Urban geochemistry in Trondheim, Norway

ROLF TORE OTTESEN & MARIANNE LANGEDAL

Ottesen, R.T. & Langedal, M. 2001: Urban geochemistry in Trondheim, Norway. *Norges geologiske undersøkelse Bulletin 438*, 63-69.

The chemical composition of urban surface soil in Trondheim, Norway, has been mapped to serve a two-fold purpose. 1) To assess whether stack-emissions from industrial sites, incinerators and crematoria, as well as road traffic, have caused local elevated concentrations of certain elements. 2) To provide a database for environmental health risk evaluation. Surface soil samples were collected from 314 sites in gardens, parks and industrial areas. The samples were analysed for the Aqua Regia soluble fraction of 31 elements. Natural background concentrations were determined in the deeper parts of overbank sediment profiles from the region. In general, the pollution levels were low. However, Cd, Hg, Pb and Zn pollute the surface soils in the central and older parts of the city and along the main roads. The most dominant sources are presumably automobile exhaust (Pb), tyre wear (Zn and Cd), and emissions from a crematorium or a hospital incinerator (Hg). In the eastern parts of Trondheim, industries burning coal have probably caused elevated As concentrations.

Rolf Tore Ottesen1 & Marianne Langedal, Department of Environment, City of Trondheim, N-7004 Trondheim, Norway 1. Present address: Geological Survey of Norway, N-7491 Trondheim, Norway.
E-mail: rolf.ottesen@ngu.no & marianne.langedal@trondheim.kommune.no

Introduction

Urban environments are polluted by a number of different sources such as road traffic, industry, waste incineration, waste sites, crematoria and incineration of coal, oil and wood (e.g., Berglund et al. 1994, Birke & Rauch 1994, Ahlgren 1996, Chen et al. 1997, Mielke & Reagan 1998, Mielke et al. 1999, and Ottesen et al. 2000a & b). Spills and deliberate disposal from point sources have caused extremely high levels of pollutants in soils at industrial sites and waste dumps (Ottesen et al. 1989, Karlsaune 1995). Airborne pollutants are deposited on surface soils and often accumulated in the soil compartment. Lately, it has been observed that general consumption and waste disposal have caused non-point pollution of urban soils (Ottesen et al. 2000a, Langedal & Ottesen 2001). Soils act as reservoirs for heavy metals and organic micro-pollutants. Human activity may create pathways from these reservoirs to the urban populations. Thus, the quality of urban soils can influence human health (Mielke & Reagan 1998).

Only a few urban soil studies have so far been carried out, compared with the number of studies on agricultural and forest soils. A survey of the content of inorganic and organic pollutants in urban soil can serve as a basis for community planning and to assess the need for emission regulation.

In Trondheim, the third largest city in Norway, concern about local air pollution was expressed in the early 1990s, and in 1994 the city administration decided to map the chemical composition of urban surface soils in order to evaluate the state of pollution. This geochemical mapping had a two-fold purpose: 1) To assess whether stack-emissions from industrial sites, incinerators and crematoria as well as road traffic had caused local, traceable pollution. 2) To provide a database for environmental health risk evaluation. In addition, the dataset should provide background knowledge for further community planning. In this article we present a brief overview of the methods used and the main results of the mapping.

Study area

Geography

The city of Trondheim lies in central Norway, 350 km south of the Arctic Circle (Fig.1). The climate is typically cool and humid. Trondheim was founded in 997, and during the first 900 years of its history the urban area was concentrated in the present city centre (Fig. 2). During the the 20th century, the urban area increased markedly and today the densely populated area covers 70 km^2. The city now has a population of 164, 000.

Geology

Metamorphosed volcanic and sedimentary rock sequences of mainly Early Ordovician to Early Silurian age constitute a significant part of the allochthon in the Caledonides of central Norway (Wolff 1979). The Støren Nappe of the Upper Allochthon dominates in the Trondheim region (Gale & Roberts 1974, Roberts & Gee 1985). The main rocks in and around the city are MORB-type tholeiitic basalt with subordinate cherts and hemi-pelagic sedimentary rocks and also bodies and dykes of trondhjemite, all metamorphosed at greenschist facies. These form part of the Bymarka ophiolite (Slagstad 1998).

