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Heavy Metals Uptake by Trees near a Waste Incinerator

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Abstract. Incinerators produce energy burning virtually everything including waste, but emit pollutants such as heavy metals and carbon monoxide (CO). These substances can be uptaken by trees through their roots, leaves or stems. To evaluate the quantity of heavy metals uptaken, and to validate the methodology, we studied an incinerator and its area of influence. In order to catalogue the impact of the incinerator on the environment, sampling sites were grouped into seven categories according to the prevailing wind direction. The selected tree species was Populus Alba and heavy metals considered were antimony (Sb), arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), nickel (Ni), lead (Pb), copper (Cu), vanadium (V), and zinc (Zn). In a first stage, the metals concentrations were compared with literature data. Metals with higher concentrations were chromium (Cr) and lead (Pb). Metal concentrations of polluted zones were then compared, with control site. Sample points near the incinerator showed lower metals concentrations whereas, all samples taken in an urban area had higher concentrations, especially chromium (Cr) and lead (Pb). A final analysis revealed that the tree species chosen are not a good choice to evaluate bioaccumulation since its dynamic factors of biophilicity are low. However such trees proved suitable for phytoremediation.

Keywords: heavy metals, incinerator, air pollution, *Populus Alba*, dynamic factors.

Conference topic: Environmental protection.

Introduction

Aim of this study is to probe levels of heavy metals in soil and trees within an area possibly polluted by an incinerator. After a sampling campaign, the results were compared with data reported in literature, to understand the possible extent of pollution. Afterward, heavy metal concentrations were compared with data acquired within a possibly non-polluted area, to investigate whether the incinerator could be identified as the main source of heavy metal pollution. Finally, we applied dynamic of second factors to evaluate how the selected type of trees adsorbs the pollutants and if it could be a good alternative for phytoremediation.

Waste production is one of the major environmental problem in our growing community. In 2014, the total waste generated in the European Union, by all economic activities and households, amounted to 2.598.000.000 tonnes reaching the highest level recorded since 2004 (Eurostat 2016). This is an increasing problem that can only be avoided either decreasing the overall amount of waste or, at least, decreasing the amount of waste stockpiled into garbage dumps. In this study, we focus over one of the most controversial waste disposal methods: the incineration. Waste-incineration is a debated method since incinerators have the capability to handle a big variety of waste and produce heat and/or energy but their emissions affect air quality increasing concentrations of airborne pollutants such as heavy metals, carbon monoxide (CO), nitrogen oxides (NO_x), polychlorinated dibenzodioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) etc.

Air pollution phenomena are the result of three dynamics: "emissions", "transmission" and "intakes" (i.e. deposition, increase of concentration in air, etc.). Emissions are the processes through which toxic substance like sulfur oxides (SOx), nitrogen oxides (NOx), carbon monoxide (CO), volatile organic compounds (VOC), particulate matter (PM), heavy metals, etc. are introduced in the atmosphere. Transmissions include all the processes the pollutants undergo into atmosphere, i.e. transport, diffusion, and chemical fate. Finally, intakes' are the final effects upon environment. For instance, deposition represents the intake of pollutants at ground level. After deposition, pollutants usually drain into the ground and, once in the soil, can be uptaken by plants and accumulate in different parts of the plants. For this reason, trees can be seen as environmental indicators and understanding the concentration of pollutants, especially heavy metals, in soil and trees, might help understanding the level of pollution in the surroundings. In this paper we present re results of such an investigation performed in a rather polluted area.

The main emission source under investigation is a waste disposal consortium, operating in central Italy. We focused over its area of influence i.e. where possible transfer of pollutants and the related uptake might have occurred. The treatment plant extended over an area very close to a river. The specie of tree selected to study the metal transfer from soil to plants, is the from *Populus Alba* or Silver Poplar, a type of tree very common in this region.

Heavy metal concentrations were checked in soil and trees near the principal pollution source according to sampling strategies mainly based on the orography and the meteorological factors that influence the dispersion of pollutants (i.e. the winds). Once obtained, heavy metal concentrations in wood and soil samples were compared with concentrations related to samples acquired in an area potentially not affected by the main source of pollution. The last step was to evaluate possible transfer of contaminants, biophilicity and bioremediation processes applying the method of dynamic factors (Baltrėnaitė *et al.* 2012, 2016).

