CHARACTERIZATION OF HEAVY METALS ATMOSPHERIC DEPOSITION FOR ASSESSMENT OF URBAN ENVIRONMENTAL QUALITY IN THE BOLOGNA CITY (ITALY)

CARACTERISATION DES DEPOTS DE METAUX LOURDS ATMOSPHERIQUES POUR L'EVALUATION DE LA QUALITE DE L'ENVIRONNEMENT URBAIN DANS LA VILLE DE BOLOGNE (ITALIE)

CARATTERIZZAZIONE DELLA DEPOSIZIONE ATMOSFERICA DI METALLI PESANTI PER LA VALUTAZIONE DELLA QUALITÀ AMBIENTALE URBANA NELLA CITTÀ DI BOLOGNA (ITALIA)

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Abstract

The suburban area of Bologna city in southeast portion of Po Valley (Northern Italy) is characterized by high emission from industrial, urban, agriculture and traffic sources. The presence of an urban waste incinerator get inhabitants to require answers about impact of its emissions on the environmental quality related to human health. The concentrations of some pollutants (Ba, Cd, Co, Cr, Cu, Ni, Pb, V and Zn) were determined in topsoil, plants and mosses tissues sampled in sites selected according to different falling out conditions, due to the incinerator and other sources of atmospheric emissions that affect the monitoring area. No correlation was found between metal content and the distance of the incinerator plant. The pollution load index (PLI) calculated for soil and moss indicated a low environmental pollution, while highest values in sites downwind of incinerator and in craft area indicate a moderate pollution.
Key words: *air quality, leaf-washing water, moss, soil, pollution load index, incinerator plant, enrichment factor*

Résumé

La banlieue de ville de Bologne dans la partie sud-est de la vallée du Pô (Italie du Nord) est caractérisé par l'émission de haute industrielle, urbaine, agricole et des sources de trafic. La présence d'un incinérateur de déchets urbains obtenir habitants d'exiger des réponses quant à l'impact de ses émissions sur la qualité de l'environnement liés à la santé humaine. Les concentrations de certains polluants (Ba, Cd, Co, Cr, Cu, Ni, Pb, V et Zn) ont été déterminées dans la couche arable, les plantes et les tissus mousses échantillonnées dans des sites sélectionnés en fonction de différentes conditions qui tombent, en raison de l'incinérateur et d'autres sources d'émissions atmosphériques qui affectent la zone de surveillance. Aucune

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corrélation n'a été trouvée entre la teneur en métal et la distance de l'usine d'incinération. L'indice de charge de la pollution (PLI), calculé pour le sol et la mousse ont indiqué une faible pollution de l'environnement, tandis que plus des valeurs dans les sites sous le vent de l'incinérateur et dans la zone artisanale indiquent une pollution modérée.
Mots clés: *qualité de l'air, la feuille-lavage à l'eau, la mousse, le sol, l'indice de charge de pollution, usine d'incinération, facteur d'enrichissement*

Riassunto

L'area suburbana di Bologna città, in parte sud-est della Pianura Padana (Italia settentrionale) è caratterizzata da alta emissione da industriale, urbano, l'agricoltura e fonti di traffico. La presenza di un inceneritore di rifiuti urbani per ottenere abitanti richiedono risposte circa l'impatto delle emissioni sulla qualità ambientale connesso alla salute umana. Le concentrazioni di alcuni inquinanti (Ba, Cd, Co, Cr, Cu, Ni, Pb, V e Zn) sono stati determinati in topsoil, piante e tessuti muschi campione in siti selezionati in base a diverse condizioni che cadono, per l'inceneritore e altri fonti di emissioni in atmosfera che interessano l'area di monitoraggio. Nessuna correlazione tra il contenuto di metallo e la distanza del dell'inceneritore. L'indice di carico inquinante (PLI), calcolato per il suolo e muschio hanno indicato un basso inquinamento ambientale, mentre i valori più alti nei siti sottovento di un inceneritore e nella zona artigianale indicano un inquinamento moderato.
Parole chiave: *qualità dell'aria, muschio, suolo, carico indice di inquinamento, impianto di incenerimento, fattore di arricchimento*

