

Potentially Toxic Elements (PTEs) in Cultivated Soils from Lombardy (Northern Italy): Spatial Distribution, Origin, and Management Implications

Elisa Sacchi ^{1,*}, Stefano Brenna ², Stefania Fornelli Genot ¹, Alessandra Leoni ²,
Vanna Maria Sale ² and Massimo Setti ¹

¹ Department of Earth and Environmental Sciences, University of Pavia, 27100 Pavia, Italy;
teltigre@vodafone.it (S.F.G.); massimo.setti@unipv.it (M.S.)

² ERSAF, Regional Agency for Agriculture and Forests of Lombardy, 20124 Milano, Italy;
stefano.brenna@ersaf.lombardia.it (S.B.); alessandraleoni54@gmail.com (A.L.);
vannamaria.sale@ersaf.lombardia.it (V.M.S.);

* Correspondence: elisa.sacchi@unipv.it; Tel.: +390382985880

Supplementary materials

CAPTIONS

Figure S1 Frequency histograms for PTEs concentration values in the top and in the deep soil samples

Figure S2 Distribution maps of PTEs concentration values for both the top and the deep soil layers

Figure S3 Distribution maps of PTEs TEF values

Table S1 Correlation matrices between the soil parameters and the PTEs content in the top and in the deep layer.

Table S2 Results of the Principal component analysis (Top layer, PTEs and soil parameters)

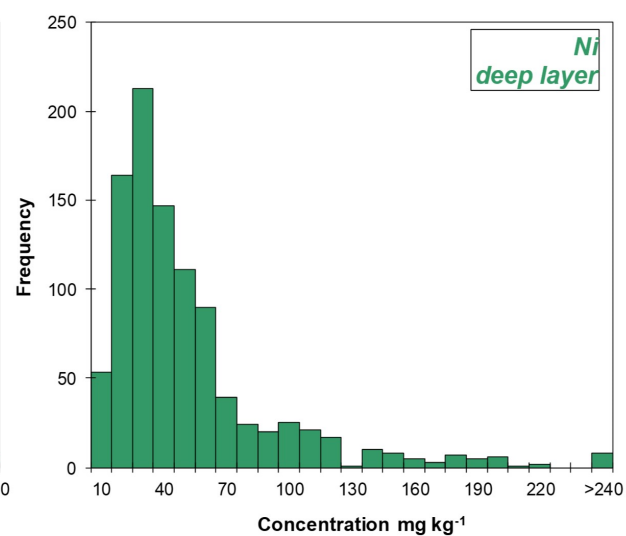
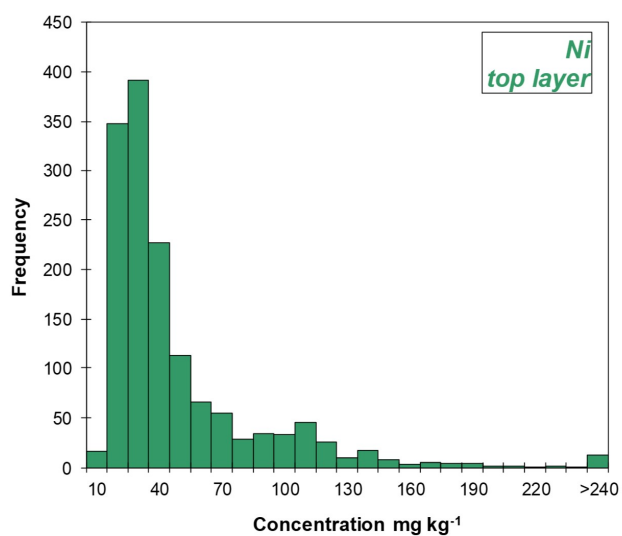
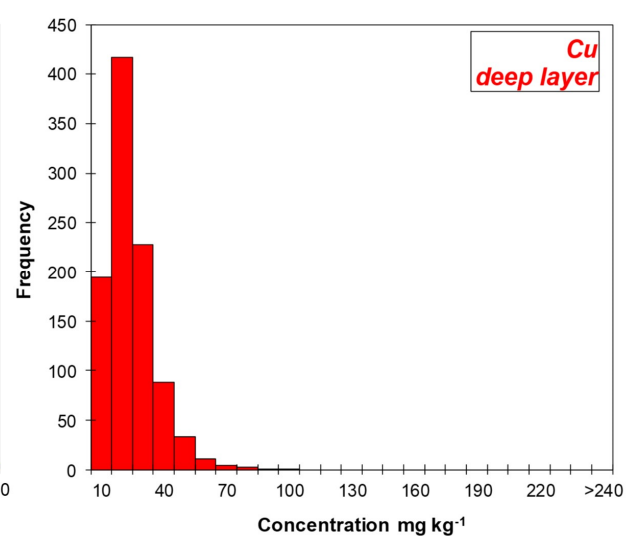
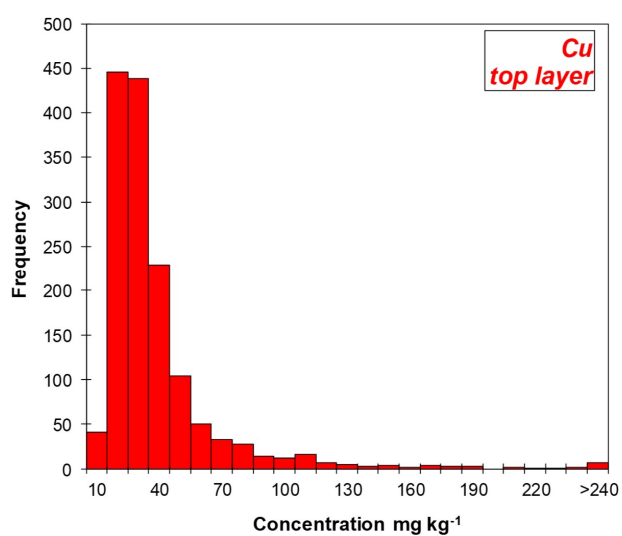
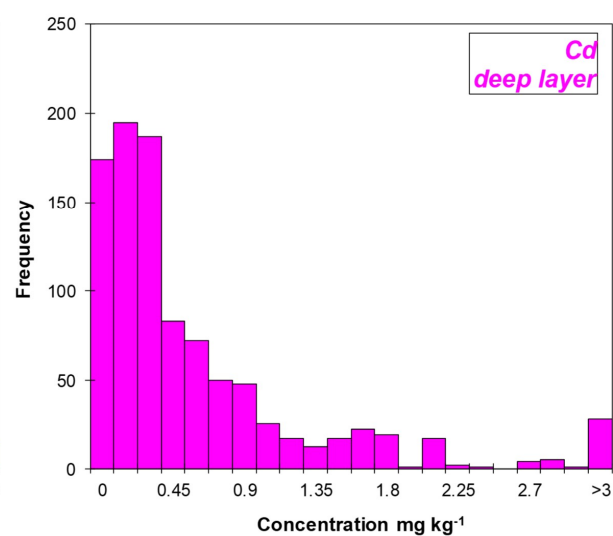
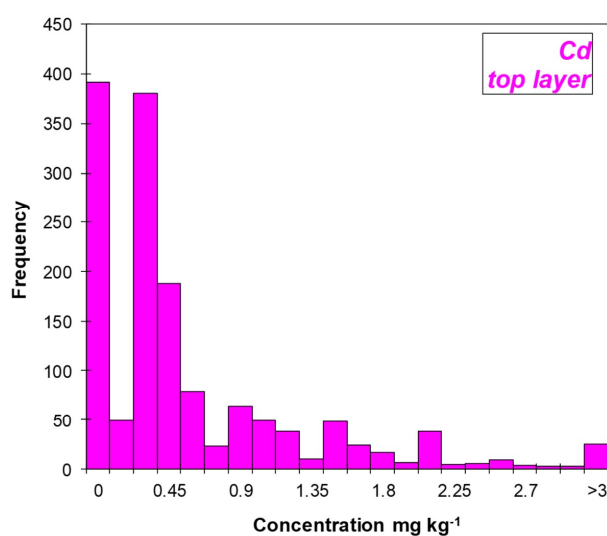
Table S3 Results of the Principal component analysis (Deep layer, PTEs and soil parameters)

Table S4 Results of the PCA of PTEs concentrations in the top layer (3 factors selected). Rotation method: Varimax.

