



TAPIR – Finnish national geochemical baseline database

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ARTICLE INFO

Article history:

Received 15 April 2010

Received in revised form 21 June 2010

Accepted 22 June 2010

Available online 31 July 2010

Keywords:

Background level

Geochemical baseline

Database

Soils

Geochemical mapping

Guideline value

Finland

ABSTRACT

In Finland, a Government Decree on the Assessment of Soil Contamination and Remediation Needs has generated a need for reliable and readily accessible data on geochemical baseline concentrations in Finnish soils. According to the Decree, baseline concentrations, referring both to the natural geological background concentrations and the diffuse anthropogenic input of substances, shall be taken into account in the soil contamination assessment process. This baseline information is provided in a national geochemical baseline database, TAPIR, that is publicly available via the Internet.

Geochemical provinces with elevated baseline concentrations were delineated to provide regional geochemical baseline values. The nationwide geochemical datasets were used to divide Finland into geochemical provinces. Several metals (Co, Cr, Cu, Ni, V, and Zn) showed anomalous concentrations in seven regions that were defined as metal provinces. Arsenic did not follow a similar distribution to any other elements, and four arsenic provinces were separately determined. Nationwide geochemical datasets were not available for some other important elements such as Cd and Pb. Although these elements are included in the TAPIR system, their distribution does not necessarily follow the ones pre-defined for metal and arsenic provinces.

Regional geochemical baseline values, presented as upper limit of geochemical variation within the region, can be used as trigger values to assess potential soil contamination. Baseline values have also been used to determine upper and lower guideline values that must be taken into account as a tool in basic risk assessment. If regional geochemical baseline values are available, the national guideline values prescribed in the Decree based on ecological risks can be modified accordingly.

The national geochemical baseline database provides scientifically sound, easily accessible and generally accepted information on the baseline values, and it can be used in various environmental applications.

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1. Introduction

In Finland, a new Government Decree on the Assessment of Soil Contamination and Remediation Needs (214/2007) came into force in June 2007. According to the Decree, baseline concentrations, referring both to the natural geological background concentrations and the diffuse anthropogenic input of substances, shall be taken into account in the assessment process. If the regional geochemical baseline of an element exceeds the threshold value given in the Decree, the regional geochemical baseline is to be used as the trigger value for the assessment of soil contamination. The new Decree has therefore generated a need for reliable and readily accessible data on geochemical baseline concentrations in Finnish soils. This information is provided in a national geochemical baseline database, TAPIR. The database was developed in co-operation between the Geological

Survey of Finland (GTK) and the Finnish Environment Institute (SYKE). In addition to GTK and SYKE, several Finnish consulting companies will both provide and use the required information on the geochemical baseline concentrations. MTT Agrifood Research Finland has also provided baseline information on agricultural soils for the database.

The terms “background” and “baseline” are often used as synonymous (e.g. Galuszka, 2007). The term “natural background” is widely used to infer background levels reflecting natural processes uninfluenced by human activities (Reimann and Garrett, 2005). Lee and Helsel (2005) define baseline as “summary of existing conditions over some time frame for some environmental system, or material of interest that typically do include influence of human activities”. Baseline represents a measure of a given sample in a specific location and time (e.g. Galuszka, 2007). Reimann and Garrett (2005) do not support the use of the term “baseline”. They have introduced the term “ambient background” that describes “the unmeasurably perturbed and no longer pristine natural background”. However, Reimann and Garrett (2005) also argue that “many slightly elevated levels in soils and sediments reflect ambient background and are no longer natural

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since natural background no longer exists". Thus, the term "natural background" could be used as long as natural processes can still be noticed. The TAPIR system presented in this article uses the term "baseline" to refer both to the natural geological background concentrations and the diffuse anthropogenic input of substances at regional scale. The chosen terminology follows the one used in the FOREGS geochemical baseline mapping programme (Salminen et al., 2005; De Vos and Tarvainen, 2006).

The TAPIR system consists of two separate databases: a relational database for geochemical baseline analysis from individual sampling points and another database for regional statistical summary data. Access to the point-wise database is restricted to the data providers and to the managing authority, GTK. Each data provider, such as a research institute, a university or a private consulting company, can enter field observations and analytical data from geochemical baseline sampling sites to the point-wise database using a web-based interface. Information on geochemical baseline concentrations from different soil parent materials and sampling depths is entered separately. The managing authority can then accept or reject the suggested baseline observations. The accepted analytical results are used to calculate statistics for pre-described geographical regions, referred to as geochemical provinces that were originally delineated by Eklund (2008).

The latter part of the database system holds the statistical summary information from the pre-defined geochemical provinces. Statistics are regularly calculated separately for each soil parent material type and for each geochemical province. These summary data are publicly available through a web-based geographical user interface (<http://www.gtk.fi/tapir>).

2. Materials and methods

A wide variety of observational data can be saved in the point-wise database of the TAPIR system. Information is collected via datasheets by logging into the web-based interface. Contact information is first entered on the organization responsible for sampling. This information is required in order to continue data input. The general information datasheet collects information on the sampling procedure including name of the person who has taken the samples and the sampling date. The general information datasheet also compiles information on the sampling site as well as the sample itself. The data provider can enter the name and coordinates of the sampling site, the sampling depth, a description of the sampling site (pre-defined list of sites), the sample material (pre-defined list of possible sampling types: till, sand, clay, man-made ground, and humus), sample type (single sample or composite sample), groundwater level (if known) and possible source of diffuse contamination that can easily be observed at the sampling site (pre-defined list of possible contamination sources). Information on coordinates of the sampling site and on sample material is mandatory, other information is entered if it is available.

The inorganic substances datasheet collects information on analysis results. The database only accepts analysis results from the <2 mm grain size fraction. The leaching method has to be selected as either aqua regia extraction or concentrated nitric acid leach. The Finnish Environmental Administration Guidelines relating to the Decree (214/2007) describe the recommended analytical methods when investigating possible soil contamination (Ministry of the Environment, 2007). Either aqua regia extraction (ISO 11466, 1995) or a concentrated nitric acid leach method (USEPA 3051A, 1998) is suggested. The determined concentrations for selected trace elements can be entered for one or several elements. In addition to the trace elements As, Cd, Co, Cr, Cu, Hg, Ni, Pb, Sb, V and Zn indicated in the Decree (214/2007), some other relevant and potentially harmful elements (Tl, Ba, B, Mo, Se and Sn) are included in the database.

Since the baseline concentration refers to both the natural geological background concentrations and the diffuse anthropogenic input of elements, it is also possible to provide information on analytical results for some organic compounds to the database, although these compounds are not usually natural in origin. PAH as well as PCB datasheets collect information on such samples. The concentrations can be reported as total concentrations of PAH compounds or PCB congeners based on the Decree (214/2007), or as concentrations of a single compound or congener. The name of the laboratory and analysis method used can also be noted.

The TAPIR system has determined acceptable concentration levels for each element to be considered as a baseline concentration. The lower guideline value is set as a maximum acceptable concentration for those trace elements and organic compounds that are indicated in the Decree (214/2007). For the other elements the limits are based on other existing risk-based reference values. However, GTK as a managing authority is able to decide if higher concentrations are also eligible to be included in the TAPIR system e.g. due to specific geological conditions of an area.

In the detailed assessments of soil contamination and especially in risk assessment procedures more parameters such as pH, total carbon content and cation exchange capacity are often needed. This information is not collected to the TAPIR system thus it has originally been generated to provide information on regional baseline concentrations to be used in the first phase of tiered based risk assessment.