Methodology

Study site description

The incinerator under investigation was part of the waste disposal consortium of the Macerata Province located in a central Italy (43°14'21"N; 13°23'17"E). The entire plant covers an area of about 50,000 square meters among the river Chienti and the freeway "SS77" (Fig. 1). The surroundings are substantially flat and their average height above sea level is about 150m. The incinerator had been operating since 1997 and it had an effective incineration capability of 220t/day. The plant emissions were monitored continuously with regard to particulate matter (PM10), nitrogen oxides (NO_x), oxygen (O_2), carbon monoxide (CO), sulfur dioxide (SO_2), hydrochloric acid (HCl), water (H_2O), pressure, temperature, and flow. Table 1 shows hourly-weighed concentrations, averaged over single years. The emission measurements were carried out while the incinerator was working in normal operating conditions (2.5t/h) with standard conditions of air temperature, atmospheric pressure and at oxygen content of 11%. The incinerator exhaust gases were conveyed to a stack having a diameter of 1.30m (i.e. a surface of 1.32m^2) and an overall height of 40m (AIA 2010).

To identify the impact of the incinerator on the environment, seven sampling sites were selected and classified according to their distance from the incinerator and the prevailing wind directions (Krastinytė *et al.* 2013). To understand meteorological conditions of the area close to the consortium, Regional Environmental Protection Agency of Marche (ARPAM) had already performed a meteorological analysis over one year, namely 2007. Arpam found that the prevailing wind directions belonged to the West-South-West (WSW) quadrant so that East-North-East (ENE) is the main sector downwind to the incinerator. In fact, WSW wind directions are predominant, particularly in January (frequency of 14%), during the spring (with a recurrence of up to 20% in April), and the beginning of summer. The intensity of such prevailing wind is between 0.3 and 4m/s in 30% to 50% of observations (ARPAM 2007).

Sampling strategy

Based on the aforementioned wind study, the ARPAM Agency had made an investigation in the vicinity of the consortium, with the goal of verifying the deposition of pollutants on the terrains. 25 soil samples were collected at various depths between 0.10 and 0.40m. 24 samples were taken in the points selected as a function of the predominant wind direction (East-North-East downwind direction). One more sample was taken within a natural reserve, out of the zone downwind of predominant wind and 2.5 Km far from the incinerator ("BIANCO-01" in Fig. 1). For the tree sampling, seven points were selected from the same 25-soil-samplimg sites. First four downwind sites were selected (02-ENE, 07-NE, 05-NE and 06-ENE in figure 1) while two more sites (01-SO and 01-NO in figure 1), respectively located South-West and North-West of incinerator, were selected for their short distance from the incinerator (ARPAM 2011). Finally "BIANCO-01" was included as reference "clean" site.

The first sampling point (02-ENE) is located about 1 Km ENE from the plant. It is quite close to the incinerator, and straight downwind of predominant winds so it was selected as a "polluted scenario". Two more points were selected along the North-Est (NE) direction. The first point (05-NE) is located within a populated area about 2.4 Km far from incinerator and should have been the representative of an "urban scenario". The second point (06-ENE) is also about 2.4Km from emission source but very close to a motorway and was selected as the "traffic scenario". The last point (07-NE) is located about 3 Km from the emission point and should have been representative of a "remote scenario". Finally, the upwind zone of the plant, according to the prevailing wind directions, was taken into account. So, the last two sampling points were selected out of the main wind direction (01-SO and 01-NO) and they represented the "upwind scenario". Fig. 1 shows all the aforementioned sampling points.

The tree samples were collected at breast height (1.5 m), using a steel increment borer, with a diameter of 5 mm and a length of 30 cm. Before and after each sampling the tool was washed with acid liquid. The samples were immediately sealed in dry papers bags and they were stored for the subsequent analyses. Afterward, the samples were sanded to make the growth rings visible. Regarding the age of the samples, the range chosen for analysis was 10 years. In each sampling point, two trees were sampled (e.g. 07-NE-A and 07-NE-B) and, to take into account possible statistical effects, two samples per each tree were collected (e.g. 07-NE-A and 07-NE-A'). The selected trees were located at least 10 m away from each other and least 100 m from any road (Pundytė *et al.* 2011).

Table 1. Types and quantity of incinerator emissions (AIA 2010)

	U.M.	2008	2009	2010
PM10	mg/Nm^3	2.11	0.3	2.67
CO	mg/Nm^3	7.97	2.23	5.15
NOx	mg/Nm^3	310.7	203.29	165.49
SO2	mg/Nm^3	26.12	11.78	6.19
TOC	mg/Nm^3	4.33	1.43	2.09
HCl	mg/Nm^3	0.07	0.73	0.8
(Cd+Ti)	$\mu g/Nm^3$	2.48	4.05	1.73
(Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V)	$\mu g/Nm^3$	51.7	34.75	22.61
PAHs	ng/Nm^3	123.24	209.42	195.38
(PCDDs+PCDFs)	pg/Nm^3	31.95	34.64	58.00