Most of the city is situated on marine clay, deposited about 10, 000 years ago as the sea-level rose during

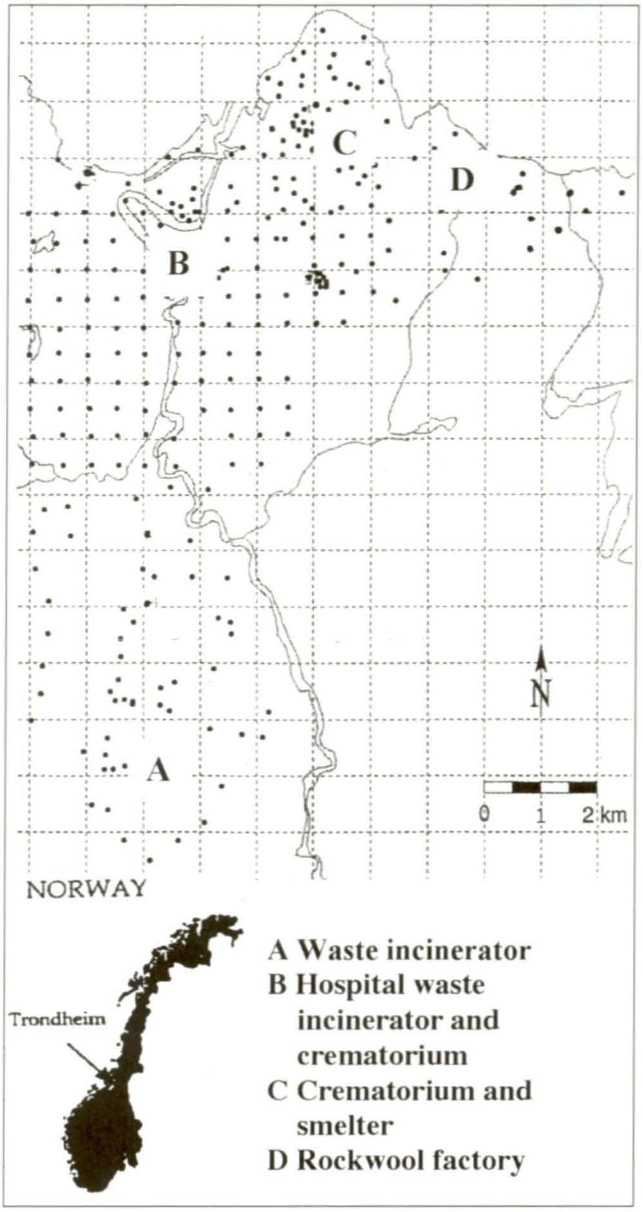

Fig. 1. The study area smapling points for surface soils (314 samples)

deglaciation. Later, isostatic forces caused a relative sea-level decrease leaving the marine clay onshore. Along the Nidelva river, the city rests on fluvial sediments (Reite 1983, Reite et al. 1999). In the city centre, the overburden has been used and recycled many times during historical times. It is therefore difficult to determine the original type of material (Reite et al. 1999).

The urban soil also contains building materials (bricks, paint, concrete, metal), waste, ash, slag, transported soils, organic materials and local original mineral matter (Ottesen et al. 1999a & b, Langedal & Ottesen 2001).

Methods

Sampling and sample preparation

Surface soil was selected as the sampling medium since it is readily accessible and is known to accumulate airborne pollutants. From gardens, parks, fields and industrial sites within the populated parts of Trondheim, 314 samples were collected at a density of 4.5 samples per km^2 (Fig.1). The samples were collected from areas consisting of marine clay, fluvial sediments or reworked urban soil. From each site, grass was removed before one half kilogram of material was collected at 0-2 cm depth. The samples were packed in paper bags and air dried.

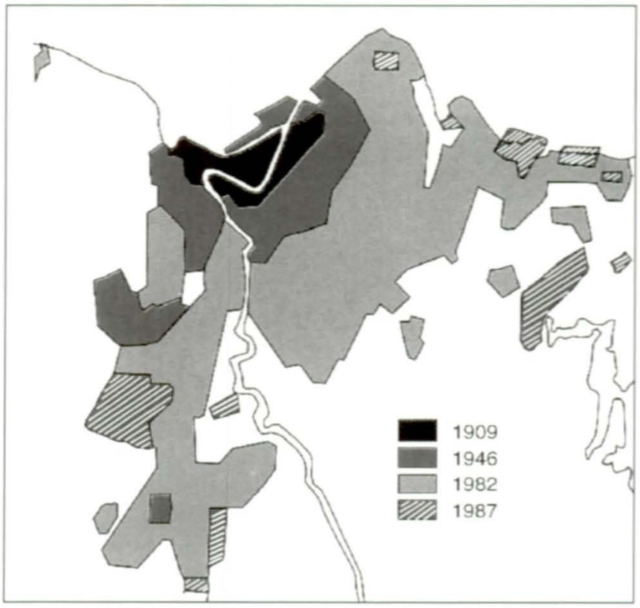

Fig. 2. Map showing the development of densely populated areas in Trondheim during the period 1909-1987.

Overbank sediments of varying age from the Nidelva river and from 55 other rivers or streams in the area were also sampled and analysed to study the chemical changes through time (Hana 1996, Ottesen et al. 1989, 2000c). The element concentrations in the deeper and older overbank sediments were interpreted as providing a reasonable indication of pre-industrial, natural concentrations.