Introduction

The evaluation of atmospheric depositions and emission traceability from scattered and point sources in the region (e.g. city, craft, industry, agriculture) are the main objectives of scientific studies to assess environmental quality and human health risks. High population density in the presence of pollution sources (e.g. very busy roads, industrial poles and solid municipal waste incinerators) increase the risk for human health. The size and chemical characterization of pollutant emissions into the atmosphere (Cazier et al., 2011; Khan et al., 2010) and their effect on soil, plants and bryophytes has been the subject of several studies (Vianna et al., 2011; Nriagu and Pacyna, 1988). The degree of environmental contamination by heavy metals is widely studied, and the pollution risk can be determined by measuring their concentrations in soil and plants. The soil surface usually has higher heavy metal concentrations than the subsoil and the enrichment can be mainly due to airborne deposition deriving from human activities such as agricultural practices and emissions by urban areas (Alloway, 1999; Azimi et al., 2003; 2005; Gray et al., 2003; Madrid et al., 2002; Mantovi et al., 2003; Nicholson et al., 2003; Rodiguez et al., 2008; Valerio et al., 1995), by solid municipal waste incinerators (Capuano et al., 2005; Hutton et al., 1998; Llobet et al., 2002; Meneses et al., 1999; Rimmer et al., 2006; Schuhmacher et al., 1997) and by industry (Adamo et al., 2002; Jan et al., 2010).

Many species of higher plants and bryophytes (e.g. moss and lichens) have been investigated as possible environmental indicators of pollution in relation to the characteristics of atmospheric deposition (Berg et al., 1995; Berg and Steinnes, 1997; Berthelsen et al., 1995; De Temmerman and Hoenig, 2004; Faus-Kessler et al., 1999; 2000; Fernández et al., 2002; Fernández Espinosa and Rossini Oliva, 2006; Figueira et al., 2002; Gerdol et al., 2000; Giordano et al., 2009; Nadal et al., 2004; 2005; Reiman et al., 2001; Rossini Oliva and Mingorance, 2004). Pollutant concentrations, enrichment ratios, and contamination index are used to describe the environmental quality state and pollution severity of the area (Dong et al., 2010; Fujiwara et al., 2011; Li et al., 2009; Reiman and de Caritat, 2000).

The study area is close to the city of Bologna, situated in the centre of the Emilia-Romagna region in the southeast portion of the Po Valley, in Northern Italy. The Po Valley is characterised by high emissions from industrial, urban, agriculture and traffic sources and represents one of the European regions with the worst air pollution. Furthermore, the topography, geographic location and prevailing synoptic circulation of the area favor frequent low wind speeds, fog and inversion layers that occur consistently during winter seasons. Therefore, weather-climatic factors play a large role in determining the critical conditions that lead to the high pollution situation in the area. In particular, in the studied area, located in a rural zone about 7 km northeast of Bologna, the presence of an urban waste incinerator has led inhabitants to require answers about the impact of plant emissions on the environmental quality of the surrounding area. The aims of this study were 1) to assess heavy metal deposition in the immediate surroundings of the incinerator plant in terms of concentrations (mg kg^{-1}) and enrichment factor (EF) in top-soil, higher plants and mosses; 2) to analyze the pollution degree of the study area in different sites using the contamination factor (CF) and Pollution load index (PLI) in topsoil and moss. This study of integrated (air, soil, plant and moss) monitoring was commissioned by the Governance of Bologna Province involving the University of Bologna and the Regional Agency for Prevention and Environment (ARPA) which are expert authorities for environmental protection and control. In particular, ARPA was responsible for monitoring air quality.

Materials and methods

Study area, monitoring survey and sampling.