Though neither grain size distribution nor clay or organic carbon contents are documented from the samples in the TAPIR system, the information on soil parent material is mandatory. The TAPIR system distinguishes the used sample material in nine classes based on variation in grain size and organic carbon content: (1) glacial till, (2) clay and other fine-grained sediments, (3) sand and other coarse-grained sorted sediments, (4) humus or other natural biogenic topsoil, (5) peat, (6) man-made soil dominated by biogenic material, (7) coarse-grained man-made soil, (8) fine-grained man-made soil, and (9) man-made soil with variable texture. Statistics (e.g. median, mean, 25th and 75th percentiles) are always calculated to each sample material separately.

The scheme of the TAPIR system is illustrated in Fig. 1.

In 1997, Salminen and Tarvainen (1997) demonstrated that geochemical background concentrations in Finland change regionally according to the bedrock geology and locally according to the type and genesis of overburden. Salminen and Gregorauskiene (2000) compared geochemical baseline concentrations in two very different geological environments in Finland and in Lithuania. Geochemical baseline concentrations are dependent on bedrock geology, the provenance of the sample material collected, the sample medium (e.g. topsoil, stream sediment), its grain size and the extraction method. In the TAPIR system, all the metal analysis results are based on aqua regia extraction or concentrated nitric acid leach, the analysed grain size is <2 mm, and statistics are calculated for different soil parent material types. However, even within Finland the chemical composition of soil parent material varies between geological units. Thus, it will not be possible to define a single baseline value for each soil parent material type that is valid throughout the country. This is why geochemical provinces are introduced in the TAPIR system and statistics are presented for each soil parent material within each geochemical province separately.

Reimann and Garrett (2005) concluded that geochemical mapping at an appropriate scale is essential to construct a map showing areas of relatively homogeneous geochemistry. A map of geochemically homogeneous areas with other relevant information can be used to deduct the natural and anthropogenic processes that determine the distribution of elements.

GTK carried out nationwide geochemical mapping of till in Finland on a reconnaissance scale (1 sample/300 km²) in 1983 (Koljonen, 1992) and on a regional scale (1 sample/4 km²) during 1984–1992 (Salminen, 1995). These surveys provided information on the natural elemental

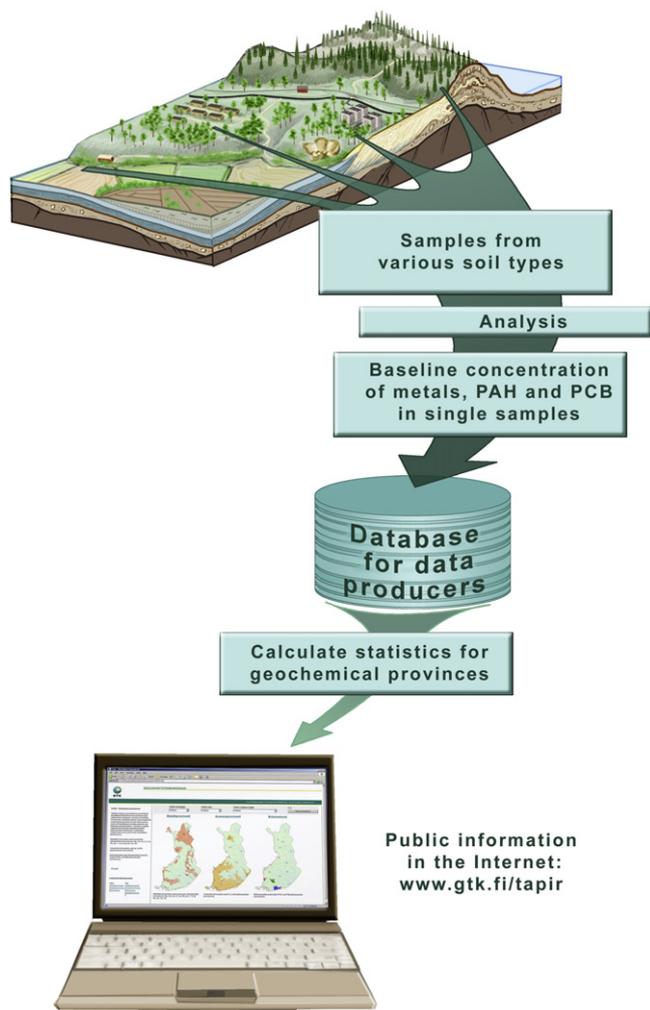


Fig. 1. Scheme of the TAPIR system.

distribution in slightly weathered subsoil of the most common soil parent material in Finland, glacial till. These datasets were used to divide Finland into geochemical provinces. Determinations of Cd, Hg and Pb were missing from these nationwide mapping programmes, but the concentrations of these elements were determined in the later Barents Ecogeochemistry project (Salminen et al., 2004).

Koljonen (1992) divided Finland into geochemical provinces and sub-provinces according to the co-occurrence of elements. This delineation was based on the chemical composition of the underlying bedrock, which reflects the chemical concentrations in till. While delineating the provinces presented in the TAPIR system, the threshold values indicated in the Government Decree on the Assessment of Soil Contamination and Remediation Needs (214/2007) were also taken into account. The distribution of concentrations was examined and provinces were delineated based on a comparison with both threshold values and geological and geochemical data (Eklund, 2008). Provinces presented in the TAPIR system indicate the distribution of smaller amounts of trace elements than the provinces presented by Koljonen (1992).

The similarity of the elemental distribution of studied elements was tested with hierarchical cluster analysis. The results indicated that Co and V have a similar distribution, following that of Cu, Ni, Cr and Zn. These elements were selected to present areas with ascending concentrations, i.e. metal provinces. The distribution of the remaining studied elements, As, Sb and Pb, was not similar to that of any other elements. The results of hierarchical cluster analysis are presented as a dendrogram in Fig. 2.

Dendrogram using Single Linkage

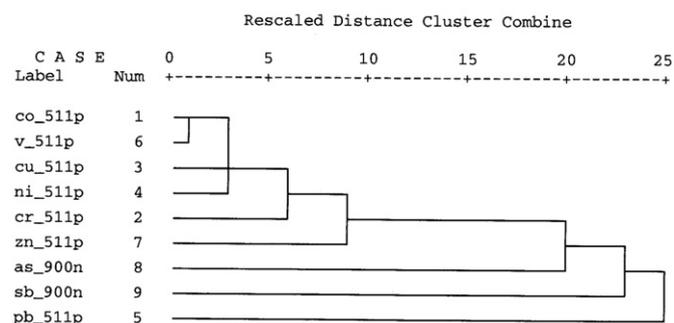


Fig. 2. Hierarchical clustering results (dendrogram) of the element concentrations in the fine-fraction of glacial till in Finland. The dendrogram is based on samples from the nationwide geochemical mapping of till in Finland (Koljonen, 1992). 511p = total dissolution, ICP-AES; 900n = neutron activation analysis.