Table S5 Results of the PCA of HM concentrations in the deep layer (4 factors selected). Rotation method: Varimax.

Table S6 Soil parameters and PTEs contents from the dedicated profiles

Table S7 Number of samples and percentage of samples exceeding the SQG defined by the Italian legislation for residential/green and for industrial/commercial areas [38], for agricultural areas [39], and for sewage sludge re-use in agriculture [40].



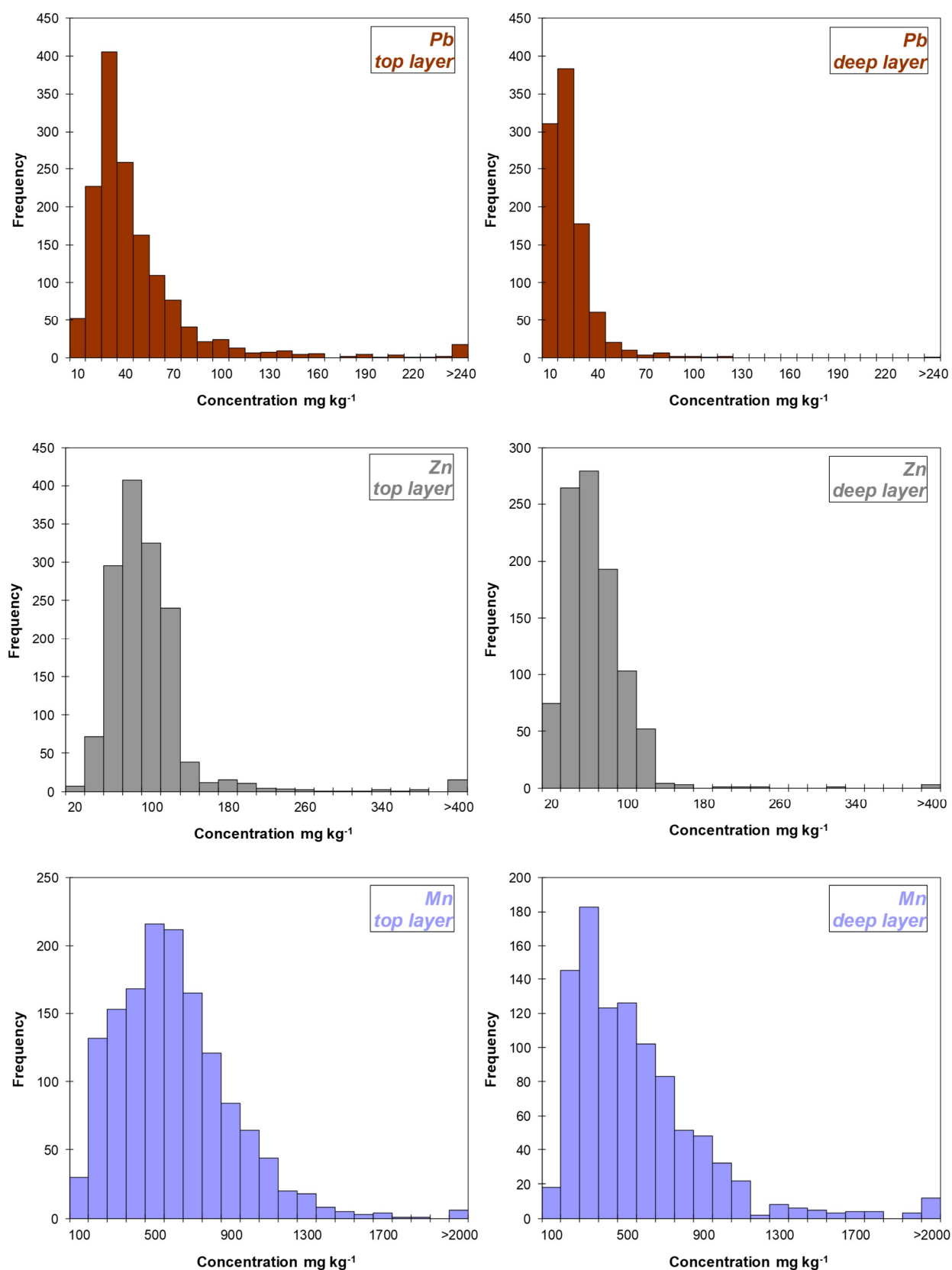
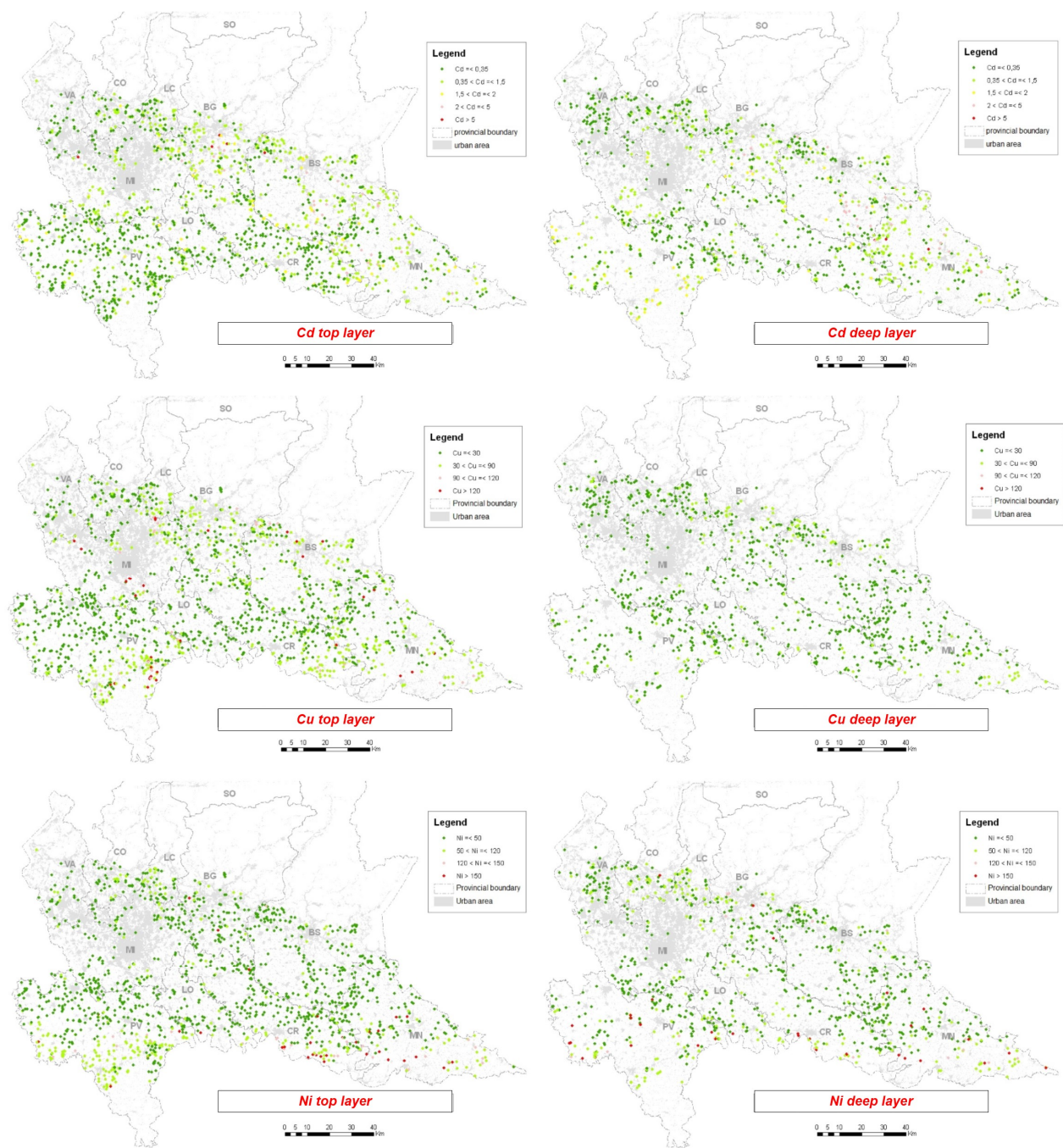