The width of the studied area was defined trying to include, in the neighborhood of the incinerator, the most relevant sources of atmospheric emissions, i.e. industrial areas, highways, main roads and urban areas surrounded by agricultural land. The sites, defined in Figure 1 by capital letters, are selected from gardens of ancient house. In particular sites A, C, D, L, M and N are in the fallout area of incinerator emissions, sites B, and F are exposed to roads, while site E is within an craft area. The sites G, H and I are rural sites. The monitoring survey was started in springtime 2005. The samples (soil, moss and plants) were collected at the

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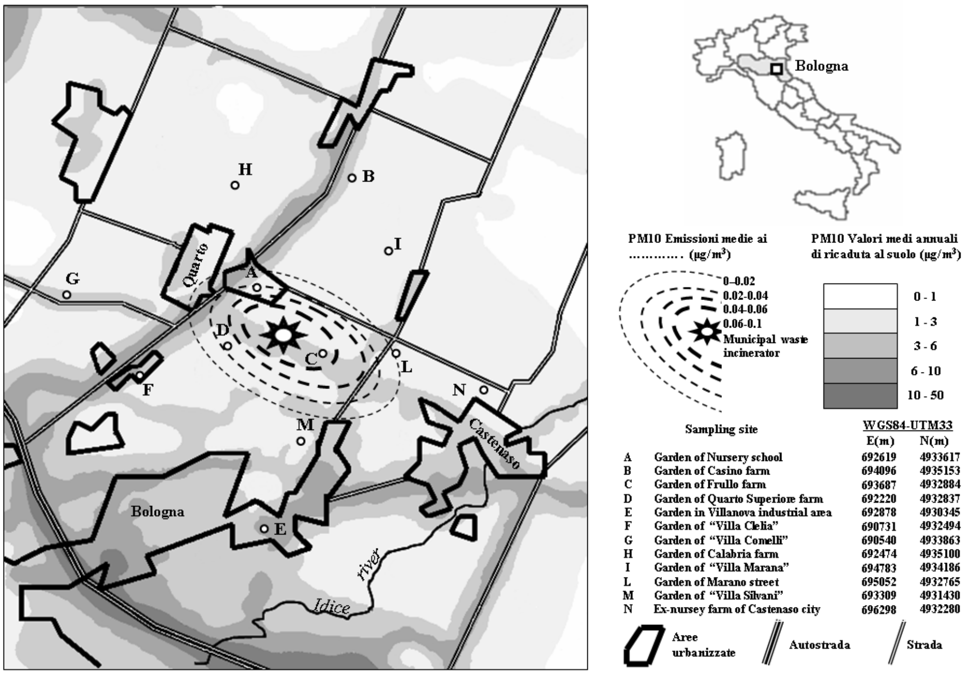
beginning and after 1 year, while the leaves of higher plants were also sampled in summer (July) and autumn (September) time.
Top soil was sampled at 3 cm depth and collected in polyethylene bags, while to determine the background of heavy metal concentrations, soil composting samples were collected at 0.8-1.00 m depth. The soil samples were dried and sieved through a 2mm mesh size, then reduced to powder in an agate mortar.
Leaves of evergreen and broad-leaf trees, herbage after cutting at 4 cm from the soil and moss were dried in a forced air oven (T<40°C) and homogenised (in a blender with blades made of pure titanium, carefully checked to not introduce any further metal contamination to samples). Unwashed plant samples were used.

Figure 1 - *The monitoring sites are showed. In particular the sites were gardens as following: A-Nursery school, B-Casino farm, C-Frullo farm, D-Quarto Inferiore farm, E-Villanova craft area, F-Villa Clelia, G-Villa Comelli, H-Calabria Farm, I-Villa Marano, L-Marano Street, M-Villa Silvani, N-ex nursery farm of Castenaso town. The sites A,C, D, L, M, N are in the fallout area of incinerator plant, sites B and F are exposed to roads, while the sites G, H, I are in rural areas.*