Several metals (Co, Cr, Cu, Ni, V, and Zn) showed anomalous concentrations in seven regions, which were defined as metal provinces 1–7 (Fig. 3). The threshold values given in the Decree (214/2007) are occasionally exceeded in natural till parent material in these areas. The regional baseline value of the metal concentration should be used as the trigger value for assessing soil contamination. The regional distribution of arsenic is different from the above-

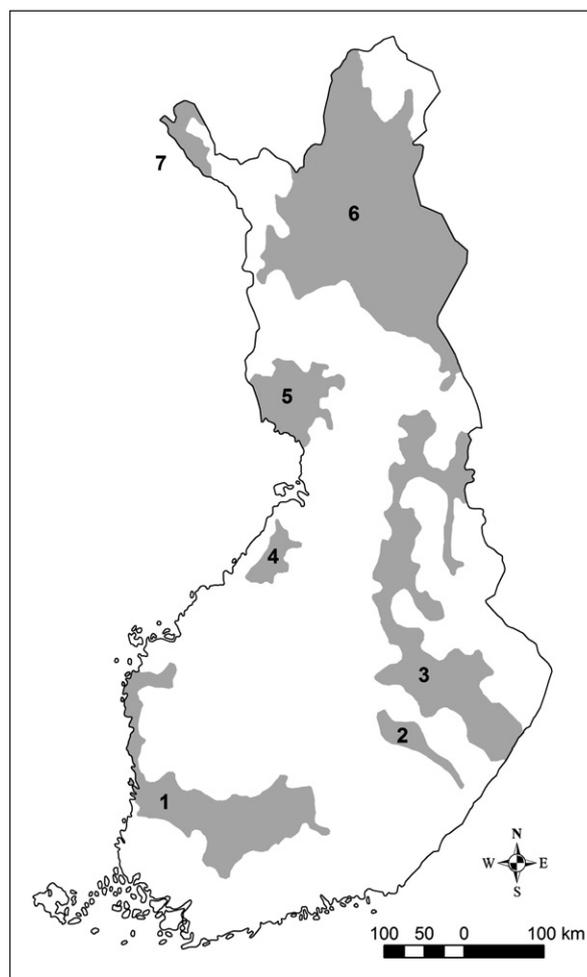


Fig. 3. Geochemical baseline provinces for metals. 1 = Southern Finland metal province; 2 = Varkaus metal province; 3 = Northeastern metal province; 4 = Oulainen metal province; 5 = Kemi metal province; 6 = Lapland metal province; 7 = Enontekiö metal province.

mentioned metals. Thus, an alternative province map with four anomalous areas was designated for As (Fig. 4).

Concentrations of Sb in glacial till hardly ever exceed the threshold value of 2 mg kg⁻¹ given in the Decree (214/2007). Due to lack of nationwide information, Sb provinces have not been defined, but it will be possible to distinguish areas with ascending Sb concentrations. At present, Sb is included in the arsenic provinces.

There was also lack of nationwide analytical data for Hg, Cd and Pb concentrations to define anomaly provinces for these elements. The statistical parameters for these elements are presented within metal provinces. The other potentially harmful elements (Tl, Ba, B, Mo, Se and Sn) presented in the TAPIR system are also reported within metal provinces.

Statistics are separately calculated for each geochemical province and each soil parent material type. In addition to the most common statistical parameters such as the median and mean, the upper limit of the baseline variation within a geochemical province is an important parameter for decision makers. As suggested in the Annex B of the ISO 19258:2005 standard (2005), upper outliers are to be removed using box and whisker plots. The maximum acceptable baseline concentration for a geochemical province is to be based on the upper limit of the upper whisker line (Fig. 5).

The upper limit of geochemical baseline variation for element X (ULBL_X) can be calculated as follows:

$$ULBL_X = P_{75} + 1.5 \times (P_{75} - P_{25}) \quad (1)$$

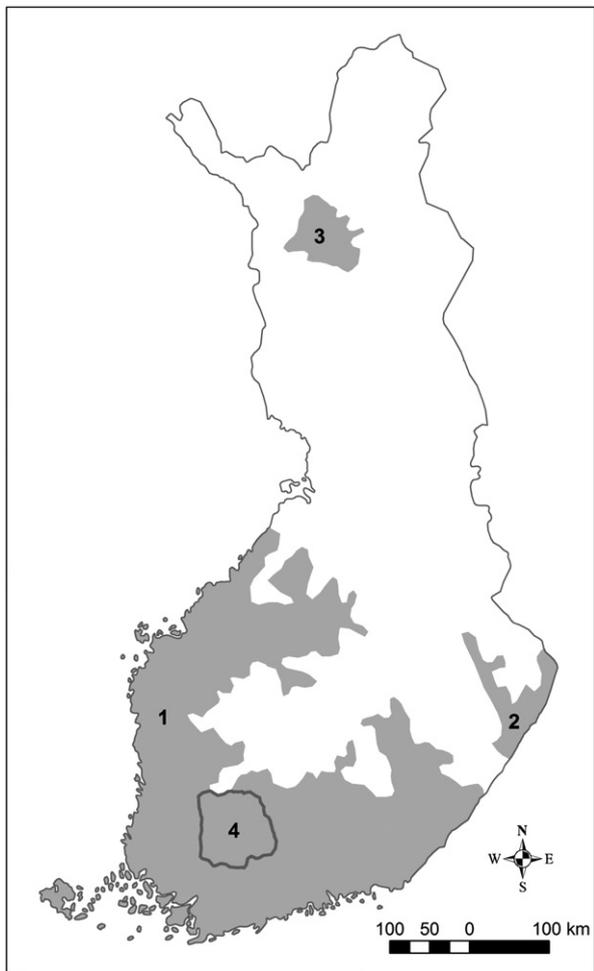


Fig. 4. Geochemical baseline provinces for arsenic. 1 = Southern Finland arsenic province; 2 = Ilomantsi arsenic province; 3 = Kittilä arsenic province; 4 = Southern Pirkanmaa arsenic province.

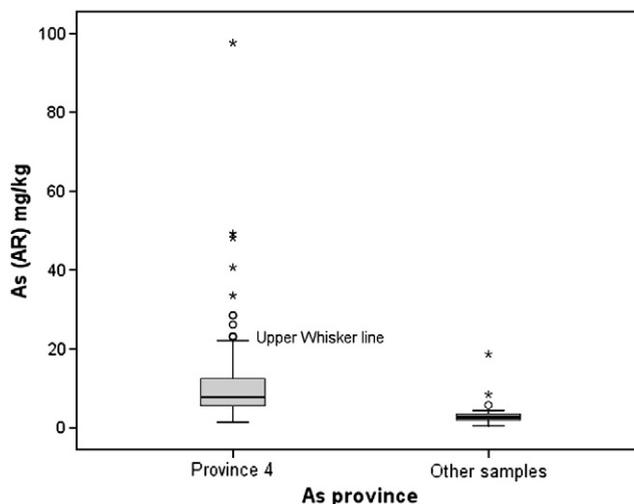


Fig. 5. Example of the boxplot presentation of the distribution of arsenic in topsoils within Southern Pirkanmaa arsenic province. The upper whisker line defines the upper limit of the background variation in the TAPIR system.

where

- P_{75} 75th percentile of element X concentrations
 P_{25} 25th percentile of element X concentrations.

Four different methods for the removal of outliers from the datasets were tested: normal probability plots, log-transformed probability plots, a box and whisker plot after logarithmic transformation and a box and whisker plot. The methods are described in detailed in the Annex B of the ISO 19258:2005 standard (2005). A box and whisker plot without any logarithmic transformation led to the highest number of upper outliers and it was chosen for the calculations of the upper limit of geochemical baseline variation for elements, following the precautionary principle. This method enables to achieve robust estimate of upper limit of geochemical baseline variation even if datasets are relatively small.

Reimann et al. (2005) have shown that the boxplot is a statistically oriented method to identify outliers as long as they comprise less than 15% of a dataset. Outliers and extreme values above the upper whisker line may represent natural concentrations of an element at the sampling site. However, they are most probably not representative of the geochemical province as a whole.

The differences in concentrations between pre-defined metal or arsenic provinces and the surrounding area were tested with the Mann–Whitney and the Kolmogorov–Smirnov tests. The Mann–Whitney Test is commonly used to compare the medians of two independent groups, while the Kolmogorov–Smirnov Test is used to compare the cumulative distribution of two independent sample groups.