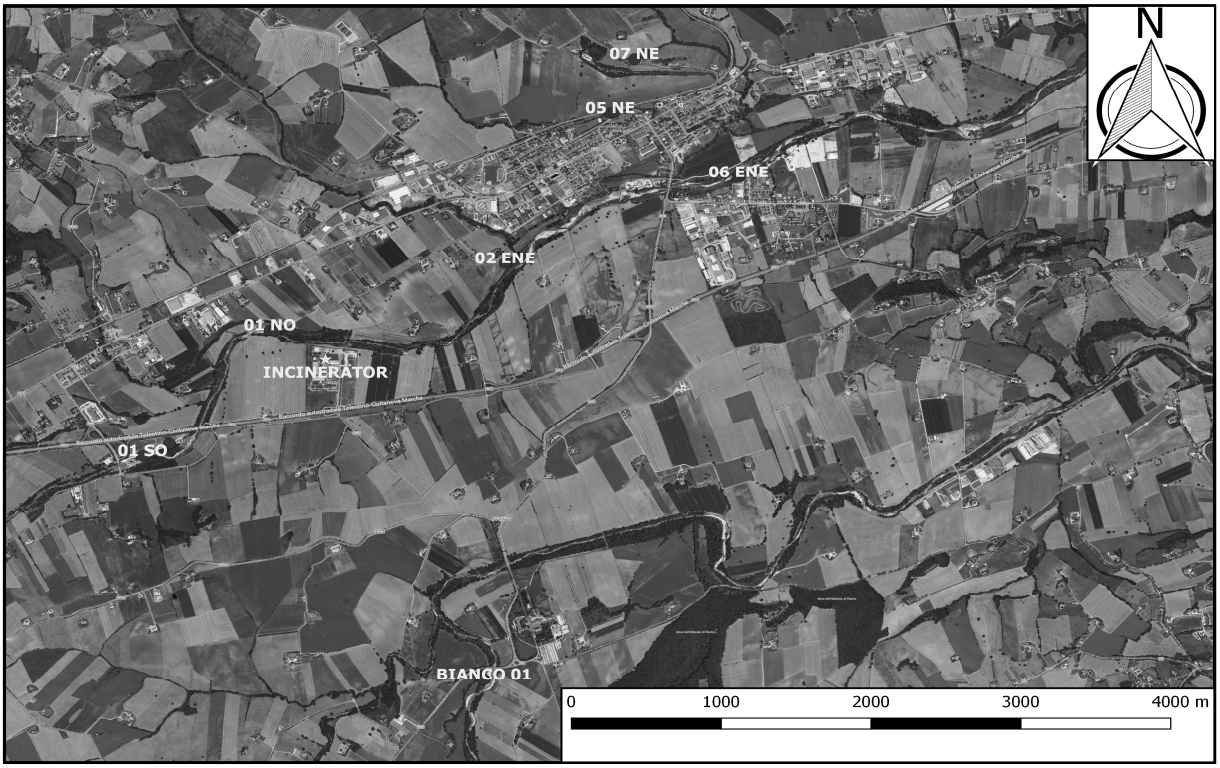

Fig. 1. Tree samples selected based on predominant wind direction (East-North-East) (Software: QuantumGIS)

Chemical analysis of samples

Individual tree samples were placed in small ceramic containers then, in a drier for about 1 hour. Then, they were weighed with an accuracy of ±0.0001g. At that point, the samples were incinerated, first on electric plate, then in a muffle at 400 °C for about 10 hours. Higher temperatures would have triggered the volatilization of some elements such as lead (Pb) and cadmium (Cd). Finally, the samples were treated with nitric acid (HNO_3), placed for 1 hour in microwave mineralizator, and brought to volume in a 50 ml flask with ultrapure water. The mineralization of samples followed the guidelines of EPA's "METHOD 3051A: microwave assisted acid digestion of sediments, sludges, soils and oils" (EPA, 2007). The concentrations of heavy metals were determined using an inductively coupled plasma-mass spectrometer (ICP-MS, Agilent 7500cx Series) by ARPAM agency. Spectrometry activities were performed according to guidelines of "UNI EN ISO 17294-2:2005 Water quality – Application of mass spectrometry, inductively coupled plasma (ICP-MS) – Part 2: Determination of 62 elements" (UNI EN ISO 17294-2 2005). The method used for

the mineralization of the soil samples was the same used for the wood samples: "METHOD 3051A". In addition, to determine the concentrations of metals, the above-mentioned inductively coupled plasma-mass spectrometry was employed. This time the guide methodology was taken from "APAT IRSA-CNR 29/2003: Metodi analitici per le acque" (APAT - IRSA/CNR 2003).

Results and Discussion

Tree samples

The mean values of the heavy metal concentrations were compared with the data reported in literature. A range of concentration values that could be considered "standard" was identified according to Andriano and Kabata-Pendias studies (Adriano 2001; Kabata-Pendias 2000). Concentrations measured for some metals resulted noteworthy. For instance chromium (Cr) and lead (Pb) had concentration values higher than the maximum level of the literature data in different sampling points.