Figure S1. Frequency histograms for PTEs concentration values in the top and in the deep soil samples.



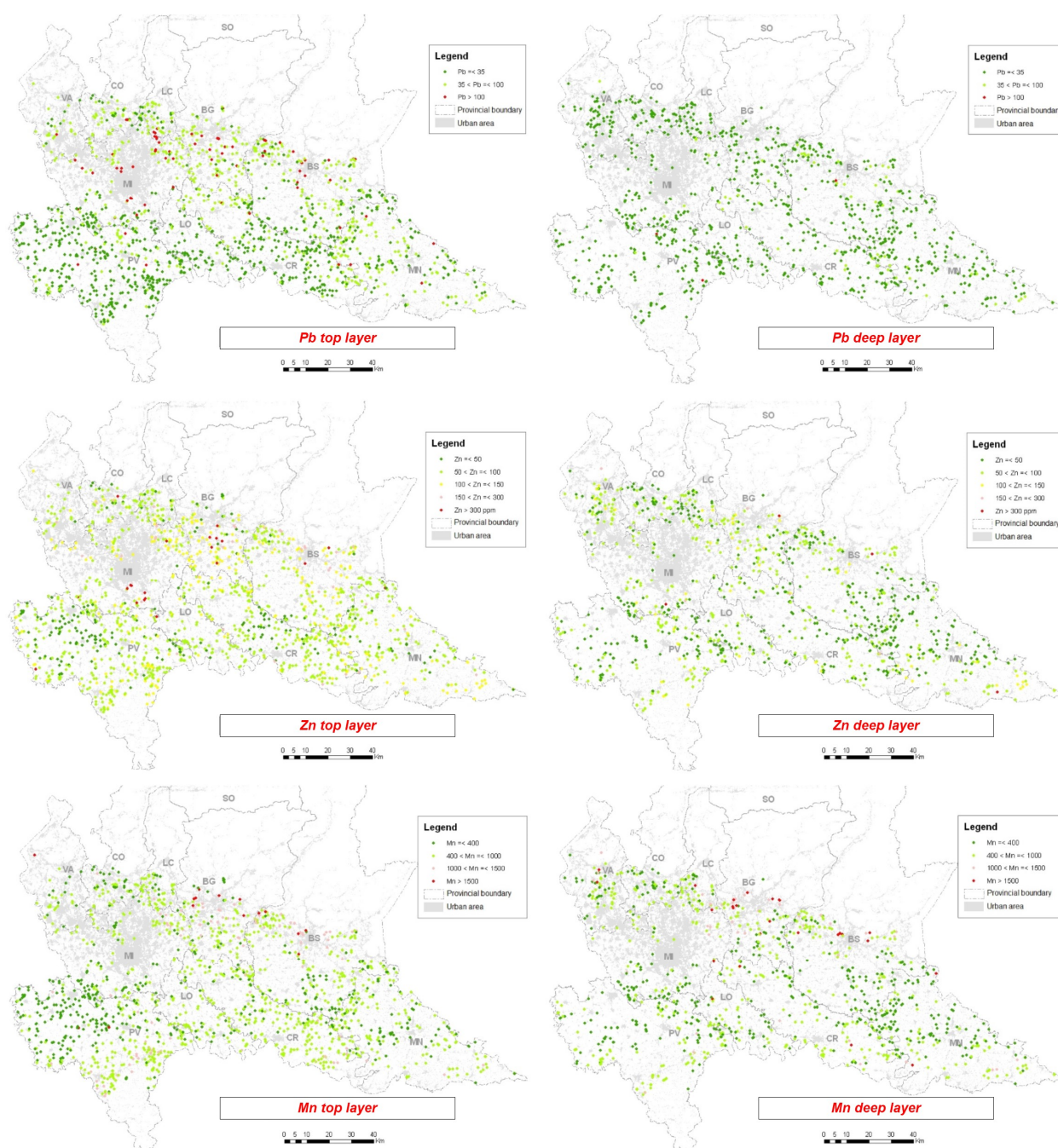


Figure S2. Distribution maps of PTEs concentration values for both the top and the deep soil layers.