Chemical analysis, inorganic substances

The samples were sieved through a 2-mm nylon cloth. One gram of this < 2 mm sample material was digested in hot Aqua Regia (3ml 3:2:1 $HCl:HNO_3:H_2O$). The solutions were analysed for 31 elements by ICP-AES. In addition, the solutions were analysed by GFAAS for As and Cd. Hg was determined by AAS (cold vapour technique) after HNO_3 digestion. Se was determined after HNO_3 and H_2O_2 digestion. The analytical work was carried out by the Geological Survey of Finland, which is accredited after EN 45001.

Loss-on-ignition

Loss-on-ignition was determined in all samples by heating 2 grams of material of each sample to 200°C for 2 hours, followed by 20 hours at 430°C.

Statistical methods

The analytical results were treated statistically by summary statistics and factor analysis.

Table 1. Contents of aqua regia extractable elements in 314 samples of surface soil from Trondheim, Norway.

Element	Arithmetic mean	Median	Minimum	Maximum
Al (%)	1.91	1.86	0.17	4.47
As (mg/kg)	3.0	2.8	0.5	83
B (mg/kg)	5.8	5.0	3.0	28.0
Ba (mg/kg)	77.4	72.2	18.0	385
Ca (%)	0.68	0.54	0.06	10.60
Cd (mg/kg)	0.24	0.16	<0.01	11.3
Co (mg/kg)	14.4	13.5	1.6	45.0
Cr (mg/kg)	73.3	69.3	7.9	199
Cu (mg/kg)	42.3	34.5	1.7	706
Fe (%)	3.21	3.10	0.33	8.49
Hg (mg/kg)	0.21	0.13	0.02	4.49
K (%)	0.29	0.23	0.04	1.11
La (mg/kg)	15.9	15.4	1.4	33.8
Li (mg/kg)	18.5	17.8	0.9	39.3
Mg (%)	1.34	1.29	0.15	3.04
Mn (mg/kg)	479	442	43	4410
Mo (mg/kg)	-	-	<1.0	7.2
Na (%)	0.02	0.02	0.007	0.76
Ni (mg/kg)	47.8	45.0	6.0	231
P (mg/kg)	848	794	50	2480
Pb (mg/kg)	51.2	35	9.0	976
S (mg/kg)	605	475	37	4813
Sc (mg/kg)	3.6	3.3	0.1	9.2
Se (mg/kg)	0.27	0.20	0.04	3.69
Sr (mg/kg)	30.8	27.0	5.8	255
Ti (mg/kg)	1171	1110	83.8	3170
V (mg/kg)	55.6	55.1	6.7	144
Y (mg/kg)	8.4	8.0	0.6	17.5
LOI (%)	13.7	10.9	0.4	91.5

Table 2.. Median values for the contents of acid-soluble elements in overbank sediments from the city of Trondheim and the Trøndelag region, Norway.

Element (mg/kg)	Surface soil, Trondheim (N=314)	Overbank sediments Trøndelag region (N=55)	Overbank sediments Nidelva river. Trondheim (N=25)
Al	18 600	17 400	10 000
As	2.8	2.8	< 3
B	5.0	4.1	< 3
Ba	72.2	43	46.8
Ca	5 400	5 000	2 700
Co	13.5	15.7	8.5
Cu	34.5	27	28.9
Cr	69.3	53.6	43.4
Fe	31 000	25 000	17 000
K	2 300	1 500	2 500
La	15.4	23	8.3
Li	17.8	13.3	5.2
Mg	12 900	9 200	7 100
Mn	442	400	136
Na	20	30	40
Ni	45	35.6	32.9
Å	794	900	771
Pb	35	9.6	< 3
Sc	3.3	5.2	2.7
Sr	27.0	28.1	17.5
Ti	1 110	1 200	850
V	55.1	40.4	30.5
Zn	98	44	37.9

Mineralogical analysis

Twelve samples of surface soil (6 samples of marine clay and 6 samples of fluvial sediments) were analysed by XRD for determination of the main minerals present in the samples.

Results and discussion

Geochemistry of surface soil from Trondheim

Table 1 summarizes the results of the chemical analyses. The geographical distributions of high and low concentrations vary from one element to another (Fig. 3). Comparison with the regional and local geochemical background (Table 2) shows that Pb, Zn, Ba and Mg are significantly enriched in the urban surface soils. The enrichment of Cr, Cu, Fe, Ni and V in the same material is less significant.

Table 3 Principal component factor analysis of the correlation matrix. Rotated factor loading and communalities. (Varimax rotation).