Namely, for the sampling points indicated in subscripts, such values for chromium were

$$Cr_{06ENE} = 1.19\ mg/kg$$
$$Cr_{07NE} = 0.72\ mg/kg$$
$$Cr_{05NE} = 0.70\ mg/kg$$

being $Cr_{max} = 0.50\ mg/kg)$ the highest standard value in literature.

Particularly high lead concentrations were

$$Pb_{06ENE} = 1.49\ mg/kg$$
$$Pb_{07NE} = 1.03\ mg/kg$$
$$Pb_{01SO} = 0.67\ mg/kg$$
$$Pb_{01NO} = 0.63\ mg/kg$$
$$Pb_{05NE} = 0.55\ mg/kg$$

being $Pb_{max} = 0.50\ mg/kg)$ the highest standard value in literature.

The highest values belong to the "traffic scenario" 06-ENE (Fig. 2). The results are confirmed by literature, since elements such as lead (Pb) and chromium (Cr), are recognized as good indicators of anthropogenic pollution in populated areas (Wischow 1995). According to these theories, it is reasonable that such high values were influenced by the presence of the village and/or by the road traffic of freeway "SS77" that is close to the sampling point. Two other points show the same behaviour: the "distant scenario" (07-NE) and the "urban scenario" (05-ENE) are both close to an urban area and both presented lead values and chromium values above the maximum standard levels in literature. All these three points are close to an urban zone. The "distant scenario" sampling point (07-NE) is not very close to urban areas or the incinerator, but it is close to an important road and this could have influenced the concentrations of heavy metal in trees.

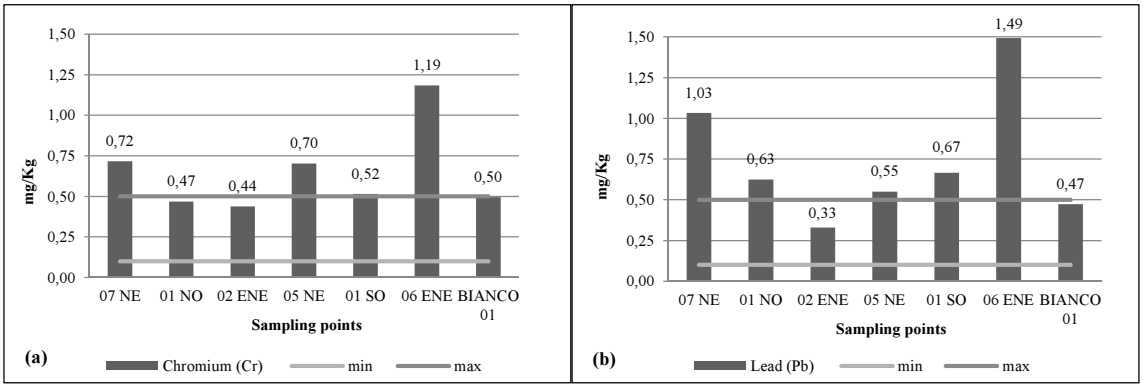

Fig. 2. (a) Average concentration on tree samples of chromium (Cr) for each sampling point.
(b) Average concentration on tree samples of lead (Pb) for each sampling point

To compare the heavy metal concentrations in trees at polluted sites with those at the control site (BIANCO-01), the mean of all the four samples taken at each sampling point (e.g. 07-NE-A, 07-NE-A', 07-NE-B, 07-NE-B') was evaluated and employed.

The first point analysed was the "polluted scenario" (02-ENE). The name was assigned a-priori based on the location of the site, but we found that we possibly made a wrong assessment. Concentrations of some elements such as chromium (Cr), nickel (Ni), and lead (Pb) were lower than the concentrations at the control point (Table 2). Namely such values were:

$$Cr_{02ENE} = 0.44\,mg/kg; Cr_{\mathrm{BIANCO01}} = 0.50\,mg/kg$$

$$\mathrm{Ni_{02ENE}} = 0.52\ \mathrm{mg/kg}; \mathrm{Ni_{BIANCO01}} = 0.67\ \mathrm{mg/kg}$$
$$\mathrm{Pb_{02ENE}} = 0.33\ \mathrm{mg/kg}; \mathrm{Pb_{BIANCO01}} = 0.47\ \mathrm{mg/kg})$$

