. 1. Map of Poland indicating geographical features discussed in the article and the study area.

methodology and facilitation of the interpretation of the results from later investigations [13–17]. Silver birch has often been used as an environmental pollution biomonitor [18–24]. The reason there has not been a wide-scale use of silver birch (and Scots pine) as a monitor is the lack of fundamental methodological studies.

The goal of this work was to evaluate different bioindication methods that provide a biologically-based complementary information for the mandatory environmental monitoring of metals. Application of four bioindication methods allowed for a more complete determination of environmental pollution for an area of extreme historical contamination with metals, originating from long-range transport as well as local sources.

2. Study area

The study area is a region around the town of Olkusz and is one of the oldest European centers for the metallurgic industry. It is situated between three large industrial regions. On the west and east, it borders the Upper Silesian Industrial Region and the Cracovian Region, respectively, and from the south, it is under the influence of emissions from Moravia (Czech Republic), reaching the area through the Moravian Gate Pass (Fig. 1). These three regions are characterized by high concentrations of plants belonging to industries that are particularly harmful to the environment (power generation, steel, and non-ferrous industrial extraction and processing, power production, mining, chemical and cement production). One of the most important industrial plants in the area is the mining and metallurgical Bolesław complex, located in the region of Bukowno near Olkusz. This plant started functioning in 1952 [25].

The study area encompassed the waste heap from the refining process of the zinc and lead ores. The dust from this heap (height of 25–30 m; area of 1.09 km^2) was transported by the wind and contributed to the contamination of the surrounding areas. In addition, dust emissions from the stacks of the Bolesław complex were transported over much longer distances. This pattern also applies to other industrial plants located outside of the study area, such as the Katowice Steel Works. Another problem comes from the secondary emissions from the contaminated uncovered bedding [26].

The study area was situated to the west of Olkusz with its border reaching the suburbs of the town (Fig. 1). The area was 14 km × 14 km and was divided into 49 smaller squares of 2 km × 2 km. The sampling locations were selected to meet two criteria: (1) they had to be at least 300 m from the main roads with heavy traffic; (2) the appropriate pines, birches and mosses (within the distance of at most 100 m) had to be present. Four additional monitoring sites were selected near Bolesław complex.

3. Materials and methods

The study was conducted using four common methods for the biomonitoring of environmental pollution due to metals determined by their accumulation in the following:

- the exposed *Sphagnum fallax* moss (the "moss bags" method);
- the growing moss *Pleurozium schreberi*;
- the leaves of silver birch(*Betula pendula* Roth) and
- the needles of Scots pine (*Pinus silvestris* L.) trees.

Table 1 summarizes the properties of the applied bioindication methods and defines what sources of contamination the measurements reflect. The main factor that determines the absolute values of measurements in relation to the degree of environmental pollution is the time of exposure, which is expressed through the level of accumulation of heavy metals in the biomonitors plants. The level of heavy metal accumulation is also impacted by the specific features of the bioindication method applied, the source of contamination (air, soil) and the properties (morphological structure) of the biomonitoring plant.

Table 1
Properties of the applied bioindication methods.

Method	Period of exposure	Source of contamination
Moss-bag method	12 weeks	air
Accumulation in the moss *Pleurozium schreberi*	2–3 years	air
Accumulation in birch foliage	3 months	air and soil
Accumulation in pine needles	14 months	air and soil