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communality
LogCo	0.964	0.080	0.033	0.035	-0.179	0.970
LogCr	0.950	0.040	0.063	0.036	-0.086	0.934
Logv	0.935	0.205	0.037	0.183	0.058	0.953
LogFe	0.910	0.371	0.040	0.071	0.008	0.973
LogNi	0.901	0.183	-0.026	-0.087	-0.262	0.922
LogMg	0.901	0.308	-0.012	-0.039	-0.197	0.947
LogMn	0.853	0.061	0.102	0.107	-0.092	0.761
LogTi	0.824	0.246	-0.176	-0.164	0.003	0.801
LogAl	0.822	0.521	-0.036	0.123	0.093	0.972
La	0.099	0.941	-0.120	0.083	-0.033	0.917
Y	0.230	0.882	-0.150	-0.175	-0.153	0.907
LogNa	0.133	0.874	0.065	-0.211	-0.115	0.844
LogK	0.387	0.849	-0.116	-0.130	-0.097	0.911
Ba	0.403	0.728	0.319	0.026	-0.060	0.799
Li	0.601	0.715	-0.028	0.059	0.111	0.889
LogSc	0.644	0.677	-0.173	-0.151	-0.098	0.936
LogB	0.096	0.567	0.134	0.289	-0.421	0.609
LogPb	-0.067	-0.109	0.866	0.098	0.076	0.781
LogZn	0.183	0.018	0.822	-0.086	-0.304	0.809
LogCd	0.057	-0.038	0.736	0.007	-0.321	0.650
LogHg	-0.178	-0.183	0.607	0.366	0.310	0.664
LogpH	-0.213	0.086	0.578	0.478	-0.124	0.630
LogAs	0.055	0.189	0.394	0.127	-0.327	0.317
LogLOI	0.051	-0.046	0.112	0.853	-0.048	0.747
LogS	-0.105	-0.154	0.200	0.809	-0.354	0.854
LogSe	0.260	-0.153	-0.026	0.743	-0.060	0.648
LogCa	0.074	0.114	0.090	0.164	-0.906	0.873
LogCu	0.351	0.075	0.384	0.074	-0.640	0.691
LogSr	0.072	0.481	0.217	0.322	-0.529	0.667
Variance	8.7716	6.0103	3.3380	2.7822	2.4769	23.3789
% Var	0.302	0.207	0.115	0.096	0.085	0.806

Table 4. Minerals detected by X-ray diffraction (XRD) in surface soils from Trondheim, Norway.

Mineral	Characteristic chemical elements
Amphibole	Si, Al, Mg, Ca, Na, Ni, Co, Cr, Cu
Chlorite	Si, Mg, Fe, Al, Li, Mn, Ni, B
Biotite	Si
Muscovite	Si, Fe, Mg, Al, K
Plagioclase	Si, Al, Fe, Ca, Na, Ba
Potassium feldspar	Si, Al, K, Na, Ba