The sampling point "urban scenario", located North-East from incinerator (05-NE), was the second to be analysed. The mean values of all elements were higher than the control point, except for antimony (Sb), arsenic (As), and vanadium (V) (Table 2). Namely such values were:

$$\mathrm{Sb_{05NE}} = 0.02\ \mathrm{mg/kg};\ \mathrm{Sb_{BIANCO01}} = 0.03\ \mathrm{mg/kg}$$
$$\mathrm{As_{05NE}} = 0.08\ \mathrm{mg/kg};\ \mathrm{As_{BIANCO01}} = 0.13\ \mathrm{mg/kg}$$
$$\mathrm{V_{05NE}} = 0.03\ \mathrm{mg/kg};\ \mathrm{V_{BIANCO01}} = 0.03\ \mathrm{mg/kg}$$

Then the "traffic scenario" point (06-ENE) was analysed. This point had all the heavy metal concentrations higher than those at control point ()

The last point, "upwind scenario" (01-NO), showed concentrations in agreement with the sampling strategy and with its nickname. Heavy metal concentrations were all lower than those at control point but for three elements: lead (Pb), copper (Cu), and zinc (Zn) (Table 2). Namely such values were:

$$\mathrm{Pb_{01NO}} = 0.63\ {}^{\mathrm{mg}}/_{\mathrm{kg}};\ \mathrm{Pb_{BIANCO01}} = 0.47\ {}^{\mathrm{mg}}/_{\mathrm{kg}}$$
$$\mathrm{Cu_{01NO}} = 3.97\ {}^{\mathrm{mg}}/_{\mathrm{kg}};\ \mathrm{Cu_{BIANCO01}} = 2.30\ {}^{\mathrm{mg}}/_{\mathrm{kg}}$$
$$Zn_{\mathrm{01NO}} = 12.8\ {}^{mg}/_{kg};\ Zn_{\mathrm{BIANCO01}} = 8.1\ {}^{mg}/_{kg})).$$

This does not come as a surprise since more than a half of the heavy metal airborne emissions derive from car engines' combustion. For instance, although we now use Unleaded Fuels only (i.e. gasoline without lead-based additives), still lead is present, as an impurity, in the gasoline due to the lead content of crude oil (Pacynaa *et al.* 2007).

The last point in North-East direction was the "distance scenario" (07-NE). Here the heavy metal concentrations were higher than expected. Being a point 3Km far from the incinerator, the outlook was to find rather low heavy metals concentrations. Actually, they were still influenced by local emissions, probably by the incinerator or the surrounding environment, since all concentrations were higher than those monitored at the control point. Only antimony (Sb), arsenic (As), and Vanadium (V) showed an opposite trend (Table 2). Namely such values were:

$$\mathrm{Sb_{07NE}} = 0.01\ \mathrm{mg/kg};\ \mathrm{Sb_{BIANCO01}} = 0.03\ \mathrm{mg/kg}$$
$$\mathrm{As_{07NE}} = 0.07\ \mathrm{mg/kg};\ \mathrm{As_{BIANCO01}} = 0.13\ \mathrm{mg/kg}$$
$$\mathrm{V_{05NE}} = 0.02\ \mathrm{mg/kg};\ \mathrm{V_{BIANCO01}} = 0.03\ \mathrm{mg/kg}$$

The last sampling two points were chosen as control points being upwind to the incinerator (01-SO, 01-NO). The first point (01-SO) was close to the incinerator as well as to the highway (SS77). In fact, the heavy metal concentrations resulted higher than the concentrations at less polluted sites and comparable with those recorded at "urban scenario" and "traffic scenario" (Table 2). Some notable values were:

$$\mathrm{Cr_{01SO}} = 0.52\ \mathrm{mg/kg};\ \mathrm{Cr_{BIANCO01}} = 0.50\ \mathrm{mg/kg}$$
$$\mathrm{Ni_{01SO}} = 0.82\ \mathrm{mg/kg};\ \mathrm{Ni_{BIANCO01}} = 0.67\ \mathrm{mg/kg}$$
$$\mathrm{Pb_{01SO}} = 0.67\ \mathrm{mg/kg};\ \mathrm{Pb_{BIANCO01}} = 0.47\ \mathrm{mg/kg}$$
$$\mathrm{Cu_{01SO}} = 3.47\ \mathrm{mg/kg};\ \mathrm{Cu_{BIANCO01}} = 2.30\ \mathrm{mg/kg}$$
$$\mathrm{Zn_{01SO}} = 14.0\ \mathrm{mg/kg};\ \mathrm{Zn_{BIANCO01}} = 8.1\ \mathrm{mg/kg})$$

The last point, "upwind scenario" (01-NO), showed concentrations in agreement with the sampling strategy and with its nickname. Heavy metal concentrations were all lower than those at control point but for three elements: lead (Pb), copper (Cu), and zinc (Zn) (Table 2). Namely such values were:

$$\mathrm{Pb_{01NO}} = 0.63\ \mathrm{mg/kg};\ \mathrm{Pb_{BIANCO01}} = 0.47\ \mathrm{mg/kg}$$
$$\mathrm{Cu_{01NO}} = 3.97\ \mathrm{mg/kg};\ \mathrm{Cu_{BIANCO01}} = 2.30\ \mathrm{mg/kg}$$
$$Zn_{\mathrm{01NO}} = 12.8\ mg/kg;\ Zn_{\mathrm{BIANCO01}} = 8.1\ mg/kg)$$