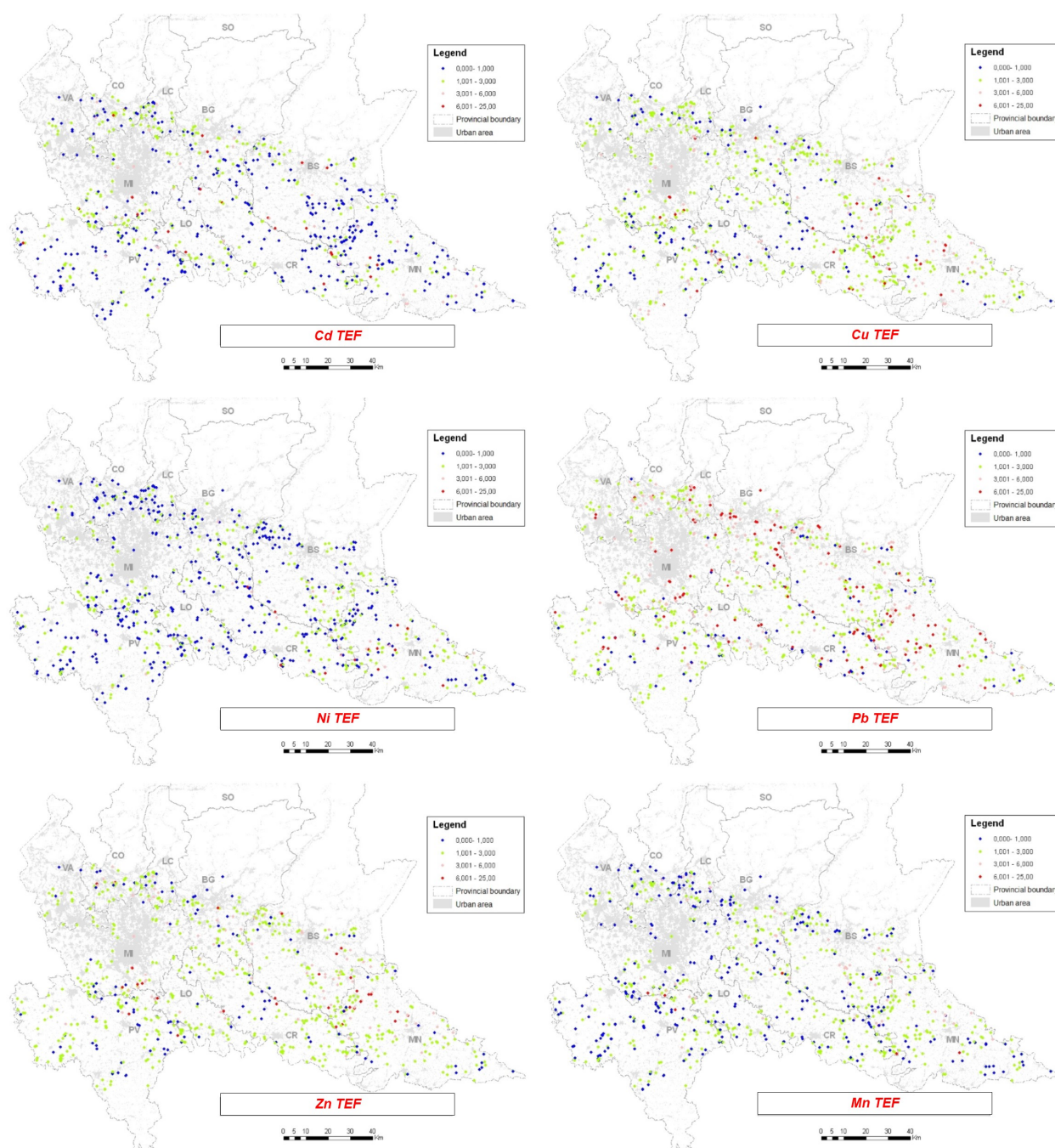


Figure S3. Distribution maps of PTEs TEF values.

Table S1. Correlation matrices between the soil parameters and the PTEs content in the top and in the deep layer.

Top layer	Cu	Ni	Pb	Zn	Cd	Mn	Sand	Silt	Clay	pH	Carb	OC	CEC	%BS
Cu														
Ni	0.14													
Pb	<i>0.09</i>	<i>−0.01</i>												
Zn	0.34	<i>0.04</i>	0.15											
Cd	0.17	<i>0.01</i>	0.16	0.35										
Mn	0.20	0.19	<i>0.08</i>	0.11	<i>0.08</i>									
Sand	−0.26	−0.15	<i>0.01</i>	−0.11	<i>−0.01</i>	−0.40								
Silt	0.20	<i>0.09</i>	<i>0.01</i>	0.14	<i>0.03</i>	0.32	−0.84							
Clay	0.22	0.16	<i>−0.04</i>	<i>0.03</i>	<i>−0.01</i>	0.33	−0.79	0.33						
pH	0.12	0.16	<i>−0.06</i>	<i>0.05</i>	0.11	0.19	−0.35	0.15	0.44					
Carb	<i>0.07</i>	<i>0.02</i>	<i>−0.03</i>	<i>−0.02</i>	0.14	<i>−0.04</i>	−0.23	0.10	0.28	0.54				
OC	<i>0.06</i>	<i>−0.03</i>	<i>0.02</i>	<i>0.09</i>	<i>0.04</i>	<i>0.01</i>	<i>−0.03</i>	<i>0.04</i>	<i>0.01</i>	<i>−0.03</i>	<i>0.05</i>			
CEC	0.21	<i>0.05</i>	<i>0.03</i>	0.17	<i>0.03</i>	0.32	−0.55	0.32	0.60	0.15	<i>0.09</i>	0.23		
%BS	0.12	0.16	<i>−0.07</i>	<i>0.05</i>	0.11	0.21	−0.32	0.13	0.42	0.91	0.47	<i>0.01</i>	0.16	

Table S1. (cont.) Correlation matrices between the soil parameters and the PTEs content in the top and in the deep layer.

Deep layer	Cu	Ni	Pb	Zn	Cd	Mn	Sand	Silt	Clay	pH	Carb	OC	CEC	%BS
Cu														
Ni	0.38													
Pb	0.27	0.18												
Zn	0.29	0.10	0.20											
Cd	−0.08	−0.10	−0.03	0.03										
Mn	0.58	0.23	0.22	0.25	−0.08									
Sand	−0.54	−0.25	−0.23	−0.19	−0.07	−0.41								
Silt	0.39	0.23	0.17	0.14	0.08	0.30	−0.92							
Clay	0.59	0.20	0.24	0.22	0.03	0.44	−0.79	0.49						
pH	−0.04	0.06	0.00	−0.08	0.24	−0.05	−0.08	0.09	0.04					
Carb	−0.30	−0.15	−0.04	−0.16	0.34	−0.23	−0.02	0.08	−0.07	0.59				
OC	0.02	−0.02	0.05	0.01	−0.01	0.00	−0.05	0.05	0.04	−0.05	−0.07			
CEC	0.56	0.17	0.23	0.20	−0.07	0.42	−0.62	0.43	0.72	−0.18	−0.29	0.33		
%BS	−0.02	0.06	0.03	−0.05	0.20	−0.03	−0.08	0.06	0.09	0.80	0.38	−0.03	−0.06	

Table S2. Results of the Principal component analysis (Top layer, PTEs and soil parameters).

Total Variance Explained									
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative%	Total	% of Variance	Cumulative%	Total	% of Variance	Cumulative%
1	3.767	26.906	26.906	3.767	26.906	26.906	2.872	20.515	20.515
2	1.927	13.767	40.673	1.927	13.767	40.673	2.447	17.476	37.991
3	1.64	11.713	52.386	1.64	11.713	52.386	1.695	12.104	50.094
4	1.142	8.157	60.543	1.142	8.157	60.543	1.212	8.655	58.749
5	0.997	7.123	67.666	0.997	7.123	67.666	1.131	8.081	66.83
6	0.905	6.465	74.13	0.905	6.465	74.13	1.022	7.3	74.13
7	0.792	5.654	79.784						
8	0.771	5.506	85.29						
9	0.683	4.882	90.173						
10	0.543	3.876	94.049						
11	0.454	3.245	97.294						
12	0.295	2.107	99.401						
13	8.39E-02	0.599	100						
14	2.28E-15	1.63E-14	100						

Table S2. (cont.) Results of the Principal component analysis (Top layer, PTEs and soil parameters).