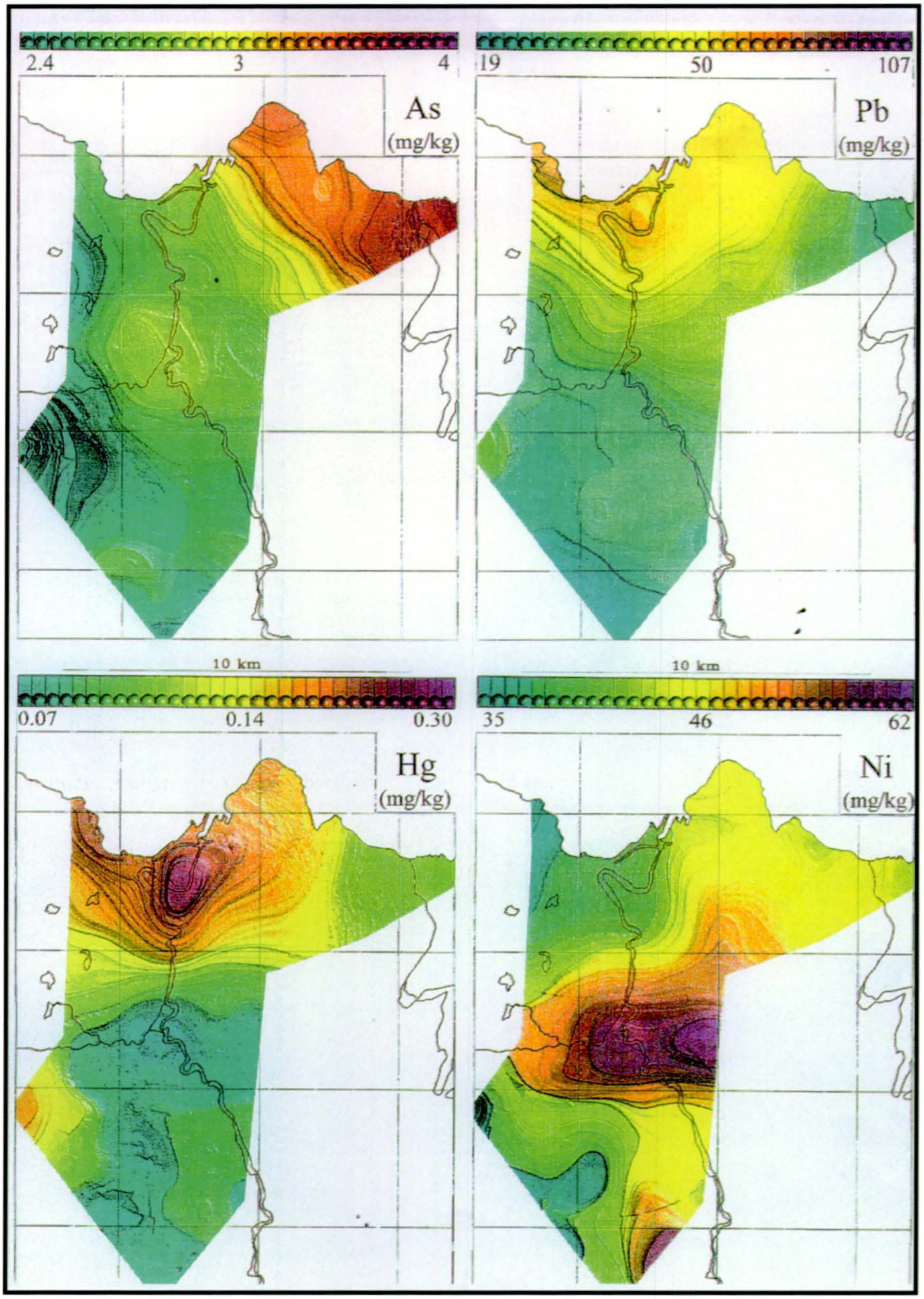

Fig. 3. Content of acid-soluble AS, Hg, Ni, and Pb (moving median) in surface soils from Trondheim.

Factor analysis of the dataset indicates certain element associations that point to particular sources. Factor 1 (Table 3) explains a significant part of the variance for Al, Co, Cr, Fe, Li, Mg, Mn, Ni, Sc, Ti and V in the surface soil. For these elements, the communalities are relatively high (>0.8).

Factor 2 explains a significant part of the variance for Al, B, Ba, La, Li, Na, Sc and Y. Except for B, all the elements of factor 2 have high communalities. The mineralogical analysis (Table 4) shows that natural minerals contribute to the Al, Ba, Ca, Cr, Fe, K, La, Li, Mg, Mn, Na, Ni, Sc, Si, Ti, and Y concentrations of the samples. Since these elements belong to factors 1 and 2, local geology probably controls the covariation between elements within these factors. As an example, it can be seen that the distribution of Ni in soil (Fig. 3) is largely related to occurrences of basic volcanic rocks in the Trondheim region (Gale & Roberts 1974, Wolff 1979).

Factor 3 includes Pb, Zn, Cd, Hg and P. The communalities for Cd, Hg and P are relatively low, and only 65% of the variance for these elements is explained by the factor model. However, Pb and Zn are clearly enriched in the surface soil compared with the natural background represented by the deeper parts of overbank sediment profiles (Tables 1 and 2). It is assumed that Pb, Zn, Cd and Hg mainly have anthropogenic sources. The highest concentrations of these elements are found at some industrial sites and in the city centre (Hg and Pb for example in Fig. 3). This pattern is common in several other cities around the world (Moir & Thornton 1989, Birke et al. 1992, Kelly et al. 1994, Viverette et al. 1996, Ottesen & Volden 1999).

A large part of the variance for LOI, S and Se is explained by factor 4. S and Se probably mainly reflect the content of organic matter in the samples. Ca is described by factor 5. The model indicates a co-variance with Sr and Cu.

The variance of As is not explained by the factor model. However, the geographical distribution of this element shows that As concentrations are generally higher in the eastern part of Trondheim than in other parts of the city (Fig. 3). The eastern part of Trondheim has hosted several industries burning coal such as a smelter, a rockwool factory, and an abandoned gasworks. It is assumed that these are the probable sources of the elevated As concentrations.

Evaluation of main pollution sources

Municipal waste incinerator

A municipal waste incinerator, located approximately 10 km south of the city centre, became operative in late 1985. The plant has two incinerators with a capacity of 13 tonnes waste /hour. The plant produces energy for central heating, covering 15 per cent of the heating requirements for the city. The flue gas passes through electrofilters for dust removal and then through a washing tower before being released from a 70 m-high chimney stack.