To test and better illustrate the differences in concentrations between provinces, a quantile probability plot, i.e. a Q–Q plot was used. This is a graphical technique for determining whether two datasets come from populations with a common distribution. The normal Q–Q plot that was used in this study graphically compares the distribution of given variables to a normal distribution. StatSoft® STATISTICA data analysis software system, version 9.0 was used. Alongside a Q–Q plot, beanplots were also used to compare the distribution of different groups. A beanplot is an alternative to the boxplot for visual comparison of data between groups (Kampstra, 2008). Beanplots were developed by using R software for statistical computing and graphics.

Due to the lack of nationwide geochemical data for different sampling media, only till samples were included in these statistical tests. Concentrations exceeding the upper limits of geochemical baseline values of each province were excluded from the testing. The

aim was to determine whether there is a difference between concentrations in the provinces and the surrounding area, i.e. to test the confidence of the pre-defined geochemical provinces.

Currently, the TAPIR system includes data mostly from nationwide geochemical mapping programmes that have collected samples from rural areas. Only recently geochemical mappings have concentrated on urban areas and their surroundings, and samples with possible anthropogenic influence are only available from restricted areas. Thus, separate “urban geochemical provinces” could not yet be defined. Some information on detailed geochemical baseline studies in urban areas and their surroundings are, however, already available via the TAPIR system.

3. Results

The identified geochemical metal and arsenic provinces and their general geological characteristics are presented in Table 1. In Figs. 6 and 7, the provinces are presented together with bedrock maps. The special characteristics in bedrock that influence element concentrations and their distribution are not necessarily seen on the maps in Figs. 6 and 7 due to downscaling and generalization of bedrock mapping data. The recommended geochemical baseline values, which are based on the upper limit of geochemical baseline variation (Eq. (1)), are presented for each pre-defined geochemical arsenic province in Table 2 and those for geochemical metal provinces in Tables 3–5.

Comparison of As and Sb concentrations between the arsenic provinces (Southern Finland and Southern Pirkanmaa) and the surrounding area with Mann–Whitney and the Kolmogorov–Smirnov tests showed highly significant differences. The differences between three provinces were evident while illustrating the distribution with a Q–Q plot (Fig. 8) and with a beanplot (Fig. 9). The surrounding area is dominated by lower arsenic concentrations when comparing the shape of the beanplots to those of arsenic provinces. On the other hand, the Southern Pirkanmaa arsenic province has higher concentrations than the Southern Finland arsenic province. Thus, it is reasonable to use the upper limit of baseline variations that have been specifically defined for arsenic provinces instead of national geochemical baseline values.

Comparison of Co, Cr, Cu, Ni, Zn and V concentrations between the metal provinces and surrounding area also revealed highly significant differences. The difference between metal provinces was evident while illustrating the distribution of Cr and Ni concentrations with a beanplot (Figs. 10 and 11). The surrounding area is dominated by lower concentrations when comparing the shape of the beanplots to those of metal provinces. Thus, it is also reasonable to use the upper limit of baseline variations that have been specifically defined for metal provinces instead of national geochemical baseline values for these metals. According to the Kolmogorov–Smirnov Test results, the most extreme differences were positive.

Comparison of Hg, Cd and Pb concentrations between metal provinces (Southern Finland and Lapland) and the surrounding area

Table 1
Geochemical provinces and their general geological characteristics.

	Bedrock	Till	Other comments concerning concentrations
<i>Metal provinces</i>			
1. Southern Finland	Svecofennian and Karelian mica schists, mica gneisses and migmatites (northern part; Pirkanmaa belt); Svecofennian and Karelian mafic to intermediate metavolcanic rocks (southern part; Häme belt) (Kähkönen, 2005)	Medium or high fines and high clay fraction content (Lintinen, 1995)	Upper limit of baseline variation higher than the threshold value in fine-grained sediments for Co, Cr, Ni and V, and in humus for Pb. Upper limit of baseline variation higher than in surrounding areas in till and sand for Co, Cr, Cu, Ni, Zn, V, Ti, Ba, Mo and Be.
2. Varkaus	Svecofennian and Karelian mica schists, mica gneisses and migmatites (Saimaa area) (Kähkönen, 2005)	Medium fines and low clay fraction content (Lintinen, 1995)	Upper limit of baseline variation higher than in surrounding areas in till for Co, Cr, Cu, Ni, Zn, V and Ba.
3. Northeastern Finland	Supracrustal greenstone belt within the Karelian domain (Sorjonen-Ward and Luukkonen, 2005), abundance of black shale (Arkimaa et al., 2000)	Medium fines and low clay fraction content (Lintinen, 1995)	Upper limit of baseline variation higher than in surrounding areas in till for Co, Cr, Cu, Ni, Zn, V and Ba.
4. Oulainen	Svecofennian and Karelian mica schists, mica gneisses and migmatites (Pohjanmaa belt) (Kähkönen, 2005).	High fines and clay content (Lintinen, 1995)	Upper limit of baseline variation higher than in surrounding areas in till for Co, Cr, Cu, Ni, Zn, V and Ba.
5. Kemi	Peräpohja belt, including layered mafic intrusions and volcanic sedimentary layers (Laajoki, 2005).	Medium fines and low clay fraction content (Lintinen, 1995)	Upper limit of baseline variation higher than in surrounding areas in till for Co, Cr, Cu, Ni, Zn, V and Ba.
6. Lapland	Central Lapland greenstone belt and Lapland granulite belt (Hanski and Huhma, 2005)	Central part of the province has high fines and clay fraction content (Lintinen, 1995)	Upper limit of baseline variation higher than in surrounding areas in till for Co, Cr, Cu, Ni, Zn, V and Ba.
7. Enontekiö	Archean gneiss and granite (Hanski and Huhma, 2005), Caledonian assemblages	Low fines and clay fraction content (Lintinen, 1995)	Upper limit of baseline variation higher than in surrounding areas in till for Cu, Ni, Zn, V and Ba.
<i>Arsenic provinces</i>			
1. Southern Finland	Svecofennian domain (Kähkönen, 2005)	Varies from low to high (Lintinen, 1995)	As: Upper limit of baseline variation higher than threshold value for all soil parent material Sb: Upper limit of baseline variation higher than in surrounding areas in till and sand
2. Ilomantsi	Ilmonatsi greenstone belt, Svecofennian and Karelian mica schists, mica gneisses and migmatites (Kähkönen, 2005).	Medium fines and low clay content (Lintinen, 1995)	As: Concentrations exceed national baselines
3. Kittilä	Central Lapland greenstone belt (Hanski and Huhma, 2005)	High fines and clay fraction content (Lintinen, 1995)	As: Concentrations exceed national baselines
4. Southern Pirkanmaa	Svecofennian and Karelian mica schists, mica gneisses and migmatites (northern part; Pirkanmaa belt); Svecofennian and Karelian mafic to intermediate metavolcanic rocks (southern part; Häme belt) (Kähkönen, 2005)	Medium or high fines and high clay fraction content (Lintinen, 1995)	As: Upper limit of baseline variation higher than the threshold value for all soil parent material except humus Sb: Upper limit of baseline variation higher than in surrounding areas in till