Soil samples

The values of the heavy metals concentrations in the soil samples were all in the range of values suggested by literature (Kabata-Pendias 2000; Adriano 2001). Some heavy metals had values closer to the upper limit than others. These elements were arsenic (As), cadmium (Cd), cobalt (Co), nickel (Ni), and, remarkably, copper (Cu). Actually, for the last one the values recorded at four sampling points (01-NO, 01-SO, 02-ENE, and BIANCO-01) resulted higher than the average value in literature. Surprisingly, the highest value was recorded at the control point "BIANCO 01" (Fig. 3):

$$Cu_{\mathrm{max}\,literature}40.0\ mg/kg$$
$$Cu_{BIANCO01}35.0\ mg/kg$$
$$Cu_{02ENE}26.0\ mg/kg$$
$$Cu_{01NO}25.5\ mg/kg$$
$$Cu_{01SO}25.5\ mg/kg$$
$$Cu_{06ENE}16.0\ mg/kg$$
$$Cu_{05NE}15.0\ mg/kg$$
$$Cu_{07NE}14.0\ mg/kg$$

This may be due to the fact that the control site belongs to a farmed area and copper is contained within fertilizers, fungicides, etc. More in general, all the soil sampling points but one showed a common behaviour: all the heavy metal concentrations resulted lower than those recorded at control site 'BIANCO01'. In fact, only soil samples at "polluted scenario" (02 ENE) showed higher values (Table 3):

$$As_{02ENE} = 6.5\,mg/kg;\ As_{BIANCO01} = 5.1\,mg/kg$$
$$Cd_{02ENE} = 0.4\,mg/kg;\ Cd_{BIANCO01} = 0.4\,mg/kg$$
$$Co_{02ENE} = 6.3\,mg/kg;\ Co_{BIANCO01} = 4.9\,mg/kg$$
$$Cr_{02ENE} = 19.0\,mg/kg;\ Cr_{BIANCO01} = 18.0\,mg/kg$$
$$Ni_{02ENE} = 32.0\ mg/kg; Ni_{BIANCO01} = 24.0\,mg/kg$$
$$Pb_{02ENE=}9.8\,mg/kg\ ;\ Pb_{BIANCO01} = 9.0\,mg/Kg$$
$$V_{02ENE} = 18.0\,mg/kg;\ V_{BIANCO01} = 35.0\,mg/kg$$
$$Zn_{02ENE} = 53\,mg/kg\ ; Zn_{BIANCO01} = 39\,mg/kg)$$

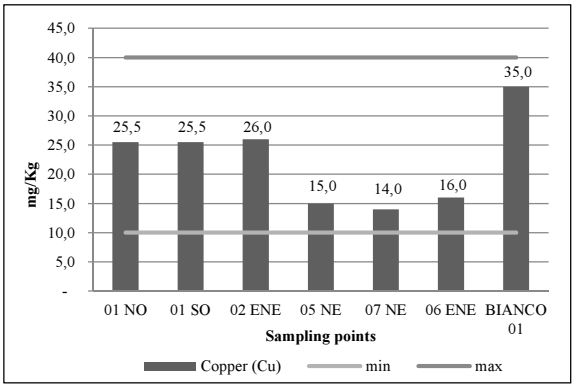

Fig. 3. Average concentration on soil samples of copper (Cu) for each sampling site

Table 2. Heavy metals average concentrations in tree samples for each sampling site (mg/kg d.w.)

	Sb	As	Cd	Co	Cr	Ni	Pb	Cu	V	Zn
07 NE	0.01	0.07	0.14	0.17	0.72	0.84	1.03	4.28	0.02	11.34
01 NO	0.01	0.05	0.05	0.09	0.47	0.48	0.63	3.97	0.02	12.86
02 ENE	0.01	0.05	0.04	0.11	0.44	0.52	0.33	3.71	0.01	13.00
05 NE	0.02	0.08	0.06	0.16	0.70	0.95	0.55	4.27	0.03	15.25
01 SO	0.02	0.06	0.05	0.09	0.52	0.82	0.67	3.47	0.03	14.02
06 ENE	0.10	0.19	0.07	0.12	1.19	1.46	1.49	3.06	0.06	10.23
BIANCO 01	**0.03**	**0.13**	**0.05**	**0.10**	**0.50**	**0.67**	**0.47**	**2.30**	**0.03**	**8.11**