Metal concentrations in samples collected within a radius of 2.5 km around the municipal waste incinerator (marked A in Fig. 1) are lower than the median concentrations for the whole dataset (Fig. 4). So far, the incinerator has not emitted sufficient quantities to pollute the nearby soil.

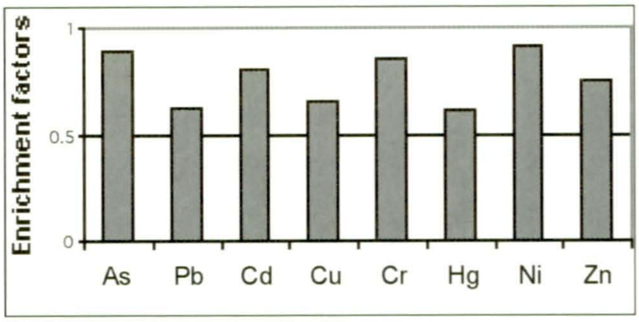

Fig. 4. Enrichment factors for As, Pb, Cd, Cu, Cr,, Hg, Ni and Zn in the area close to the wasteincinerator (B - Fig. 1), Trondheim, Norway.

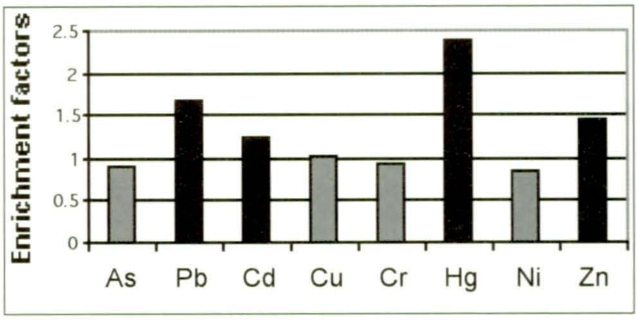

Fig. 5. Enrichment factors for As, Pb, Cd, Cu, Cr,, Hg, Ni and Zn in the area close to the crematorium and the hospital incinerator (B - Fig. 1), Trondheim, Norway.

Crematorium and hospital incinerator

In the area around the main crematorium and the hospital waste incinerator (marked B in Fig. 1) there is a clear Hg halo in the downwind direction. The same area is also enriched in Pb, Zn and Cd (Fig. 5). However, a main road passing through the area is also likely to influence the chemistry of the surface soils.

Crematorium and smelter

In the eastern part of the city, there is a crematorium, an abandoned gasworks, and some heavy industry (marked C and D in Fig. 1). There is also a main road running through

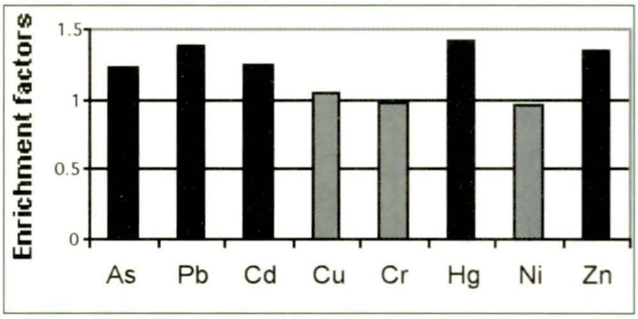

Fig. 6. Enrichment factors for As, Pb, Cd, Cu, Cr,, Hg, Ni and Zn in the area close to the crematorium and heavy industry in the eastern part of the city of Trondheim.

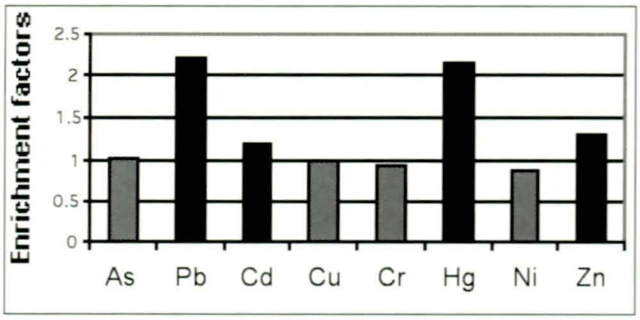

Fig. 7. Enrichment factors for As, Pb, Cd, Cu, Cr,, Hg, Ni and Zn in the area close to the main roads, Trondheim, Norway.

the area. In this part of the city, the surface soils are enriched in As, Pb, Cd, Hg and Zn (Fig.6).

Road traffic

Samples collected close to the main roads are enriched in Pb, Hg, Zn and Cd (Fig. 7). Leaded petrol is the most probable source for the Pb enrichment, while tyre wear may be the main source for Zn and Cd in these samples (Table 5). Elevated Pb levels were measured in the urban air compared to rural air before the amount of lead in petrol was reduced (Hagen et al. 1989).

Table 5. Contents of Zn and Cd in tyres (Duun-Moen 1996).