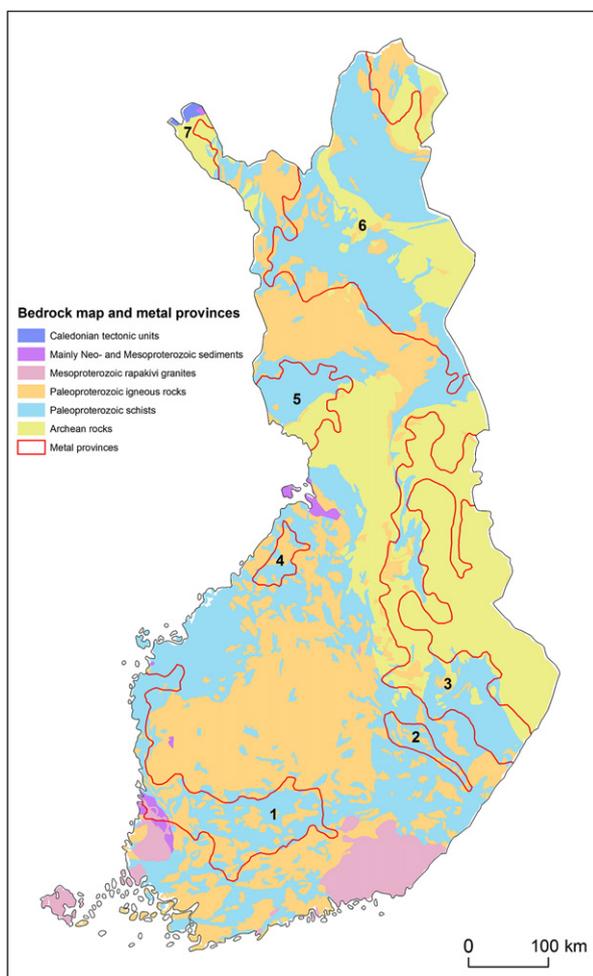


Fig. 6. Metal provinces in the generalized bedrock map of Finland. Bedrock map© Geological Survey of Finland.

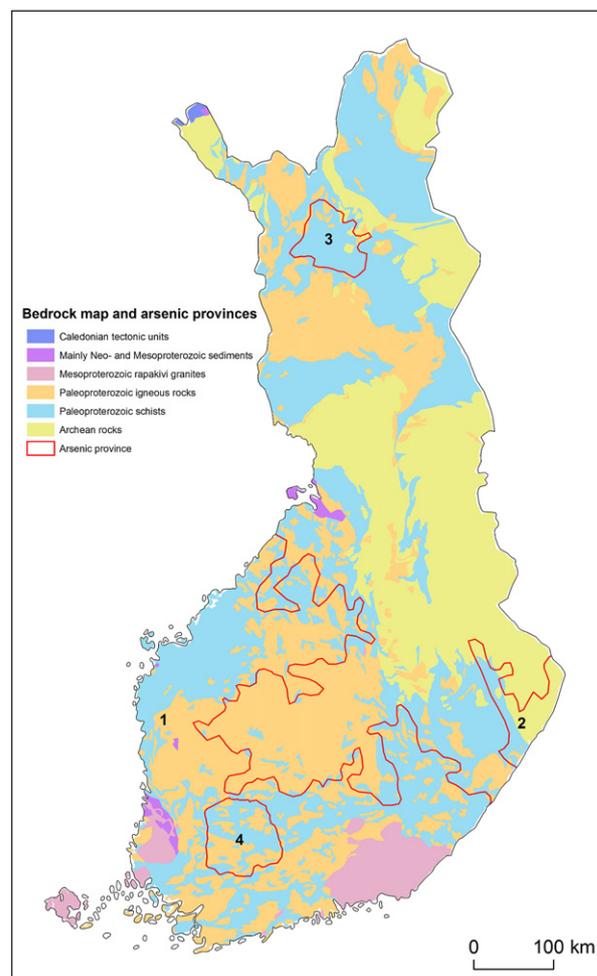


Fig. 7. Arsenic provinces in the generalized bedrock map of Finland. Bedrock map© Geological Survey of Finland.

showed highly significant differences, except for Hg, when comparing the Lapland metal province with the surrounding area. In latter case, the difference was significant at the 0.034 significance level. Thus, Hg concentrations do not necessarily follow the delineation of the Lapland metal province. Based on the Kolmogorov–Smirnov Test, the extreme differences were mainly positive. However, negative differences were also found. The most extreme difference was negative when comparing Cd and Pb between the Lapland metal province and the surrounding area. This means that Cd and Pb concentrations in the Lapland province are often lower than in the surrounding area. The difference between Southern Finland and Lapland metal provinces and the surrounding area was evident while illustrating the distribution of Pb concentrations with a beanplot (Fig. 12). The concentrations were lowest in Lapland and there was also no marked difference in the distribution of concentrations between Southern Finland and the surrounding areas.

The use of metal province delineation for Hg, Cd and Pb should still be considered. Previous studies in South Finland have shown that anthropogenic diffuse input can be a relevant factor determining the concentrations of these elements in mineral topsoil at regional scale (e.g. Tarvainen et al., 2006; Hatakka et al., 2010). In the surroundings of the Helsinki metropolitan area, Hg, Cd and Pb showed enrichment in mineral topsoil in comparison to subsoil concentrations (Tarvainen et al., 2006). In the Tampere region, enrichment of Hg, Cd and Pb in mineral topsoil was also detected. In addition, the median concentration of Pb in mineral topsoil samples taken inside the municipalities was higher than in mineral topsoil samples representing the

surrounding areas of the Tampere region (Hatakka et al., 2010). Variation in concentrations at national scale based on geological factors has not been possible to study due to the lack of nationwide geochemical data for these elements. In addition, the concentrations of Hg and Cd in natural soils are low and very often close to the detection limits.

Comparison of Ba concentrations between metal provinces and the surrounding area showed highly significant differences. Based on the Kolmogorov–Smirnov Test, the most extreme differences were positive. Comparison of Tl concentrations in the Southern Finland metal province and the surrounding area also showed a highly significant difference in concentrations. Comparison of Sn concentrations in the Southern Finland metal province and the surrounding area revealed no significant differences ($p=0.333$). Thus, Sn concentrations in the Southern Finland metal province did not differ from those in the surrounding area.

Comparison of Be, Mo and Se concentrations in metal provinces (Southern Finland and Lapland) and the surrounding area revealed highly significant differences, except for Be, between the Lapland metal province and the surrounding area. In latter case, the difference was significant at the 0.089 significance level. Thus, Be concentrations do not necessarily follow the delineation of the Lapland metal province. Based on the Kolmogorov–Smirnov Test, the most extreme difference was negative when comparing Se and Mo between the Lapland metal province and the surrounding area. This means that Se and Mo concentrations in the Lapland province are often lower than in the surrounding area. Negative differences were also found in other

Table 2

Arsenic concentration in various soil parent materials within the pre-defined arsenic provinces of Southern Finland and Southern Pirkanmaa and within the surrounding area. *N* = number of samples. ULBL = Upper Limit of BaseLine variation. Threshold value refers to the Decree (214/2007). All values are given as mg kg⁻¹. Shading indicates that the upper limit of baseline variation exceeds the threshold value prescribed in the Decree on the Assessment of Soil Contamination and Remediation Needs (214/2007).