Analytical procedures

Soil and plants (tree leaves, mosses and herbage) tissues. Approximately 0.25g of dried samples of soil were treated with aqua regia (6 mL HCl Plus 2 mL HNO_3 37 and 65 % Suprapur, Carlo Erba). Approximately a 0.4 g sub-sample of plant tissues was dissolved in 8 mL of concentrated suprapure nitric acid plus 2 mL of Hydrogen Peroxide (Carlo Erba for electronic use).
Both mineralization were carried out in Teflon bombs in a microwave oven (Milestone, 2100). After cooling, solutions were made up to 20 mL with milli-Q water and then filtered with Whatmann 42. The accuracy of the instrumental method and analytical procedures used was checked by triplication of the samples, as well as by using reference material, which was run after every 10 samples to check for drift in the sensitivity. The analytical quality of the results was checked against the following reference materials, which certify values of the studied elements close to the measured ones: CRM 060 (aquatic plants), CRM 062 (Olive leaves) provided by the European Commission Institute for Reference Materials and Measurements. Replicated measures of International Reference Materials (BCR 141) and laboratory internal standards (MO and ML), reagent blanks and three soil sample repetitions were used to assess contamination and precision.
The solution as analyzed by Inductive Coupled Plasma Optical Emission Spectrometry (ICP-OES) (Spectro Ametek, Arcos) and the data discussed in this paper were Ba, Cd, Co, Cr, Cu, Pb, V and Zn.

Index of environment pollution. The enrichment factor (EF) was calculated in moss and soil by assuming the geogenic origin of aluminum. Therefore EF was calculated as the ratio of the concentration of M_X in the moss and topsoil compared to the concentration of the M_X in the topsoil (for moss) and soil local background (for soil) as the ratio to the corresponding Al concentrations (Sutherland and Tolosa, 2000) as reported in equation 1.

$$EF= [M]/[Al]/ [M]/[Al]. \qquad [1]$$

Five contamination categories for the topsoil are recognized (Sutherland, 2000) where: <2 = minimal enrichment, 2 to 5 = moderate, 5 to 20 = significant, 20 to 40 = very high and >40 = extremely high enrichment.
The magnitude of contamination of each element in moss and soil was evaluated by the use of a Contamination Factor (CF) calculated as:
$CF= C_x/C_0$
Where C_x is the metal concentration in topsoil or moss tissues and C_0 is the metal concentration in an unpolluted station (blank site) for the moss (Fernández et al., 2000) and the metal concentration in deeper horizons for soil.
The pollution load index for soil (Angulo, 1996; Galan et al., 2008) and bryophyte (Boamponsem et al., 2010) is calculated obtaining the n-root from the n-concentration. This index is quickly understood by unskilled personnel in order to compare the pollution status of different places.

$$PLI_{sampling\ site} = (CF_{Ba} \times CF_{Cd} \times CF_{Co} \times CF_{Cr} \times CF_{Cu} \times CF_{Ni} \times CF_{Pb} \times CF_{V} \times CF_{Zn})^{1/9}$$

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PLI values of less than 0 indicate an unpolluted area and values greater than 0 show a progressive deterioration of the environment.

Data analysis. The experimental data were treated statistically using a software package (e.g. Excel, Statgraphic plus 5.0, Systat 12.0). The one-way analysis of variance (ANOVA) test is a general technique that can be used to test the hypothesis that the means among two or more groups are equal. Tukey's test ($p<0.05$) was used.

Results and discussion

Soil moss, herbage and higher plant elemental concentration

The mean metals concentrations and ANOVA test of some metals (Ba, Cd, Co, Cr, Cu, Ni, Pb, V e Zn) in the topsoil of the twelve monitoring sites is shown in Table 1

Table 1 - *Mean metal concentrations (mg kg^{-1}) and ANOVA test in topsoil of selected monitoring sites (n=6). Values followed by a different lowercase letter within columns (metal concentration) indicate significant differences (using Tukey's test) at α=<0.05, while means having the same letter(s) in the same column are not significant difference between the different sites. The highest values are reported in italic fonts.*

Sites	**Ba**		**Cd**		**Co**		**Cr**		**Cu**	
	mg/kg	Anova	mg/kg	Anova	mg/kg	Anova	mg/kg	Anova	mg/kg	Anova
		***		ns		***		***		***
A	259	abc	0.3	a	15.5	de	71.4	de	41.1	b
B	269	abcd	0.2	a	13.4	bc	72.5	de	58.9	de
C	263	abcd	0.3	a	14.3	cd	68.5	de	60.1	de
D	198	ab	0.2	a	8.2	a	51.1	b	32.6	ab
E	655	d	0.2	a	8.7	a	60.2	c	*71.1*	*f*
F	*381*	*c*	0.3	a	12.8	bc	66.3	cd	138	g
G	199	a	0.1	a	8.1	a	43.1	a	30.1	ab
H	317	bcd	0.2	a	*16.7*	*e*	75.1	c	63.7	ef
I	289	abcd	0.3	a	11.7	b	*99.1*	*f*	51.9	d
L	343	cd	0.2	a	11.6	b	67.3	cde	171	b
M	269	abcd	0.2	a	11.5	b	64.8	cd	42.3	bc
N	252	abc	0.2	a	12.7	bc	67.6	cde	40.3	b