Table 3. Heavy metals average concentration in soil samples for each sampling site (mg/kg). The antimony (Sb) values are not reported since they resulted below the detection level ($0.01 mg/kg$) in all sampling points

	As	Cd	Co	Cr	Ni	Pb	Cu	V	Zn
01 NO	4.1	0.3	3.3	9.9	16.5	4.9	25.5	8.9	29.0
01 SO	4.1	0.3	3.3	9.9	16.5	4.9	25.5	8.9	29.0
02 ENE	6.5	0.4	6.3	19.0	32.0	9.8	26.0	18.0	53.0
05 NE	2.4	0.3	2.9	7.1	18.0	3.7	15.0	7.4	20.0
07 NE	4.7	0.2	3.0	9.3	17.0	3.6	14.0	8.9	26.0
06 ENE	5.0	0.3	4.3	12.0	22.0	6.3	16.0	9.3	28.0
BIANCO 01	**5.1**	**0.4**	**4.9**	**18.0**	**24.0**	**9.0**	**35.0**	**15.0**	**39.0**

Second-level factors

All the vegetable samples were taken from *Populus Alba* trees, commonly called Silver Poplar. Silver Poplar is a medium-sized deciduous tree, growing to heights up to 16–27 m. Silver Poplar trunk may reach a diameter up to 2m and its leaves are five-lobed and 4 to 15 cm wide (Rushforth 1999). Previous studies showed that present experiments carried out on coniferous trees led to more accurate results than studies on deciduous trees (Yua *et al.* 2007). However, we considered the Silver Poplar for the present study since it is the most common specie in the river's riparian zone and some authors, notwithstanding the most part of researcher, argue that fast-growing tree species, while producing high biomass volumes, can be a good "accumulator" of elements (Unterbrunner *et al.* 2007).

Transfer of metals from soil to plants is not simple to analyse and model. In order to understand the whole process, first the physiological proprieties of plants and soils (e.g. type of soil, tree species, etc.) should be understood. Then, the environment where they are situated shall be analysed. A common mistake is to consider the soil and the trees as two different media whereas the transfer of heavy metals, from soil to plants, should be seen as happening within the same medium. To better describe the transfer-process, the second-level factors were evaluated by the method of dynamic factors. They take into account both the interactions between plants and soil and the other processes triggered by the contiguous environment. The second-level factors are essential to describe four types of activities deriving from the soil-plants transfer of metals: bioaccumulation, translocation, biophilicity and phytoremediation (Baltrėnaitė *et al.* 2012, 2016).

The dynamic factor of metal bioaccumulation (BA_{dyn}) reflects the physiological sensitivity of plants to soil contamination. It was calculated according to the following equation:

$$BA_{dyn} = \frac{C_{i,tree,treated}}{C_{i,soil,treated}} \times \frac{C_{i,soil,control}}{C_{i,tree,control}} \quad (1)$$

where $C_{i,tree,treated}$ is the concentration of *ith*-metal in trees of a polluted site $[mg/kg]$, $C_{i,soil,treated}$ is the concentration of *ith*-metal in the soil of the polluted site $[mg/kg]$, $C_{i,tree,control}$ is the concentration of *ith*-metal in trees of a control site $[mg/kg]$, and $C_{i,soil,control}$ is the concentration of *ith*-metal in the soil of the control site $[mg/kg]$, Bioaccumulation values lower than 1 ($BA_{dyn} \leq 1$) show that tree metal concentrations at polluted site, are not higher than the control site ($C_{i,tree,treated} \leq C_{i,tree,control}$) and, then, the capacity of trees to retain the substances are low. In the present study, the values of metal bioaccumulation were below one only for zinc (Zn) and arsenic (As) and for the sites '01-NO', '01-SO', and '07-NE' (Fig. 4). At the sampling point 02-ENE the values of BA_{dyn} are below one for all the metals (Fig. 4). Apart from the aforementioned cases, all the metals exhibited relatively low values for bioaccumulation factor, the maximum value being 6.11 for cadmium (Cd) at the 07-NE sampling site. This might confirm that the tree species selected for this study (*Populus Alba*) does not retain trace elements such as conifers (e.g. *Pinus Sylvestris L*) (Baltrėnaitė *et al.* 2012).