	<i>n</i>	Mean	Median	Max	Percentiles		ULBL	Threshold value
					25	75		
<i>Southern Finland</i>								
As humus	580	2.76	2.17	28.00	1.62	3.12	5.4	5
As clay	441	4.93	4.60	20.00	2.00	7.10	15	5
As till	399	4.34	2.72	56.30	1.72	4.63	9.0	5
As sand	390	3.15	2.00	48.20	1.12	3.49	7.0	5
Sb humus	598	0.68	0.44	12.70	0.26	0.63	1.2	2
Sb clay	332	0.24	0.20	1.16	0.16	0.26	0.41	2
Sb till	498	0.13	0.08	2.30	0.04	0.12	0.24	2
Sb sand	373	0.26	0.09	2.80	0.05	0.50	1.2	2
<i>Southern Pirkanmaa</i>								
As humus	90	2.51	2.00	12.00	1.41	2.56	4.3	5
As clay	111	7.69	7.30	33.00	5.04	9.44	16	5
As till	184	12.08	7.21	233.00	4.23	12.93	26	5
As sand	390	3.15	2.00	48.20	1.12	3.49	7.0	5
Sb humus	131	0.24	0.25	0.66	0.17	0.31	0.52	2
Sb clay	108	0.24	0.24	0.60	0.18	0.29	0.45	2
Sb till	192	0.12	0.11	0.39	0.08	0.16	0.27	2
Sb sand	146	0.11	0.10	0.30	0.08	0.14	0.23	2
<i>Surroundings</i>								
As clay	31	2.28	1.70	11.40	0.00	3.47	8.7	5
As till	211	1.67	0.76	32.40	0.40	1.40	2.9	5
As sand	80	1.79	1.10	12.80	0.51	2.15	4.61	5
As peat	34	1.21	0.50	9.90	0.20	1.55	3.6	5
Sb till	421	0.03	0.01	0.50	0.01	0.03	0.05	2
Sb sand	34	<1	<1	<1	<1	b1		2
Sb peat	34	<1	<1	<1	<1	b1		2

cases, indicating that Be, Mo and Se concentrations in metal provinces do not necessarily differ from those in the surrounding area.

The use of metal province delineation for Be, Mo, Se and Sn should still be considered. Variations in concentrations at national scale based on geological factors have not been possible to study due to the lack of nationwide geochemical data for these elements. While investigating the concentrations of selenium it must also be pointed out that Se concentrations in natural soils are rather low and very often close to the detection limit.

4. Discussion

In the surrounding area outside the pre-defined provinces, arsenic concentrations were usually lower than the threshold value of 5 mg kg⁻¹ given in the Decree (214/2007). On the other hand, the upper limit of baseline variation was higher than the threshold value in most of the soil parent material types within the Southern Finland arsenic province and the Southern Pirkanmaa arsenic province (Table 2). Thus, it is recommended to use redefined baseline concentration levels while assessing soil contamination in these areas. The summary statistics have not been calculated for the arsenic provinces of Ilomantsi and Kittilä because the number of samples was less than 30. Arsenic province delineations can also be used to predict ascending baseline levels for Sb.

The concentrations of Co, Cr, Cu, Ni, V and Zn were higher within the pre-defined metal provinces compared to the background areas outside them (Table 3). However, the upper limit of the baseline variation seldom exceeded the threshold values given in the Decree (214/2007). The concentrations of Cd, Hg and Pb (Table 4) and B, Ba, Be, Mo, Se, Sn, and Tl (Table 5) are also given based on pre-defined metal provinces. However, the concentrations of these elements do

Table 3

Upper limit of baseline variation of Co, Cr, Cu, Ni, V and Zn within pre-defined metal provinces in various soil parent materials. All values are given as mg kg⁻¹. Shading indicates that the upper limit of baseline variation exceeds the threshold value prescribed in the Decree on the Assessment of Soil Contamination and Remediation Needs (214/2007). The number of samples varies greatly but is always >30.

	Co mg kg ⁻¹	Cr mg kg ⁻¹	Cu mg kg ⁻¹	Ni mg kg ⁻¹	V mg kg ⁻¹	Zn mg kg ⁻¹
<i>Southern Finland metal province</i>						
Humus	8.4	27	52	29	40	200
Clay	40	110	61	64	130	180
Till	17	64	44	40	75	70
Sand	18	76	41	42	93	130
<i>Varkaus metal province</i>						
Till	17	66	44	42	69	62
<i>Northeastern Finland metal province</i>						
Till	19	71	53	49	85	78
<i>Oulainen metal province</i>						
Till	18	64	47	43	77	70
<i>Kemi meta l province</i>						
Till	15	59	38	36	64	60
<i>Lapland metal province</i>						
Till	19	72	51	47	84	76
<i>Enontekiö metal province</i>						
Till	14	53	38	33	70	62
<i>Surrounding area</i>						
Humus	5.5	23	27	16	39	120
Clay	37	120	68	64	145	200
Till	13	53	33	30	61	51
Sand	9	36	19	16	42	70
Peat	7.8	33	41	22	60	84
Threshold value	20	100	100	50	100	200

not necessarily follow the metal province delineation, as described above.

The pre-defined geochemical provinces presented in the TAPIR system can be used while estimating the geochemical baseline concentrations for sandy soils and especially for glacial tills. However, geochemical baseline concentrations of fine-grained sediment do not necessarily follow the distribution of these geochemical provinces.

Table 4

Upper limit of baseline variation of Hg, Cd and Pb within pre-defined metal provinces in various soil parent materials. All values are given as mg kg⁻¹. Shading indicates that upper limit of baseline variation exceeds the threshold value prescribed in the Decree on the Assessment of Soil Contamination and Remediation Needs (214/2007). The number of samples varies greatly but is always >30.

	Hg mg kg ⁻¹	Cd mg kg ⁻¹	Pb mg kg ⁻¹
<i>Southern Finland metal province</i>			
Humus		0.85	66
Clay	0.09	0.5	31
Till	0.06	0.18	15
Sand	0.04	0.2	13
<i>Lapland metal province</i>			
Till	0.05	0.07	7.9
<i>Surrounding area</i>			
Humus	0.44	0.82	97
Clay	0.1	0.36	36
Till	0.06	0.11	16
Sand	0.09	0.14	11
Peat		0.67	7.5
Threshold value	0.5	1	60

Table 5

Upper limit of baseline variation of B, Ba, Mo, Se, Sn, Be and Tl within pre-defined metal provinces in various soil parent materials. All values are given as mg kg⁻¹. The number of samples varies greatly but is always >30.

	B mg kg ⁻¹	Ba mg kg ⁻¹	Mo mg kg ⁻¹	Se mg kg ⁻¹	Sn mg kg ⁻¹	Be mg kg ⁻¹	Tl mg kg ⁻¹
<i>Southern Finland metal province</i>							
Humus	8.7	240	1.6	0.90		0.38	0.42
Clay	13	310	2.7	0.65	2.7	2.2	0.82
Till		140	2.9	0.94	1.8	2.7	0.53
Sand	2.8	110	2.2	1.0	1.4	1.1	0.43
<i>Varkaus metal province</i>							
Till		110					
<i>Northeastern Finland metal province</i>							
Till		110					
<i>Oulainen metal province</i>							
Till		145					
<i>Kemi metal province</i>							
Till		150					
<i>Lapland metal province</i>							
Till		170	0.70	0.20		0.79	
<i>Enontekiö metal province</i>							
Till		170					
<i>Surrounding area</i>							
Humus	1.5	170	0.70	0.20	5.0	0.79	0.41
Clay	20	320	2.7	1.1	4.3	2.2	0.94
Till		92	1.7	1.1	2.0	0.96	0.36
Sand		59	1.0	0.90	2.0	0.95	0.38
Peat		200	1.5	0.65			

Based on regional geochemical mappings (Tarvainen et al., 2003, 2006; Kuusisto and Tarvainen, 2008; Hatakka et al., 2010), baseline concentrations of fine-grained sediments are usually higher than baseline concentrations of glacial tills or sandy soils, correlating with the higher clay fraction content. The main factor affecting the increased element concentrations in the anomalous zones is the variation in mica and clay mineral types (Räisänen et al., 1992), but organic matter and the oxyhydroxides of iron, aluminium and