Sites	**Ni**		**Pb**		**V**		**Zn**	
	mg/kg	Anova	mg/kg	Anova	mg/kg	Anova	mg/kg	Anova
A		***		***		***		***
B	*57.5*	*g*	21.3	ab	59.2	de	98.7	ab
C	53.5	efg	22.2	ab	63.5	e	113.2	abc
D	47.8	cd	30.7	bc	49.5	bc	122.6	abc
E	36.5	b	43.6	cd	47.1	bc	100.7	ab
F	42.4	cd	*243.9*	*f*	35.3	a	*247.8*	*d*
G	46.7	cd	84.7	e	*79.5*	*f*	145.3	c
H	29.3	a	80.8	e	32.9	a	92.2	a
I	56.2	fg	42.5	cd	65.1	e	124.2	abc
L	51.6	def	72.6	e	64.9	e	136.2	bc
M	49.1	de	74.1	e	50.1	bc	*215.4*	*d*
N	49.8	de	54.6	d	52.3	bc	109.8	abc

*** = significance at $p<0.001$

ns = not significant

The amount of cadmium in topsoil of different sites did not differe statistically, while in craft area (site E) highest concentrations of Ba, Pb and Zn were found, followed by site F for Cu and V elements . The highest values of Co and Cr in sites H and I, exposed to many pollution sources, were found. The concentrations of metals in the topsoil were comparable to those found in other European countries, even for the highest values, under the control of waste incinerator plants (Goodman and Roberts, 1971; Vogg et al., 1986; Schuhmacher et al., 1996; 1997; Mesenes et al., 1999), except for Cd which had lower values (Abbott et al., 1997; Collett et al., 1998; Meneses et al, 1999; Llobet et al., 2002; Morselli et al., 2002). The metal concentrations in the topsoil of some sites exceeded the threshold concentrations, and sites L and E were polluted for Cu and Zn and Pb and Zn, respectively, according to Italian Law (Decreto legislativo 152/2006), although no positive correlation between the metal concentrations in the topsoil and the distance of the incinerator plant was found (Hutton et al., 1988; Abbott et al., 1997; Collett et al., 1998). The statistical overview and ANOVA test (Tukey test, $p<0.05$) of metal concentrations determined in the plant species is given in Table 2.

Table 2 - *Statistical summary (mean, standard deviation, maximum and minimum value) and ANOVA test of trace elements in higher plant (broad-leaf and evergreen), moss and herbage tissues. Values followed by a different lowercase letter within columns (metal concentrations) indicate significant differences (using Tukey's test) at $\alpha=<0.05$, while means having the same letter(s) in the same column indicate no significant difference at 5%.Different letters within column (metal concentration) indicate significant differences between the different plant species.*