Component Matrixes													
Element	Communalities	Component matrix						Rotated component matrix					
		F1	F2	F3	F4	F5	F6	F1	F2	F3	F4	F5	F6
%BS	0.850	0.643	−0.61	0.233	−3.22E ^{−02}	7.33E ^{−02}	6.56E ^{−02}	0.127	0.89	3.72E ^{−02}	0.198	5.54E ^{−03}	−2.68E ^{−02}
Carb	0.625	0.441	−0.531	0.224	0.265	−0.165	−3.05E ^{−02}	8.20E ^{−02}	0.75	5.20E ^{−02}	−0.223	4.59E ^{−02}	−1.55E ^{−02}
Cd	0.579	0.15	0.152	0.688	5.58E ^{−02}	−0.218	−0.1	−8.23E ^{−02}	0.181	0.683	−0.155	−5.81E ^{−02}	0.215
CEC	0.699	0.643	0.336	−0.198	0.307	0.166	0.106	0.673	7.09E ^{−02}	7.79E ^{−02}	9.68E ^{−02}	0.471	6.28E ^{−02}
Clay	0.724	0.808	−1.96E ^{−02}	−0.254	3.98E ^{−02}	1.68E ^{−02}	7.34E ^{−02}	0.717	0.393	−5.77E ^{−02}	0.187	0.133	−6.41E ^{−03}
Cu	0.580	0.387	0.379	0.4	−0.116	0.186	−0.28	0.222	4.53E ^{−03}	0.669	0.251	9.38E ^{−02}	−0.109
Mn	0.514	0.5	0.281	−5.51E ^{−02}	−0.319	0.12	0.257	0.458	2.30E ^{−02}	0.101	0.49	−6.79E ^{−03}	0.233
Ni	0.725	0.247	−9.14E ^{−03}	4.90E ^{−02}	−0.592	0.544	0.124	8.92E ^{−04}	8.16E ^{−02}	4.82E ^{−02}	0.842	−4.10E ^{−02}	−6.65E ^{−02}
OC	0.854	9.33E ^{−02}	0.184	7.08E ^{−02}	0.709	0.535	0.133	−5.54E ^{−03}	−5.63E ^{−03}	6.62E ^{−02}	−6.32E ^{−02}	0.92	−3.50E ^{−03}
Pb	0.911	6.10E ^{−03}	0.307	0.346	1.09E ^{−03}	−0.317	0.772	−2.41E ^{−03}	−6.13E ^{−02}	0.126	6.09E ^{−04}	1.12E ^{−02}	0.944
pH	0.895	0.661	−0.633	0.232	−4.19E ^{−02}	8.22E ^{−03}	4.63E ^{−02}	0.149	0.918	3.99E ^{−02}	0.16	−4.78E ^{−02}	−2.64E ^{−02}
Sand	0.956	−0.86	−0.221	0.342	−2.20E ^{−03}	0.211	8.01E ^{−02}	−0.952	−0.205	−5.41E ^{−02}	−5.29E ^{−02}	2.08E ^{−02}	3.39E ^{−02}
Silt	0.733	0.605	0.356	−0.3	−3.16E ^{−02}	−0.337	−0.187	0.826	−3.12E ^{−02}	0.133	−8.30E ^{−02}	−0.149	−4.62E ^{−02}
Zn	0.733	0.243	0.458	0.638	−1.74E ^{−02}	1.42E ^{−02}	−0.237	7.54E ^{−02}	−4.38E ^{−02}	0.844	5.48E ^{−02}	6.94E ^{−02}	7.05E ^{−02}

Table S3. Results of the Principal component analysis (Deep layer, PTEs and soil parameters).

Total Variance Explained									
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative%	Total	% of Variance	Cumulative%	Total	% of Variance	Cumulative%
1	4.168	29.773	29.773	4.168	29.773	29.773	3.233	23.091	23.091
2	2.468	17.625	47.399	2.468	17.625	47.399	2.176	15.545	38.636
3	1.224	8.745	56.144	1.224	8.745	56.144	1.797	12.834	51.469
4	1.063	7.594	63.738	1.063	7.594	63.738	1.349	9.636	61.105
5	1.019	7.282	71.02	1.019	7.282	71.02	1.176	8.403	69.508
6	0.845	6.038	77.058	0.845	6.038	77.058	1.057	7.55	77.058
7	0.777	5.552	82.61						
8	0.713	5.095	87.706						
9	0.566	4.04	91.746						
10	0.448	3.202	94.948						
11	0.351	2.508	97.455						
12	0.209	1.496	98.951						
13	0.147	1.049	100						
14	1.31E-16	9.37E-16	100						

Table S3. (cont.) Results of the Principal component analysis (Deep layer, PTEs and soil parameters).

Component Matrixes													
Element	Communalities	Component matrix						Rotated component matrix					
		F1	F2	F3	F4	F5	F6	F1	F2	F3	F4	F5	F6
%BS	0.846	−1.02E ⁻⁰²	0.799	0.248	0.301	−9.28E ⁻⁰²	−0.217	6.75E ⁻⁰³	0.917	5.62E ⁻⁰²	6.18E ⁻⁰³	3.94E ⁻⁰²	−2.68E ⁻⁰²
Carb	0.713	−0.258	0.762	−0.151	−9.81E ⁻⁰²	6.69E ⁻⁰²	0.17	5.86E ⁻⁰²	0.576	−0.402	0.436	−0.136	8.79E ⁻⁰²
Cd	0.583	−6.08E ⁻⁰²	0.477	−0.289	−0.156	0.494	−1.67E ⁻⁰²	0.102	0.24	3.18E ⁻⁰³	0.712	−6.82E ⁻⁰²	6.66E ⁻⁰²
CEC	0.804	0.794	−0.127	−0.288	0.23	−5.21E ⁻⁰²	−0.138	0.644	−0.131	0.378	−0.122	0.463	−2.11E ⁻⁰²
Clay	0.761	0.834	0.153	−0.129	−5.98E ⁻⁰²	−1.76E ⁻⁰²	−0.15	0.77	7.25E ⁻⁰²	0.387	−3.68E ⁻⁰²	0.11	−6.35E ⁻⁰³
Cu	0.729	0.791	−8.19E ⁻⁰²	0.254	3.61E ⁻⁰²	−1.92E ⁻⁰²	−0.174	0.515	8.00E ⁻⁰³	0.589	−0.329	1.69E ⁻⁰²	9.17E ⁻⁰²
Mn	0.601	0.65	−0.102	0.277	1.44E ⁻⁰²	7.71E ⁻⁰²	−0.291	0.361	5.68E ⁻⁰³	0.643	−0.239	−2.97E ⁻⁰²	5.94E ⁻⁰³
Ni	0.624	0.402	8.79E ⁻⁰³	0.506	6.24E ⁻⁰²	−0.33	0.305	0.241	0.138	7.09E ⁻⁰²	−0.615	−0.15	0.375
OC	0.894	0.134	−9.67E ⁻⁰²	−0.505	0.777	−3.88E ⁻⁰²	7.53E ⁻⁰²	3.56E ⁻⁰²	−1.59E ⁻⁰²	−5.99E ⁻⁰²	1.37E ⁻⁰²	0.94	7.68E ⁻⁰²
Pb	0.823	0.389	2.15E ⁻⁰²	0.272	0.265	0.346	0.639	0.133	−8.92E ⁻⁰⁵	0.167	−5.46E ⁻⁰²	9.76E ⁻⁰²	0.875
pH	0.904	−6.35E ⁻⁰²	0.888	0.221	0.204	−8.15E ⁻⁰²	−0.125	3.11E ⁻⁰²	0.944	−5.58E ⁻⁰²	8.40E ⁻⁰²	−4.87E ⁻⁰²	1.75E ⁻⁰²
Sand	0.970	−0.868	−0.269	0.247	0.247	0.104	−0.105	−0.969	−5.06E ⁻⁰²	−0.126	−1.99E ⁻⁰²	−8.85E ⁻⁰⁴	−0.106
Silt	0.835	0.709	0.287	−0.27	−0.314	−0.138	0.245	0.894	2.61E ⁻⁰²	−6.61E ⁻⁰²	5.17E ⁻⁰²	−6.83E ⁻⁰²	0.155
Zn	0.699	0.364	−0.112	0.216	4.13E ⁻⁰²	0.697	−0.139	1.29E ⁻⁰²	−0.103	0.721	0.281	−4.31E ⁻⁰²	0.297

Table S4. Results of the PCA of PTEs concentrations in the top layer (3 factors selected). Rotation method: Varimax.

