The “Gandalf” soil sampling project at a former industrial site in Copenhagen, Denmark: evaluating soil classification reliability

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Introduction

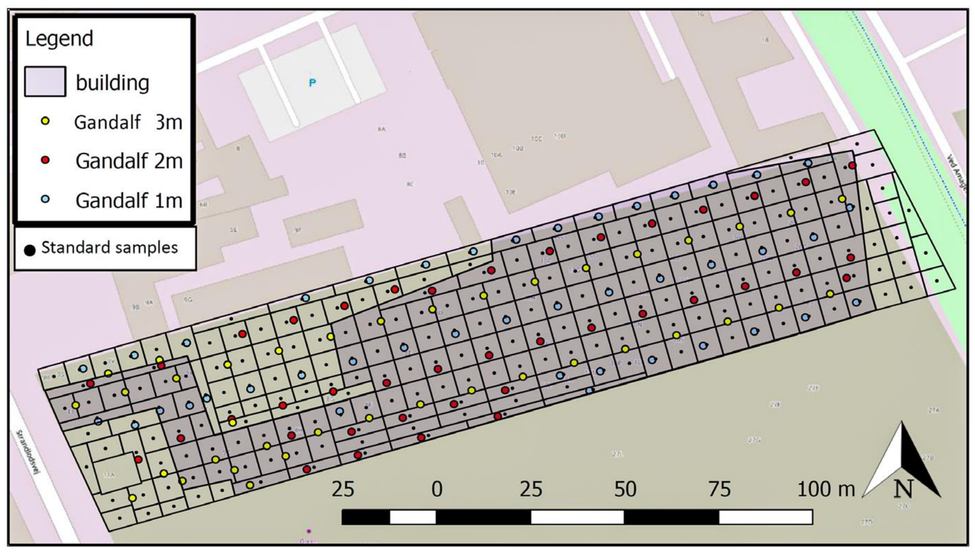
Handling and transport of contaminated soil from industrial sites in Denmark requires classification based on concentrations of selected contaminants. Today’s sampling process in Denmark is based on grab sampling of standard volumes of soil; 30 tons is typically used as the Decision Unit. Soil classification into five classes (class 0 to class 4) based on analytical results from sub-samples of 50 g is the most common.

In this study samples were taken at a former industrial site in Copenhagen, Denmark. The aim of the study was to assess the current sampling strategy by determination of soil classification errors obtained for duplicate primary samples from the same truck-load of soil, but with different distances from the original primary sample.

Sampling overview

Soil classification standard samples were collected in 7 × 7 m grids, while additional ‘Gandalf’ samples were collected at 1 m, 2 m and 3 m distances from the standard samples.

Figure 1. Map of the sampling site with all sampling positions



Sampling

Primary samples of approx. 3.7 kg were taken by a rotary auger (diameter = 10 cm). After manual mixing with a spoon, or by hand and removal of *extraneous* rocks and plastic materials, secondary samples of approximately 50 g were constructed by randomly spoon-collecting a minimum of 10 increments from each primary sample.

Table 1. Standard and Gandalf samples.
B: Inside new building; M: outside new building

Depth [m]	Stand. B	Gandalf B	Stand. M	Gandalf M	Stand. B+M	Gandalf B+M	Gandalf 1 m	Gandalf 2 m	Gandalf 3 m
0.17	158	88	58	22	216	110	34	39	37
0.5	141	1	16	5	157	6	0	0	6
0.83	141	84	34	21	175	105	31	37	37
1.17	141	0	16	5	157	5	0	0	5
1.5	141	0	16	5	157	5	0	0	5
1.83	141	0	16	5	157	5	0	0	5
2.17	141	0	16	5	157	5	0	0	5
2.5	140	1	16	5	156	6	0	1	5
2.83	140	53	16	4	156	57	17	20	20

Results overview

The distribution for all components (except Ni) are very skew with a maximum conc. >> mean conc. > median conc., typical of a polluted site with a log-normal distribution of concentrations.