Tyre	Zn (mg/kg)	Cd mg/kg
Sample 1	17 450	0.4
Sample 2	19 350	5.9
Sample 3	14 050	1.9
Sample 4	15 050	0.7

Ore mill

Severe As and heavy metal pollution (Fig. 8) has been reported from an abandoned ore mill in the western part of the harbour.

Results in relation to national guidance levels

In Norway, the national guidance levels advise concentrations that are generally safe for sensitive land-use such as children´s playgrounds and commercial market gardening.

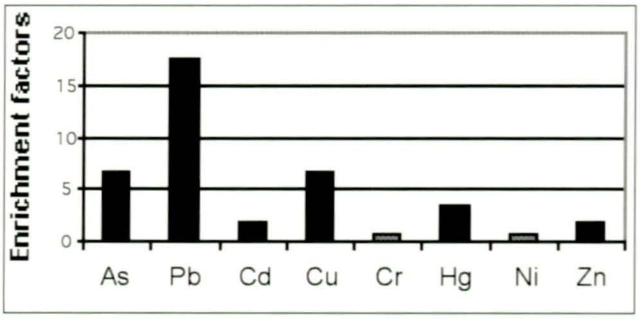

Fig. 8. Enrichment factors for As, Pb, Cd, Cu, Cr,, Hg, Ni and Zn at an abandoned industrial site, Trondheim, Norway.

Table 6. Contents of As and heavy metals in surface soils from Trondheim in relation to national acceptance levels.

Element	Guidance level	% of samples above guidance level
As	2 mg/kg	83 %
Pb	60 mg/kg	20 %
Cd	3 mg/kg	0.3 %
Cu	100 mg/kg	2.2 %
Cr	25 mg/kg	96 %
Hg	1 mg/kg	1.6 %
Ni	50 mg/kg	40 %
Zn	100 mg/kg	50 %

Large areas of Trondheim exceed these levels for As, Cr, Ni, Pb and Zn (Table 6). Levels of Pb and Zn are mainly exceeded in the city centre, while concentrations of Cr, As and Ni exceed the national guidelines throughout the study area. The guidelines consider all routes of exposure from soil to man. If the guidelines are exceeded, a specific risk analysis should be performed on the site.

Conclusions and practical implications

Local geology and rock types account for the fundamental, background compositions of urban soils in Trondheim, central Norway. However, concentrations of As, Cd, Hg, Pb and Zn are influenced by pollution sources such as road traffic, local industry, crematoria and a hospital waste incinerator. Concentrations of As, Cr, Ni, Pb and Zn exceed the national guidance levels for sensitive land-use over large areas of the city. The data indicate that there is a definite need for a health risk evaluation.

Acknowledgements

The authors wishes to thank Professors Bjørn Bølviken and Eiliv Steinnes for their helpful discussions and thorough reviews, which helped to improve the paper. Assistance from the editor, David Roberts, during final revisions of the manuscript are acknowledged with thanks.

References

Ahlgren, M. 1996: Undersökning I Falun av markblyets biotilgänglighet. Uppsala Universitet, Ekotoxikologiska avdelingen nr 42, 86 pp.

Berglund, M., Fahlgren, L., Freland, M. & Vahter, M. 1994: Metaller i mark i Stockholms innerstad och kranskommuner – förekomst och hälsorisker för barn. Institutet för miljömedisin, Karoliska Institutet I samarbete med Miljöförvaltningen i Stockholm stad, IMM-rapport 2/94. 46 pp.

Birke, M., Rauch, U. & Helmert, M. 1992: Umweltgeokemie des Ballungsraumes Berlin -Schöneide: teil 1: Bearbeitungsmetodik - Elementverteilung in Böden und Grundwassern. Zeitschrift für angewandte geologie, 38, 37 - 66.

Birke, M. & Rauch, U. 1994: Geochemical investigation of the urban area of Berlin. Federal Institute of Geosciences and Natural Resources, Branch Office Berlin, Germany, 13 pp.

Chen, T.B., Wong, J.W.C., Zhou, H.Y. & Wong, M.H. 1997: Assessment of trace metal distribution and contamination in surface soils of Hong Kong. Environmental Pollution 96, 61-68.

Gale, G. H. & Roberts, D. 1974: Trace element geochemistry of Norwegian Lower Palaeozoic basic volcanics and its tectonic implications. Earth and Planetary Science Letters 22, 380-390.

Hagen, L.O., Bartonova, A., Berg, T., Røyset, O. & Vadset, M. 1989: Kartlegging av konsentrasjoner av tungmetaller i luft i tettsteder. Statlig program for forurensningsovervåking - Report 350/89, 47pp.

Hana, K. 1996: Nidelvas utvikling ved Kjøpmannsgata. Hovedoppgave ved Institutt for geologi og bergteknikk, Norges Teknisk Naturvitenskapelige universitet, 66 pp.