Total Variance Explained									
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	1.775	29.591	29.591	1.775	29.591	29.591	1.565	26.091	26.091
2	1.161	19.355	48.946	1.161	19.355	48.946	1.271	21.179	47.270
3	0.918	15.295	64.241	0.918	15.295	64.241	1.018	16.971	64.241
4	0.798	13.294	77.536						
5	0.769	12.813	90.348						
6	0.579	9.652	100.000						

Component Matrixes							
Element	Communalities	Component matrix			Rotated component matrix		
		F1	F2	F3	F1	F2	F3
Cd	0.538	0.605	−0.391	−0.138	0.702	−0.104	0.184
Cu	0.539	0.676	0.161	−0.238	0.616	0.394	−6.908E-02
Mn	0.578	0.446	0.545	0.285	7.957E-02	0.728	0.205
Ni	0.591	0.279	0.716	2.567E-02	−1.504E-02	0.757	−0.133
Pb	0.932	0.389	−0.323	0.8.22	0.109	3.711E-02	0.958
Zn	0.677	0.724	−0.262	−0.290	0.121	3.261E-02	3.901E-02

Table S5. Results of the PCA of HM concentrations in the deep layer (4 factors selected). Rotation method: Varimax.

Total Variance Explained									
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.153	35.882	35.882	2.153	35.882	35.882	1.718	28.626	28.626
2	1.048	17.470	53.352	1.048	17.470	53.352	1.128	18.795	47.422
3	0.858	14.292	67.644	0.858	14.292	67.644	1.034	17.226	64.648
4	0.830	13.827	81.472	0.830	13.827	81.472	1.009	16.824	81.472
5	0.722	12.029	93.500						
6	0.390	6.500	100.00						

Component Matrixes							
Element	Communalities	Component matrix			Rotated component matrix		
		F1	F2	F3	F1	F2	F3
Cd	0.993	−0.164	0.838	0.513	3.151E-02	−3.73E-02	−3.09E-02
Cu	0.755	0.834	−2.87E-02	0.143	−0.193	0.745	0.433
Mn	0.690	0.757	6.27E-03	1.94E-02	−0.341	0.786	0.256
Ni	0.772	0.565	−0.309	0.554	0.223	0.181	0.848
Pb	0.956	0.524	0.174	−0.255	0.765	0.124	0.136
Zn	0.723	0.513	0.468	−0.448	−0.201	0.704	−0.369

Table S6. Soil parameters and PTEs contents from the dedicated profiles.

Profile P001

Location: Oltrepò area

Land use: former vineyard, now abandoned

Classification: fine, mixed, superactive, mesic, Oxyaquic Haplustept (USDA, 2003); Calcaric Cambisol (WRB, 1998)

Horizon	Depth (cm)	Particle size distribution (%)						pH		CaCO ₃		OC	Exchangeable cations (meq/100g)					BS
		C&VC sand	F&M sand	VF sand	C silt	F silt	Clay	(H ₂ O)	(KCl)	total %	active %	%	CEC	Ca	Mg	K	Na	%
A	0–35	2.6	2.4	8.6	4.8	47.2	34.4	8.28	7.57	24.4	13.8	1.1	22.18	16.97	1.95	1.09	0.08	90.58
Bw	35–75	1.3	1.1	14	1	51.6	31	8.38	7.56	16.0	13.0	0.7	19.22	16.65	2.31	0.78	0.08	100
C	75–130	0.2	0.5	7.4	3.8	46.4	41.7	8.46	7.59	22.4	12.0	0.2	16.47	14.63	4.42	0.5	0.11	100
Cr	130–200+	0.2	0.4	10.9	5.2	51.3	32	8.57	7.72	18.1	11.3	0.4	16.17	12.04	7.81	0.45	0.16	100

Sample	Depth (cm)	Cd (mg kg ⁻¹)	Cu (mg kg ⁻¹)	Mn (mg kg ⁻¹)	Ni (mg kg ⁻¹)	Pb (mg kg ⁻¹)	Zn (mg kg ⁻¹)
RMT09	0–10	1.95	405	421	72	29.6	176
RMT10	10–20	1.98	424	425	74.5	28	151
RMT11	20–30	1.86	300	421	75.8	21.8	124
RMT12	30–40	1.94	170	417	73.4	16.8	90.5
RMT13	40–60	1.93	126	447	75.9	16.2	91.1
RMT14	60–80	1.8	28.5	372	78.4	14.6	99.1

Profile P002

Location: Oltrepò area

Land use: vineyard since about 50 years

Classification: fine silty, mixed, active, mesic, Typic Ustorthent (USDA, 2003); Calcaric Regosol (WRB, 1998)

Horizon	Depth (cm)	Particle size distribution (%)						pH		CaCO ₃		OC	Exchangeable cations (meq/100g)					BS
		C&VC sand	F&M sand	VF sand	C silt	F silt	Clay	(H ₂ O)	(KCl)	total %	active %	%	CEC	Ca	Mg	K	Na	%
Ap1	0–30	7.4	2.2	10.3	10.1	33.9	36.1	8.38	7.63	6.9	3.3	0.5	18.06	15.81	3.6	0.69	0.09	100
Ap2	30–70	11.3	3.5	9	11	34.3	30.9	8.36	7.63	6.0	5.1	0.5	16.7	14.07	5.04	0.49	0.16	100
Cr	70–200+	12.6	2.6	12.9	7.4	42.3	22.2	8.79	7.98	7.1	2.6	0.3	14.87	5.71	12.34	0.63	1.11	100

Sample	Depth (cm)	Cd (mg kg ⁻¹)	Cu (mg kg ⁻¹)	Mn (mg kg ⁻¹)	Ni (mg kg ⁻¹)	Pb (mg kg ⁻¹)	Zn (mg kg ⁻¹)
RMT15	0–10	2.02	49.6	799	44.6	12	91
RMT16	10–20	1.21	54.1	460	48.1	14	111
RMT17	20–30	1.13	44.7	355	46.6	14.8	105
RMT18	30–40	1.25	39.7	402	46.8	13.6	103
RMT19	40–60	1.18	52.2	365	47.3	15.6	111
RMT20	60–80	1.27	33.2	433	56.5	13.5	107

Table S6. (cont.) Soil parameters and PTEs contents from the dedicated profiles.

Profile P003

Location: Lomellina area

Land use: rice cultivation

Classification: mixed, mesic, Lamellic Ustipsamment (USDA, 2003); Dystric lamellic Arenosol (WRB, 1998)

Horizon	Depth (cm)	Particle size distribution (%)						pH		CaCO ₃		OC	Exchangeable cations (meq/100g)					BS
		C&VC sand	F&M sand	VF sand	C silt	F silt	Clay	(H ₂ O)	(KCl)	total %	active %	%	CEC	Ca	Mg	K	Na	%
A	0–35	12.8	52.2	15	8.3	5.3	6.4	6.96	5.86	0	0	0.5	0.5	4.12	2.08	0.21	0.21	62.14
Bw	35–65	11.4	70.4	6.6	5.2	1.1	5.3	7.06	5.89	0	0	0.04	0.04	3.8	1.18	0.11	0.14	39.92
BC	65–115	4.1	70.6	17	2.6	1.5	4.2	7.13	5.93	0	0	0.05	0.05	2.48	0.72	0.07	0.14	39.52
C	115–200+	0.5	27.9	39.6	22.9	5.7	3.4	7.29	5.77	0	0	0.03	0.03	2.5	1.62	0.16	0.09	76.95