	Ba	Cd	Co	Cr	Cu	Ni	Pb	V	Zn	
Broad-leaf										(n=24)
Mean	13.6a	0.0a	0.3a	2.9a	12.9a	3.5a	4.9a	1.3a	36.0a	
SD	12.9	0.0	0.1	1.4	5.5	2.4	3.7	0.8	7.9	
Max	52.0	0.1	0.5	4.9	22.0	8.4	12.9	2.6	48.5	
Min	3.4	0.0	0.1	1.1	4.4	0.5	1.0	0.4	7.9	
Evergreen										(n=48)
Mean	20.7a	0.1a	0.2a	3.0a	11.5a	4.0a	2.9a	1.0a	36.8a	
SD	23.8	0.1	0.4	3.5	4.1	2.8	3.6	1.1	18.2	
Max	135.4	1.0	2.7	20.5	22.0	18.4	14.2	6.0	132.3	
Min	3.4	0.0	0.1	0.9	4.4	0.5	0.2	0.1	18.5	
Moss										(n=24)
Mean	50.1b	0.2ab	1.9b	9.8b	48.1a	8.2b	12.6b	6.9b	78.9c	
SD	45.3	0.6	3.0	10.7	124.3	7.8	22.3	4.3	11.5	
Max	221.3	2.8	12.5	40.3	588.9	30.4	101.1	35.8	552.2	
Min	13.5	0.1	0.4	2.2	10.6	1.6	0.1	1.1	24.5	
Herbage										(n=24)
Mean	49.4b	0.5b	1.4b	11.4b	20.4a	7.6b	12.3b	7.3b	51.8b	
SD	25.8	0.5	0.9	10.1	10.5	5.7	6.6	3.4	15.9	
Max	130.0	1.4	3.2	43.2	42.0	27.7	26.3	19.1	92.0	
Min	9.9	0.0	0.3	1.6	10.5	1.4	1.8	0.3	26.4	
ANOVA	***	**	***	***	ns	***	***	***	***	

***significance at $p<0.001$, ** significance at $p<0.01$; ns=not significant

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SD= standard deviation, Max is maximum value, Min is minimum value

As expected, the values of metal concentrations in the tissues of higher plants were lower than those of moss and herbage, while their concentrations are higher than those found in other European countries under the fallout area of of incinerator plants (Llobet et al., 2002; Morselli et al., 2002; Rossini-Oliva and Mingorance, 2004; Nadal et al., 2004; 2005; Schuhmacher et al, 1996; 1997). The values were comparable with those found in industrial areas (Mingorance et al., 2007; Rossini Oliva and Mingorace, 2004;Voutsa and Samara, 1998).

Higher values of Co, Cr, Cu, Ni and Zn were found in autochthonous moss (*H. cupressiforme*) than the average European values (Gonzáles-Miqueo *et al.* 2010). High values of maximum concentration of Cd and Pb (2.8 and 101.1 mg kg^{-1}, respectively) showed pollutants enrichment in atmospheric deposition in the study area (Dragović and Mihailović, 2009). Cd is emitted into the environment due to the use of fossil fuels, phosphate fertilizers and waste incinerations (Coskun *et al*., 2011). Major Cd emissions occurred during waste incineration in the 1990s in European Countries (Task Force on Heavy Metals, 2006). Manufacturing industries and construction are the larges contributors to Pb emission in Europe. The next most important emission sectors are road transportation (Coskun *et al.,* 2011).

Figure 2 shows the summary statistics (boxplot) of the concentrations of some trace elements in plant and moss tissues as a function of exposure of different sites. No statistical difference was detected between the different sites in both species. The highest concentrations were found in craft area and in some sites under control of the incinerator plant, in particular the maximum values of Cd were found in sites D and N and site A (exposed to the incinerator). Also for the plant species no correlation was found between the metal content in their tissues and the distance of the incinerator plant, as instead was highlighted by some authors (Morselli et al. 2002; Rimmer et al. 2006).

Figure 2 - *Box plot of some selected elements in plants and moss tissues, on the left the concentrations of plants on the right of moss are shown. The data are expressed as mg kg^{-1} of dry weight. Black and gray squares are the maximum and minimum values, respectively; the bold black lines are median values, while the other black lines are the Q1 and Q3, the first and third quartile, respectively.*

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Soil and moss enrichment factor (EF)

The enrichment factor (EF) assessment for heavy metals is very useful in order to determine metal anthropogenic deposition minimizing the geological influence. The EF determines the actual contribution from anthropogenic sources rather than soil dust (Fernández et al. 2002). The metal amounts normalized at Al concentrations for estimating the EF are shown in Table 3.