Karlsaune, P. A. 1995: Reproduserbarhet av geokjemiske data fra en lokalitet med forurenset grunn. Institutt for geologi og bergteknikk. Norges Tekniske Høgskole, 51 pp.

Kelly, J., Thornton, I. & Simpson, P.R. 1994: Urban geochemistry of how anthropogenic activity has influenced the geochemistry of soils in a traditionally industrial and a non-industrial area of Britain. In Helios Rybicka, A. & Sikora, R. (eds.): 3rd International Symposium on Environmental Geochemistry. Abstracts. Krakow, Poland, 194.

Langedal, M. & Ottesen, R.T. 2001: Plan for forurenset grunn og sedimenter i Trondheim. Trondheim kommune, Miljøavdelingens rapporter, TM 01/03, 15 pp.

Mielke, H.W. & Reagan, P.L. 1998: Soil is an important pathway of human lead exposure. Environmental health perspectives 106, 217-229.

Mielke, H.W., Gonzales, C.R., Smith, M.K. & Mielke, P.W. 1999: The urban environment and childrens health: Soils as an integrator of lead, zinc, and cadmium in New Orleans, Louisiana, U.S.A. Environmental Research Section A 81, 117-129.

Moir, A.M. & Thornton, I. 1989: Lead and cadmium in urban allotment and garden soils and vegetables in United Kingdom. Environmental Geochemistry and Health 11, 113-119.

Ottesen, R.T., Bogen, J. Bølviken, B. & Volden, T. 1989: Overbank sediment: A representative sample medium for geochemical mapping. Journal of Geochemical Exploration 32, 257-277.

Ottesen, R.T. & Volden, T. 1999: Jordforurensning i Bergen. Norges geologiske undersøkelse. Report 99.022, 27 pp.

Ottesen, R.T., Volden,T., Finne, T.E. og Alexander, J. 1999a: Jordforurensning i Bergen - Undersøkelse av barnehager, barneparker og lekeplasser på Nordnes, Jekteviken og Dokken. Helserisikovurdering. Norges geologiske undersøkelse. Report 99.077, 52 pp.

Ottesen, R.T., Volden,T., Finne, T.E. & Alexander, J. 1999b: Helserisikovurdering av arsen, bly og PAH fra jord og sand i barns lekemiljø. Forslag til tiltak. Norges geologiske undersøkelse. Report 99.083, 19 pp.

Ottesen, R.T., Volden, T., Finne, T.E., Aalexander, J., Langedal, M. & Eide, L. 2000a: Soil pollution in Norwegian cities - State of pollution, sources and health risk. In Burghart, W. & Dornauf, C. (eds.): First International Conference on Soils of Urban, Industrial, Traffic and Mining Areas. International Union of Soil Sciences (IUSS), University of Essen, Germany, 555-559.

Ottesen, R.T., Thijus, L., Flaten, T.P. & Steinnes, E. 2000b: Heavy metal contamination of surface soils in the city of Trondheim. In Burghart, W. & Dornauf, C. (eds.): First International Conference on Soils of Urban, Industrial, Traffic and Mining Areas. International Union of Soil Sciences (IUSS), University of Essen, Germany, 611-616.

Ottesen, R.T., Bogen, J., Bølviken, B., Volden, T. & Haugland, T. 2000c: Geokjemisk atlas for Norge. Norges geologiske undersøkelse. 140 pp.

Reite, A. 1983: Trondheim. Beskrivelse til kvartærgeologisk kart 1621 IV - M 1:50 000. Norges geologiske undersøkelse Skrifter 391.

Reite, A., Sveian, H. & Erichsen, E. 1999: Trondheim fra istid til nåtid - landskapshistorie og løsmasser. Gråsteinen 5, 40 pp.

Roberts, D. & Gee, D. 1985: An introduction to the structure of the Scandinavian Caledonides. In Gee, D.G. & Sturt, B.A. (eds) The Caledonide orogen - Scandinavia and related areas. John Wiley & Sons, Chichester, 55-68.

Slagsstad, T. 1998: High-K2O plagiogranite and greenstones in ophiolitic rocks of Bymarka, Trondheim. Diploma (M.Sc.) thesis, Norwegian University for Science and Technology, Trondheim, 98 pp.

Viverette, L., Mielke, H.W., Brisco, M., Dixon, J., Schaefer, J. & Pierre, K. 1996: Environmental health in minority and other underserved populations: benign methods & identifying lead hazards at day care centres of New Orleans. Environmental Geochemistry and Health, 18, 41-45.

Wolff, F.C. 1979: Beskrivelse til de berggrunnsgeologiske kart Trondheim og Østersund, 1: 250 000. Norges geologiske undersøkelse 353, 55 pp.