Table 2. Results

	D.M.	Pb	Cd	Cr	Cu	Ni	Zn	Fl	BbjkFl	BaPyr	Ipyr	DBah Ant	PAH
Results	1792	1792	1792	1792	1792	1792	1792	1780	1762	1762	1762	1762	1762
% Detect.	100	100	96	100	100	100	100	68	74	59	53	39	75
Max	100	5000	18	7500	10000	270	16000	420	210	120	68	16	830
Mean	88	59	0.3	25	92	15	180	1.8	1.2	0.8	0.5	0.2	4
Median	89	11	0.1	17	15	14	40	0.16	0.09	0.14	0.13	0.06	0.28

	C6-C10	C10-C15	C15-C20	C20-C35	C10-C20	C6-C35	Benz-ene	Tolu-ene	Ethyl-benz-ene	o-Xylene	m+p-Xylene	Xyle-nes	BTEX
Results	1792	1792	1792	1792	1792	1792	1652	1652	1652	1652	1652	1646	1646
% Detect.	11	14	26	36	27	40	1	4	6	5	8	9	10
Max	3700	6600	4400	9600	7000	12000	0.9	310	420	210	1300	1500	2200
Mean	130	220	110	270	220	420	0.4	6.1	8.1	5.7	22	24	29
Median	12	27	21	96	28	110	0.3	0.3	0.6	0.7	1	1.1	1.2

Pb to Zn: Metals Fl to PAH: PAH’s C6 to C6-C20: Hydrocarbons Benzene to BTEX: BTEX

Maps of contamination

The map for Pb, Fig. 2, is typical for most contaminants.
All contaminants except hydrocarbons have high concentrations at the surface, and all contaminants have background levels with very low concentrations below 2.5 m depth. Most contaminants have high concentration around a depth of 1.5 m (~ground water level?), Fig. 3.

Figure 2. Map of Pb

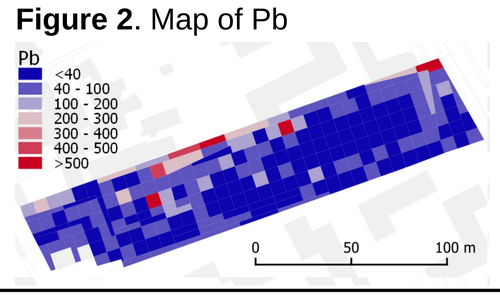
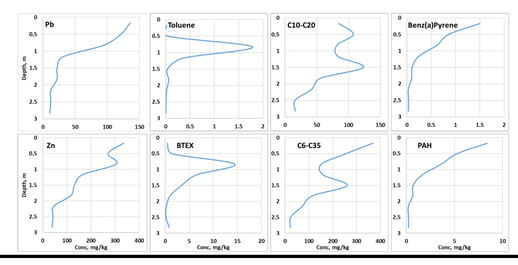


Figure 3. Contamination *vs* depth



Sampling uncertainty

The total uncertainty (sampling + analysis) of the primary and secondary sampling was estimated based on 28 duplicate primary samples. Analysis RSD % is typical 10 - 20 % which will have only a very small effect, i.e. these RSD % are nearly exclusively due to sampling.

Table 2 Global estimation error

ALL	Metals	BTEX	Hydrocarb.	PAH	All contam.
RSD %	58	98	66	78	71
N	196	53	76	122	447

Classification errors

In average 53 % of the samples were misclassified and 20 % by 2 or more classes, Table 4. Classification error increases from 32 % for duplicate primary samples to 57 % for samples taken from the same Decision Unit at a distance of 3 m, Table 3.

Table 3 Soil classification errors

Dist, m	N	N(Error)	% Error	Mean error, classes
0	28	9	32	0.7
1	81	40	49	1.0
2	96	56	58	1.2
3	110	63	57	1.1
All	315	168	53	1.1

Classification
BTEX and light hydrocarbons have small effect on classification, Table 5**.**

Table 4. Soil classification errors

All samples, duplicates + Gandalf			
Bin	Frequency	%	% abs
-4	0	0	
-3	13	4	
-2	19	6	
-1	63	20	
0	147	47	
1	45	14	34
2	21	7	13
3	5	2	6
4	2	1	1
Sum	315	100	53

Table 5 · % of samples classified > 0

	Pb	Cd	Cr	Cu	Ni	Zn
Class > 0	30	11	2	27	33	23
	C6-C10	C10-C15	C15-C20	C20-C35	C10-C20	C6-C35
Class > 0	4	6	6	17	9	21
	Benzene	BTEX	Ba-Pyr	DBah Ant	PAH	
Class > 0	1	6	33	13	28	

Conclusion

Classification of excavated soil is crucial for correct handling and possible reuse. Based on the official sampling strategies used in Denmark, the present large-scale investigation clearly identifies primary and secondary sampling as the main factors affecting classification of contaminated soils.

At least 50 % of all samples were misclassified, 20 % were misclassified by two or more classes. This study demonstrates that the risk of misclassification is highest for less mobile parameters, metals and PAHs compared to the volatile organic solvents.

The risk of misclassification goes two ways, leading to under- as well as overestimation of the environmental risk class for the physical soil Decision Units. The present study demonstrates that for soil contamination, sampling uncertainty dominantly exceed the uncertainty from laboratory analysis.

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