Table 3 - *Enrichment factor calculated in topsoil (1) and moss (2). The values >3.5, which represent an environmental metals enrichment are printed in bold (Fernández and Carbaillera, 2001).*

1Topsoil	A	B	C	D	E	F	G	H	I	L	M	N
Ba	2.3	2	**3.5**	2.9	**11.9**	2.3	**5.3**	2.2	2	**3.5**	**3.4**	2.2
Cd	**3.4**	2.5	**3.9**	**3.4**	**4.2**	2.5	**4.1**	2.8	2.5	**3.6**	**4.0**	2.9
Co	1.6	1.1	2.2	2.6	1.8	0.9	2.5	1.4	0.9	1.4	1.7	1.3
Cr	1.6	1.4	2.3	2	2.8	1	2.9	1.3	1.6	1.8	2.1	1.5
Cu	1	1.2	2.2	1.3	**3.6**	2.4	2.2	1.2	1.0	4.9	1.5	1.0
Ni	1.7	1.3	2.2	1.9	2.6	1	2.7	1.3	1.2	1.7	2.2	1.5
Pb	0.8	0.7	1.7	2.7	**11**	2.1	**8.8**	1.2	2.0	3.1	2.8	0.5
V	2.1	1.8	2.6	2.8	2.5	1.9	3.1	1.8	1.7	2	2.6	1.9
Zn	1	0.9	1.9	1.7	5.2	1	2.8	1	1.1	2.5	1.6	0.9

2Moss	A	B	C	D	E	F	G	H	I	L	M	N
Ba	**5.6**	**4.0**	ND	**6.6**	3.0	**6.6**	2.7	**3.7**	**5.4**	**5.0**	**7.3**	**8.7**
Cd	**75.3**	**11.0**	ND	**21.6**	**11.5**	**21.1**	**13.9**	**6.8**	**12.7**	**19.5**	**14.2**	**27.7**
Co	**5.8**	2.0	ND	1.2	**3.1**	2.3	0.8	1.3	**13.4**	**4.2**	1.3	**4.4**
Cr	**8.3**	**3.1**	ND	2.5	**5.7**	**5.8**	1.5	**3.4**	2.2	**5.7**	2.3	**5.4**
Cu	**9.6**	**7.9**	ND	**18.2**	**45.1**	**12.3**	**10.7**	**10.0**	**20.2**	**5.7**	**18.2**	**35.8**
Ni	**7.1**	**4.0**	ND	**3.3**	**5.9**	**7.8**	2.3	**4.2**	**4.0**	**6.0**	**3.3**	**7.8**
Pb	**3.6**	1.6	ND	1.1	**5.2**	0.9	**4.2**	1.7	0.8	**6.3**	**13.4**	**8.2**
V	**7.1**	**3.0**	ND	1.5	**3.4**	**5.3**	2.1	**3.2**	**3.4**	**3.1**	**4.3**	**5.6**
Zn	**10.9**	**11.1**	ND	**22.5**	**18.7**	**24.3**	**16.4**	**10.1**	**9.8**	**8.9**	**10.9**	**46.8**

The environment can be considered enriched when the average EFs is >3.5 (Fernández and Carbaillera 2001) and different degrees of environmental pollution can be found.

EF values in topsoil were lower than those found in mosses. The biomagnifications of metal concentrations in moss tissues in comparison with soil is known. Sites E and G had higher values in topsoil for many EFs related to a lot of metals whereas sites C and L had high values (>3.5) only for the Cd values. These sites are characterized by a busy road and a closeness to the incinerator plant. Environmental pollutant accumulation can vary in space and time because of the presence of widespread sources and airborne transport (Franzaring et al. 2010). In tissues of moss, 12% of EF values were < 2 (no environmental enrichment), 30% 2 to 5 (from no to moderate enrichment), 47% 5 to 20 (from moderate to heavy enrichment and 11% higher than 20 (very heavy enrichment).

Higher values of EFs than 3.5 were found in sites A, L and N, following site E.

High enrichment coefficients for elements of Cd, Cu and Zn were found in all monitoring sites. A positive correlation between EF calculated in moss and herbage

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was found, if the Cd values were excluded (Figure 3). The concentration factor, which expresses the ratio of metal concentration between herbage and soil is an index of soil-plant transfer and it is widely used in biomonitoring studies. A ratio of <1 shows that the herbage excludes the elements from uptake, while a concentration factor of Cd >1 (1.1 to 3.3 for this study) can indicate that the Cd is stored in tissues of herbage, suggesting an uptake by roots.