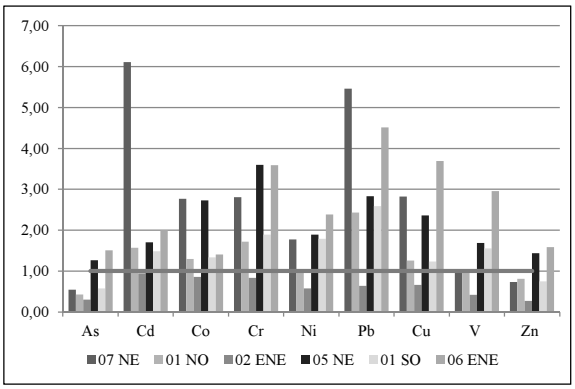

Fig. 4. Dynamic factor of metal bioaccumulation (BA_{dyn}). The antimony values are all null

The dynamic factor of phytoremediation (FR_{dyn}) quantifies the phytoremediation capability of plants. It is calculated using the follow equations:

$$FR_{dyn} = \frac{FR_{i,treated}}{FR_{i,control}} \quad (2)$$

$$FR_i = \frac{C_{i,tree} \times B}{1{,}000 \times C_{i,soil} \times \rho \times d} \quad (3)$$

where $FR_{i,treated}$ is the annual phytoremediation effectiveness factors of trees at a polluted site, $FR_{i,control}$ is the annual phytoremediation effectiveness factor of trees at a control site, FR_i is the annual *ith*-metal phytoremediation factor $[kg/ha]$, $C_{i,tree}$ is the *ith*-metal concentration in trees $[mg/kg]$, B is the annual tree increment $[kg/ha]$; $C_{i,soil}$ is the *ith*-metal concentration in the upper soil layer $[mg/kg]$, ρ is the soil density $[g/cm^3]$; d is the depth of soil layer $[cm]$. The upper soil layer is normally 40cm deep.

Fig. 5 shows $\mathrm{FR_{dyn}}$ of Populus Alba (i.e. their capability to accumulate metals in their biomass in the course of the time) evaluated by means of the recorded values. $\mathrm{FR_{dyn}} \leq 1$ show that the dynamic factors of phytoremediation on the polluted site are not higher than on the control site ($\mathrm{FR_{i,control}} \leq \mathrm{FR_{i,treated}}$). The chart also shows that most of the heavy metal $\mathrm{FR_{dyn}}$ factors are higher than one. Only for some elements they result lower in some sites (e.g. As in 07-NE, Ni Va Zn in 01-NO, all metals in 02-ENE, and Zn in 01-SO). Such values of the dynamic factor demonstrate that the Populus alba could be convenient for phytoremediation since its biomass accumulated about 1 to 9 times more chemicals (e.g. cadmium, lead, copper, chromium and vanadium), from the polluted soil than from control soil (Baltrėnaitė *et al.* 2012).

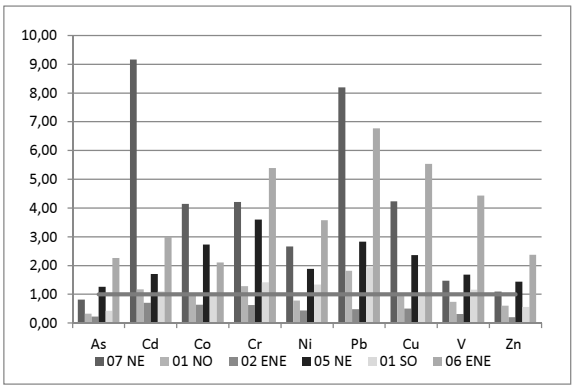

Fig. 5. Dynamic factors of phytoremediation (FR_{dyn}). The antimony values are all null

Conclusions

The main goal of the study was to validate the use of wood samples as indicators of heavy metals' pollution in an area affected by high-level airborne emissions due to human activities. The whole study focused on the possible impact of airborne pollutant emissions due to a waste incinerator, and the resulting uptake of heavy metals into *Populus Alba* trees, evaluated through the method of dynamic factors.

To analyse the results of the sampling stage, first concentration data was checked considering each heavy metal observation at each sampling point. The second step was to check the representativeness of sampling points according to their distance from the incinerator and their upwind/downwind position. Finally, the dynamic factors of *Populus Alba* trees were calculated according to the experimental results.

In the first analysis, heavy metal concentrations were compared with average data reported in literature. We found that chromium and lead concentrations were particularly higher than normal values reported in literature, the highest values belonging to a sampling point located in urban areas about 3km far from the incinerator. On the other hand, concentrations of heavy metals in the soil samples maintained readings in the range of values reported in the literature.

A first comprehensive analysis of results shows that the airborne pollutant emissions due to human activities in the exanimated area influenced heavy-metal pollution levels more than the incinerator emissions. Between all, the points near to the incinerator and those located statistically upwind had lower heavy metal concentrations then the samples taken in urban contexts and/or in the vicinity of major roads.

The final step of study was to evaluate, by applying the method of dynamic factors, if the species selected for the investigation could be a suitable choice to apply the methodology. The metal bioaccumulation factor revealed that the Poplar species is not suitable to model bioaccumulation. On the other hand, the phytoremediation factor showed that the same species could be conveniently employed for phytoremediation.

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