Sample	Depth (cm)	Cd (mg kg ⁻¹)	Cu (mg kg ⁻¹)	Mn (mg kg ⁻¹)	Ni (mg kg ⁻¹)	Pb (mg kg ⁻¹)	Zn mg kg ⁻¹
RMT48	0–20	0.64	9.01	91.39	15.3	12.05	46.59
RMT49	20–40	0.65	9.52	128.1	15.75	11.02	40.16
RMT50	40–60	0.56	9.78	116.7	13.19	4.21	31.98
RMT51	60–80	0.55	9.42	300.6	10.58	3.03	28.95

Profile P004

Location: Lomellina area

Land use: rice cultivation

Classification: mixed, active, mesic, Lamellic Haplustalf (USDA, 2003); Lamellic arenic Acrisol (WRB, 1998)

Horizon	Depth (cm)	Particle size distribution (%)						pH		CaCO ₃		OC	Exchangeable cations (meq/100g)					BS
		C&VC sand	F&M sand	VF sand	C silt	F silt	Clay	(H ₂ O)	(KCl)	total %	active %	%	CEC	Ca	Mg	K	Na	%
Ap	0–30	20.8	45.1	2.1	6.9	5.3	6.8	6.4	5.2	0	0	0.5	6.8	2.2	0.2	0.2	0.1	38.8
Apg	30–40	23.5	44.4	10.1	6.9	1.1	6.1	6.4	5.8	0	0	0.04	7.6	3.2	0.2	0.2	0.1	48.0
E	40–60	26.4	56.0	6.0	1.6	1.5	5.7	7.0	5.9	0	0	0.05	4.4	1.8	0.1	0.1	0.1	46.1
E&Bt	60–120	16.6	66.6	3.6	0.3	5.7	5.1	7.2	6.0	0	0	0.03	2.7	1.2	0.1	0.1	0.1	53.7
C	120–155+	7.7	73.5	4.4	3.0		3.5	7.4	6.0	0	0		2.7	1.3	0.1	0.1	0.1	60.2

Sample	Depth (cm)	Cd (mg kg ⁻¹)	Cu (mg kg ⁻¹)	Mn (mg kg ⁻¹)	Ni (mg kg ⁻¹)	Pb (mg kg ⁻¹)	Zn (mg kg ⁻¹)
RMT52	0–20	0.62	12.98	100.5	17.89	10.19	52.46
RMT53	20–40	0.7	13.76	113.9	19.75	12.24	57.77
RMT54	40–60	0.52	6.84	162.2	14.11	3.84	30.1
RMT55	60–80	0.56	8.17	530.9	15.36	4.66	39.69

Table S6. (cont.) Soil parameters and PTEs contents from the dedicated profiles.

rofile P005

Location: Lomellina area

Land use: poplar

Classification: mixed, mesic, Lamellic Ustipsamment (USDA, 2003); Dystric lamellic Arenosol (WRB, 1998)

Horizon	Depth (cm)	Particle size distribution (%)						pH		CaCO ₃		OC	Exchangeable cations (meq/100g)					BS
		C&VC sand	F&M sand	VF sand	C silt	F silt	Clay	(H ₂ O)	(KCl)	total %	active %	%	CEC	Ca	Mg	K	Na	%
Ap	0–30	8.7	50.3	18.7	9.9	12.3	0.1	6.77	5.76	0	0	0.7	6.48	2.99	0.31	0.49	0.06	59.41
Bw	30–45	15.9	63.3	9.6	5.6	3.2	2.4	6.17	5	0	0	0.08	3.26	0.84	0.07	0.17	0.05	34.66
C1	45–80	8.7	62.4	11.3	9.2	0.5	7.9	6.72	5.53	0	0	0.03	2.39	0.62	0.06	0.04	0.04	31.8
C2	80–150	9.9	61	17.3	8.1	1.3	2.4	6.84	5.52	0	0	0.02	2.02	0.61	0.06	0.07	0.09	41.09
C3	150–185+	1.8	28.8	43.8	19.4	2	4.2	7.3	5.78	0	0	0.03	3.89	2.27	0.2	0.07	0.22	70.95

Sample	Depth (cm)	Cd (mg kg ⁻¹)	Cu (mg kg ⁻¹)	Mn (mg kg ⁻¹)	Ni (mg kg ⁻¹)	Pb (mg kg ⁻¹)	Zn (mg kg ⁻¹)
RMT56	0–20	0.69	10.7	102.9	16.56	11.79	48.43
RMT57	20–40	0.56	9.67	123.2	15.6	6.19	42.47
RMT58	40–60	0.48	10.08	229.4	15.8	4.01	37.51
RMT59	60–80	0.56	9.44	334.6	14.09	2.77	34.23

Profile P006

Location: Lomellina area

Land use: rice cultivation

Classification: mixed, mesic, Lamellic Ustipsamment (USDA, 2003); Dystric lamellic Arenosol (WRB, 1998)

Horizon	Depth (cm)	Particle size distribution (%)						pH		CaCO ₃		OC	Exchangeable cations (meq/100g)					BS
		C&VC sand	F&M sand	VF sand	C silt	F silt	Clay	(H ₂ O)	(KCl)	total %	active %	%	CEC	Ca	Mg	K	Na	%
Apg	0–30	12.7	33.4	21.8	14.7	10.5	6.9	5.92	4.86	0	0	0.7	7.91	2.65	0.28	0.34	0.14	43.03
Bw	30–70	20.1	65.2	10.3	1.5	0.2	2.7	5.72	4.52	0	0	0.07	3.29	0.77	0.07	0.13	0.13	33.43
BC	70–100	12.8	67.9	13.1	2.3	0.4	3.5	6.54	5.4			0.06	3.41	1.34	0.12	0.18	0.14	52.2
C1	100–120	15.7	65.5	10.4	5.4	0.2	2.8	7.31	5.3	0	0	0.02	2.88	0.96	0.1	0.14	0.12	45.83
C2	120–130	7.7	40.6	0.6	24.1	19.7	7.3	6.93	5.39	0	0	0.07	5.84	3.14	0.31	0.2	0.13	64.73
C3	130–150	8.4	83.6	2.8	1.5	0.5	3.2	7.01	5.36	0	0	0.01	1.55	0.73	0.07	0.12	0.13	67.74
C4	150–200+	14.6	79	3.5	0.1	0.1	2.7	6.94	5.7	0	0	0.02	1.77	0.8	0.08	0.08	0.12	61.1

Sample	Depth (cm)	Cd (mg kg ⁻¹)	Cu (mg kg ⁻¹)	Mn (mg kg ⁻¹)	Ni (mg kg ⁻¹)	Pb (mg kg ⁻¹)	Zn (mg kg ⁻¹)
RMT60	0–20	0.66	14.31	110	20.31	17.87	59.72
RMT61	20–40	0.66	12.39	95.73	18.75	11.72	47.22
RMT62	40–60	0.64	9.69	100.9	15.49	4.02	33.82
RMT63	60–80	0.63	9.74	98.56	14.3	3.59	34.38

Table S6. (cont.) Soil parameters and PTEs contents from the dedicated profiles.