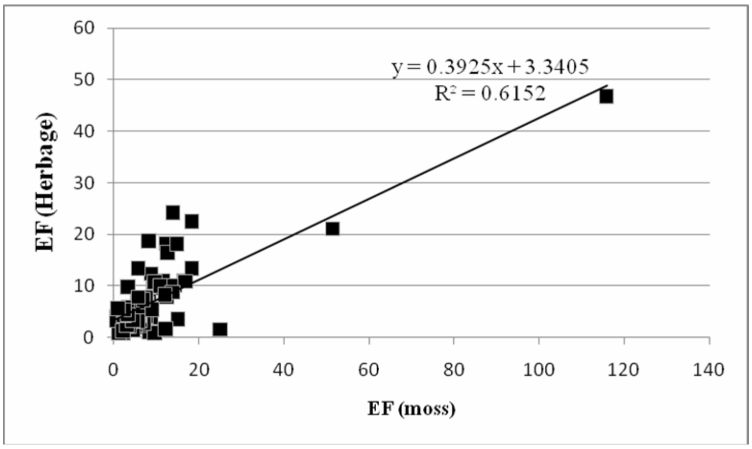

Figure 3.

Scatter plot and linear correlation between enrichment factors (EF) calculated in moss (x axis) and in herbage tissues (y axis), excepted for the Cd values are shown.

Pollution load index

The suitability of the environment for human health can be further assessed by using the pollution load index (PLI) which assesses the environmental risk caused by the contaminated soil (PLI_{soil}) and atmospheric deposition (PLI_{moss}) (Boamponsem et al., 2010). Values of PLI=1 indicate trace elements loads close to the background level while values above 1 indicate pollution. The PLI values calculated for soil and mosses are shown in Figure 4.

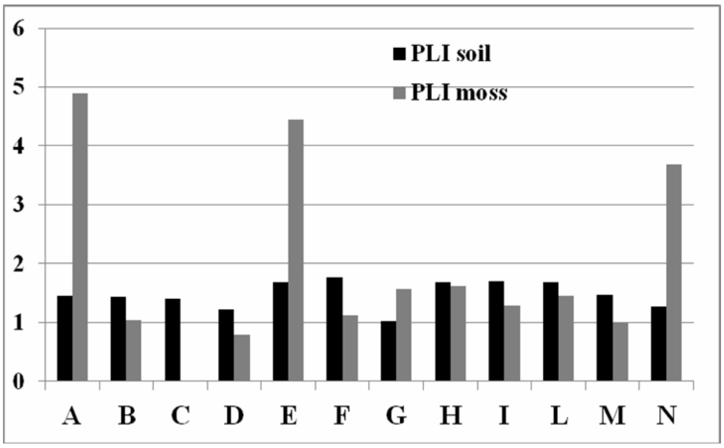

Figure 4

Pollution Load Index (PLI) calculated in soil (black bars) and moss (gray bars) according to Galan et al. (2008) and Boamponsem et al. (2010) is shown.

The values of PLI_{soil} were between 1 and 1.7, and those for the moss were between 0.8 and 1.6. Sites A, E and L, instead, had high values of PLI_{moss} (3.7, 4.5 and 4.9, respectively), indicating a moderate pollution of the environment. The PLI of both soil and moss indicates widespread environmental pollution, highlighting the sites more polluted than others. Site E is characterized by craft activity while sites A and L are under the incinerator plant domain following the dominant wind direction (from West to East).

Conclusion

The enrichment factors of both topsoil and moss as well as the pollution load index highlight that metal depositions are ascribed to the widespread anthropogenic sources. In some cases, the enrichment by atmospheric deposition is site-specific (e.g. site E) probably deriving, in this case, from craft activities. The traffic seems to be the main pollution source because it is not possible to distinguish the waste incinerator emissions from others, even if the sites that are located in the upwind area of the incinerator plant are characterized by a high enrichment of pollutants leading to deterioration of environmental quality. All the indices of environmental quality are unable to identify point and diffuse sources of pollution.

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