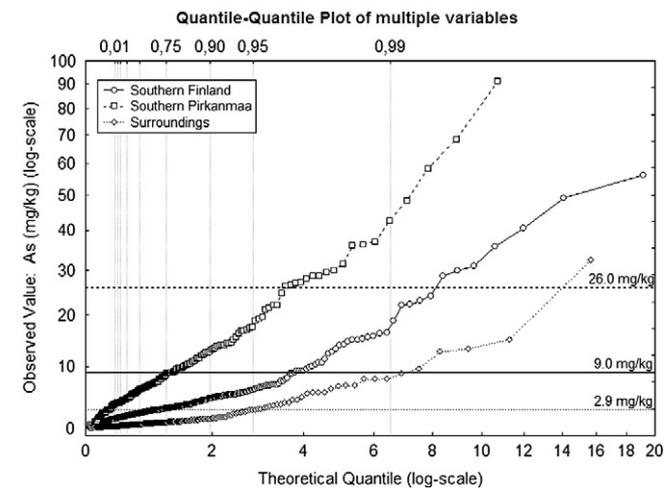


Fig. 8. A normal Q-Q plot of arsenic concentrations in till in two geochemical baseline provinces for arsenic, Southern Finland and Southern Pirkanmaa, and in the surrounding area. The upper limit of baseline variation of As within pre-defined arsenic provinces in till is marked with a dotted line for the surrounding area (2.9 mg kg⁻¹), with a black line for the Southern Finland arsenic province (9.0 mg kg⁻¹) and with a dashed line for the Southern Pirkanmaa arsenic province (26 mg kg⁻¹). Number of samples (n): Southern Finland n = 399, Southern Pirkanmaa n = 184, surrounding area n = 211.

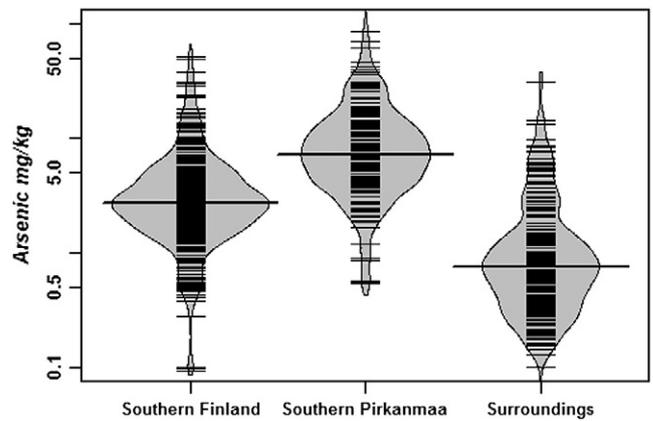


Fig. 9. A beanplot of arsenic concentrations in till in two geochemical baseline provinces for arsenic, Southern Finland and Southern Pirkanmaa, and in the surrounding area. Individual observations are shown as small black lines and the median value with a longer black line. The gray area shows the distribution of concentrations. The scale is logarithmic. Number of samples (n): Southern Finland n = 399, Southern Pirkanmaa n = 184, surrounding area n = 211.

manganese are also effective sorptive compounds in soils, resulting in the enrichment of most trace elements, including Mn, Co, Cu, Ni, Zn and Pb.

In Finland, numerous sediment cores were taken from 124 lakes between 1998 and 2001. Each core extended from the top of the sediment down to the point marking the isolation of the lake basin. Multi-element determinations from nitric acid extracts have been performed on these samples and natural average concentrations have been calculated (Mäkinen and Pajunen, 2005). Comparison of the geochemistry of aquatic sediments and the fine till fraction (Ø < 63 µm) has shown that mean element concentrations are usually lower in the till fines than in the aquatic sediments (Mäkinen, 2005). Lake sediment analyses are currently included in the TAPIR system and in calculations of regional baseline values for fine-grained sediments. The samples from the pre-isolation sediment layer representing all the water-borne sediments were selected from the lake sediment cores. The organic carbon content of these layers is usually less than 4% and they represent the element distribution in the lake basin before isolation (Mäkinen, 2005). It is necessary to define geochemical provinces separately for fine-grained sediments not

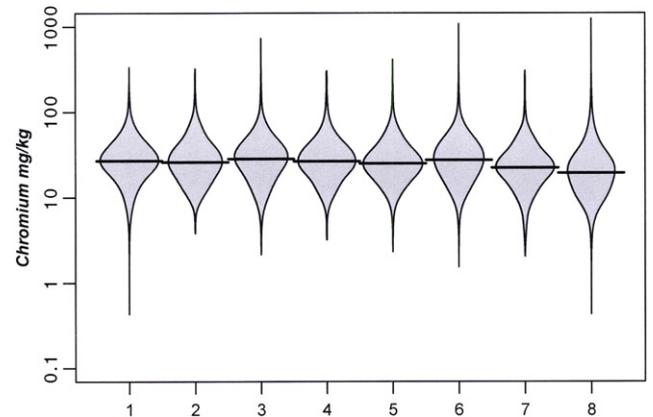


Fig. 10. A beanplot of chromium concentrations in seven geochemical baseline provinces for metals and in the surrounding area. The median value is shown with a longer black line. Individual observations are not shown due to large number of samples. The gray area shows the distribution of concentrations. The scale is logarithmic. The name of the metal province and number of samples (n) are as following: 1 = Southern Finland metal province (n = 4726), 2 = Varkaus metal province (n = 626), 3 = Northeastern Finland metal province (n = 6441), 4 = Oulainen metal province (n = 576), 5 = Kemi metal province (n = 1820), 6 = Lapland metal province (n = 11,897), 7 = Enontekiö metal province (n = 629), 8 = Surrounding area (n = 57,131).

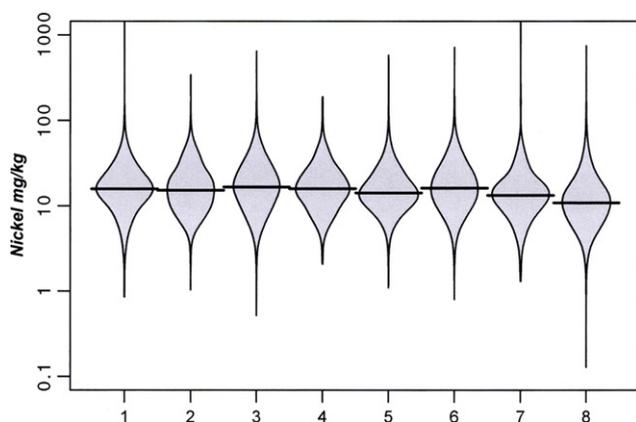


Fig. 11. A beanplot of nickel concentrations in seven geochemical baseline provinces for metals and in the surrounding area. The median value is shown with a longer black line. Individual observations are not shown due to the large number of samples. The gray area shows the distribution of concentrations. The scale is logarithmic. The name of the metal province and number of samples (n) are as following: 1 = Southern Finland metal province ($n = 4726$), 2 = Varkaus metal province ($n = 626$), 3 = Northeastern Finland metal province ($n = 6441$), 4 = Oulainen metal province ($n = 576$), 5 = Kemi metal province ($n = 1820$), 6 = Lapland metal province ($n = 11,897$), 7 = Enontekiö metal province ($n = 629$), 8 = Surrounding area ($n = 57,131$).

following the delineation defined for glacial till and sandy soils, or even consider presenting national baseline values for fine-grained sediments. However, the geochemical provinces for fine-grained sediments have not yet been determined and at present they follow the delineation of existing arsenic and metal provinces.