Profile P007

Location: Cremona plain

Land use: maize cultivation

Classification: coarse silty, mixed, superactive, mesic Oxyaquic Calciustoll (USDA, 2003). Haplic-calcic Kastanozem (WRB, 1998)

Horizon	Depth (cm)	Particle size distribution (%)						pH		CaCO ₃		OC	Exchangeable cations (meq/100g)					BS
		C&VC sand	F&M sand	VF sand	C silt	F silt	Clay	(H ₂ O)	(KCl)	total %	active %	%	CEC	Ca	Mg	K	Na	%
Ap1	0–30	3.3	2.4	14.5	13.3	54	12.5	8.06	7.29	7.4	3	1.2	25.26	20.96	2.47	0.74	0.09	96.04
Ap2	30–50	3.9	2	15	10.4	60.3	8.4	8.09	7.35	8.3	3.1	1.1	23.7	21.21	2.62	0.64	0.1	100.00
Bk1	50–70	7.4	5.2	10.7	10.4	60	6.3	8.28	7.62	23.4	12.3	0.9	22.51	19.02	2.26	0.22	0.13	96.09
Bk2	70–90	6.0	2.8	14.3	12.3	51.7	12.9	8.48	8.01	28.0	12.5	0.2	10.42	9.51	1.03	0.07	0.13	100.00
Ck	90–140+	2.1	2	15.1	21.2	35.5	24.1	8.56	8.07	28.2	9.4	0.2	8.6	7.49	1.23	0.07	0.11	100.00

Sample	Depth (cm)	Cd (mg kg ⁻¹)	Cu (mg kg ⁻¹)	Mn (mg kg ⁻¹)	Ni (mg kg ⁻¹)	Pb (mg kg ⁻¹)	Zn (mg kg ⁻¹)
RMT78	0–10	1.87	51.23	803	40.78	46.94	151.6
RMT79	10–20	1.87	50.3	852	41.11	47.25	154.6
RMT80	20–30	1.86	50.14	799	39.69	47	155.2
RMT81	30–40	1.85	46.65	870	40.2	47.57	151.7
RMT82	40–60	2.71	19.18	340	32.41	26.78	100.7
RMT83	60–80	3.64	14.07	244	28.83	19.43	81.23

Profile P008

Location: Cremona plain

Land use: set aside

Classification: fine silty, carbonatic, mesic Udic Calciustept (USDA, 2003). Haplic Calcisol (WRB, 1998)

Horizon	Depth (cm)	Particle size distribution (%)						pH		CaCO ₃		OC	Exchangeable cations (meq/100g)					BS
		C&VC sand	F&M sand	VF sand	C silt	F silt	Clay	(H ₂ O)	(KCl)	total %	active %	%	CEC	Ca	Mg	K	Na	%
Ap1	0–35	3.3	3	3.2	9.6	47.6	23.4	8.1	7.6	12.7	4.9	1.3	23.5	18.2	3.5	1.3	0.1	98.3
Ap2	35–50	3.9	3	2.6	6.5	54.6	17.2	8.3	7.6	13.2	5	1	23.1	19.6	3.5	0.7	0.3	100
Bk	50–65	7.4	10.7	5	9.1	35.9	27.2	8.5	8	47.1	13.6	0.4	12.2	10.5	1.4	0.1	0.2	100
Bw1	65–90	6	6.3	3.8	7.8	43	22.1	8.4	8	45.9	11.8	0.3	10.5	9.5	1.4	0.1	0.2	100
Bw2	90–110	2.1	4.2	5.6	18.6	39.1	20.4	8.4	8.1	27.3	8.8	0.2	10	8.6	1.5	0.1	0.2	100

Sample	Depth (cm)	Cd (mg kg ⁻¹)	Cu (mg kg ⁻¹)	Mn (mg kg ⁻¹)	Ni (mg kg ⁻¹)	Pb (mg kg ⁻¹)	Zn (mg kg ⁻¹)
RMT84	0–10	1.89	33.26	741	37.94	41.47	170.7
RMT85	10–20	1.93	34.76	634	38.38	39.89	173.2
RMT86	20–30	1.91	31.33	751	39.35	40.71	159.4
RMT87	30–40	2.02	32.08	780	40.69	43.24	157.6
RMT88	40–60	2.83	14.19	230	26.56	17.31	82.05
RMT89	60–80	3.5	14.61	256	29.52	19.75	77.77

Table S6. (cont.) Soil parameters and PTEs contents from the dedicated profiles.

Profile P009

Location: Cremona plain

Land use: soy cultivation

Classification: coarse loamy, mixed, superactive, mesic Udic Calciustoll (USDA, 2003). Haplic-calcic Kastanozem

Horizon	Depth (cm)	Particle size distribution (%)						pH		CaCO ₃		OC	Exchangeable cations (meq/100g)					BS
		C&VC sand	F&M sand	VF sand	C silt	F silt	Clay	(H ₂ O)	(KCl)	total %	active %	%	CEC	Ca	Mg	K	Na	%
Ap	0–35	4.6	16.7	17.1	14.8	29.9	16.9	8.3	7.7	10.0	1.4	0.9	17.1	14.1	1.9	0.4	0.1	96.4
Bw	35–75	17.6	35.8	16.0	7.3	13.6	9.7	8.5	8.0	37.0	3.1	0.2	9.0	7.3	0.8	0.1	0.1	92.3
Bkm	75–90	12.1	7.5	14.6	13.0	35.5	17.3	8.6	8.1	28.7	13.5	0.1	8.6	8.8	0.8	0.1	0.1	100.0
Cg	90–130+	3.2	3.4	13.9	20.5	39.9	19.1	8.5	8.0	25.8	10.3	0.1	10.8	9.8	1.0	0.1	0.1	100.0

Sample	Depth (cm)	Cd (mg kg ⁻¹)	Cu (mg kg ⁻¹)	Mn (mg kg ⁻¹)	Ni (mg kg ⁻¹)	Pb (mg kg ⁻¹)	Zn (mg kg ⁻¹)
RMT90	0–10	1.47	33.88	521	32.08	34.87	96.66
RMT91	10–20	1.54	36.75	595	33.92	35.52	113.8
RMT92	20–30	1.43	36.06	526	32.47	33.2	95.62
RMT93	30–40	1.98	24.06	314	30.26	23.47	94.26
RMT94	40–60	2.66	11.97	210	21.4	10.94	60.28
RMT95	60–80	3.06	11.57	223	20.51	6.91	45.34

Table S7. Number of samples and percentage of samples exceeding the SQG defined by the Italian legislation for residential/green and for industrial/commercial areas [38], for agricultural areas [39], and for sewage sludge re-use in agriculture [40].

Top layer (n = 1456)	Samples exceeding the threshold values									
	Cu		Ni		Pb		Zn		Cd	
	n	%	n	%	n	%	n	%	n	%
Residential land use	37	2.54	72	4.95	75	5.15	64	4.40	53	3.64
SQG value	120		120		100		150		2	
Industrial land use	2	0.14	3	0.21	3	0.21	2	0.14	1	0.07
SQG value	600		500		1000		1500		15	
Agricultural land use	12	0.82	72	4.95	75	5.15	21	1.44	6	0.41
SQG value	200		120		100		300		5	
Sewage sludge re-use	60	4.1	224	15.4	75	5.15	21	1.44	134	9.2
SQG value	100		75		100		300		1.5	

Deep layer (n = 981)	Samples exceeding the threshold values									
	Cu		Ni		Pb		Zn		Cd	
	n	%	n	%	n	%	n	%	n	%
Residential land use	0	0	57	5.81	4	0.40	9	0.92	41	4.18
SQG value	120		120		100		150		2	
Industrial land use	0	0	2	0.20	0	0	0	0	0	0
SQG value	600		500		1000		1500		15	
Agricultural land use	0	0	57	5.81	4	0.40	4	0.40	4	0.40
SQG value	200		120		100		300		5	
Sewage sludge re-use	0	0	155	15.8	4	0.4	4	0.40	100	10.2
SQG value	100		75		100		300		1.5	