Man-made ground can also have varying chemical properties. The concentrations of many substances are elevated in the urban environment as a result of diffuse contamination. The ground is often disturbed and filled in, and might have a different geochemical signature compared to the surface deposits of the surrounding rural area. Even in undisturbed urban areas, the concentrations of many potentially harmful substances can be elevated relative to the rural background as pointed out by Ellison et al. (2002). Thus, to assess and provide baseline information for urban areas, site-specific examinations of the geochemical conditions in the area under investigation are required. Recent geochemical baseline studies in Finland have focused on defining geochemical baseline values for various soil parent materials around urban areas, and samples have been taken from visually undisturbed, natural soil. Few studies have been carried out within urban centers, where the samples have mainly been taken

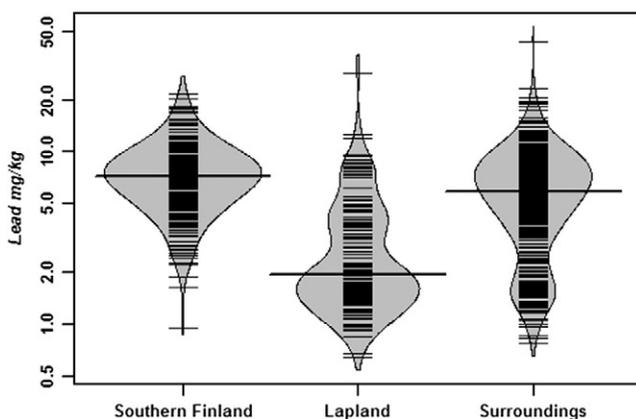


Fig. 12. A beanplot of lead concentrations in two geochemical baseline provinces for metals, Southern Finland and Lapland, and in the surrounding area. Individual observations are shown as small black lines and the median value with a longer black line. The gray area shows the distribution of concentrations. The scale is logarithmic. Number of samples (n): Southern Finland $n = 262$, Lapland $n = 150$, surrounding area $n = 401$.

from the central parks of cities and municipalities (e.g. Salla, 1999; Peltola, 2005; Salonen and Korkka-Niemi, 2007; Jarva and Tarvainen, 2008). In these studies, the concentrations of studied elements have mostly been at the same level within and around urban centers. This outcome differs from the one presented by Ellison et al. (2002) in Great Britain. The TAPIR system provides a possibility to download analysis results from man-made ground. Representative samples to determine baseline concentrations for urban centers should be carefully selected. The samples should present the overall concentrations, not any specific point-wise contamination.

The geochemical provinces have been defined at the regional scale. It was not possible to distinguish and take into account local geological anomalies or other local “hot spots”. It is still necessary to define more detailed local geochemical provinces for areas with a growing population and undergoing housing development, i.e. for areas where possible soil contamination frequently needs to be assessed. Reimann et al. (2010) have studied the variation of background concentrations of Sb of urbanised and the surrounding agricultural areas in Berlin, Germany. The resulted geochemical map showed increased concentrations in the central urban area and local anomalies in the vicinity of the point contamination sources. The study demonstrates the importance to have geochemical information both on urbanised areas and on the surroundings. The TAPIR system also provides information on separate detailed geochemical baseline studies that have been carried out in the urbanised areas and their surroundings. These data can be used to estimate local geochemical baseline values.

Regional geochemical mapping of till covers the whole country and gives reliable estimates of the geological background for many trace metals (Co, Cr, Cu, Ni, V, and Zn) in the most common soil parent material, glacial till. However, geochemical baseline data are very scarce for many other soil parent materials and for other important trace elements such as As, Cd, Hg, Pb or Sb. The national database, which combines data from various data producers, provides a means to gather information on all soil parent material types and all provinces in a reasonable time and limits the costs for such a national inventory.

Diffuse anthropogenic input can also be seen in humus but also in topsoil samples, with elevated Hg, Cd and Pb concentrations. This is seen as an enrichment of these elements in mineral topsoil compared to mineral subsoil in South Finland (Tarvainen et al., 2006; Hatakka et al., 2010). At the European scale, Hg, Cd and Pb shows enrichment in topsoil with respect to subsoil which is only partly explained by geological factors, thus anthropogenic influence is apparent (De Vos and Tarvainen, 2006). It should, however, be acknowledge that accumulation and enrichment of many elements to the O-horizon may also be due to natural biochemical cycling and not just due to anthropogenic activities (Reimann et al., 2007). The O- and B-horizons function as natural geochemical barriers (Goldschmidt, 1937) and thus enrichment of elements is seen in upper layers.

In addition to the threshold values, the Decree (214/2007) includes upper and lower guideline values that must be used as a tool in basic risk assessment. Guideline values describe maximum acceptable risks to the environment and human health. The upper guideline values can be applied to industrial areas and the lower ones to more sensitive land use types. Many of the guideline values have been defined on the basis of ecological risk, and the national baseline levels are considered in the derivation process. Guideline values set for Pb and Sb are based on their estimated health risk. Guideline values for Hg and Co have been adjusted to a lower level than their estimated ecological risk due to the lack of information on their toxicity to the environment (Reinikainen, 2007). If regional geochemical baseline values are available, the guideline values based on ecological risks can be modified accordingly. Regional guideline values can be defined by adding the regional baseline value to the concentration that describes maximum acceptable risks to the

environment. However, if the guideline values are based on human health risks, the guidelines should not be modified using the baseline data.

Guideline values are defined by adding the national baseline concentration to the concentration that prescribes the maximum acceptable risk to the environment (Reinikainen, 2007).

Lower guideline limit => maximum acceptable risk to the environment
+ baseline value

Upper guideline limit => maximum acceptable risk to the environment
+ baseline value

For example, the concentration of copper that prescribes the maximum acceptable risk to the environment is 125 mg kg^{-1} . The national baseline value for Cu is $22 (5\text{--}110) \text{ mg kg}^{-1}$ for the most common soil parent material, glacial till. Thus, the lower guideline limit for Cu is 150 mg kg^{-1} ($\approx 125 \text{ mg kg}^{-1} + 22 \text{ mg kg}^{-1}$). In the fine-grained sediments of the Southern Finland metal province, the baseline concentration of Cu is 61 mg kg^{-1} . Thus, the regional lower guideline value for Cu in fine-grained sediments of the Southern Finland metal province can be calculated as $125 \text{ mg kg}^{-1} + 61 \text{ mg kg}^{-1} = 186 \text{ mg kg}^{-1}$.

In addition to the ecological and health risks, soil contamination can pose a risk to the quality of groundwater. Groundwater risks have not always been considered in the definition of guideline values. Thus, additional information on potential risks to groundwater is needed if a contaminated site is located in an important groundwater area. Besides comparing regional baseline values to the total amount of contaminants and the total concentrations, the mobility of the contaminants is a key factor in the assessment of risks to groundwater.

The TAPIR system was established to provide information on geochemical baselines. In Finland, a tiered approach is suggested for the assessment of soil contamination starting from a qualitative site evaluation towards detailed site-specific quantitative risk assessment, when it can be considered as necessary (Reinikainen, 2008). The upper limits of geochemical baseline variation of elements that are provided by the TAPIR system for the geochemical provinces can be used as assessment thresholds in areas with baseline concentrations higher than the threshold values given in the Decree (214/2007). The exception for the use of baseline concentrations instead of the threshold values in the Decree (214/2007) is mainly given from a policy point of view in order to avoid inducing obligations to the owners of those sites, where the elevated soil concentrations are not due to the past or present activities on the site, and the owner thus cannot be held liable for them. In addition, the threshold values for inorganic elements have been set by using added risk approach, i.e. by adding a maximum permissible addition (MPA) of an element from anthropogenic sources, calculated based on the available laboratory test data, to the background concentration (Crommentuijn et al., 1997). The added risk approach assumes that organisms are adapted to higher concentrations in areas with higher baselines though it ignores the fact that the bioavailable fraction of the baseline concentration may also have negative effects on some organisms. The baseline values in the TAPIR system are defined regionally following the precautionary principle, i.e. the maximum acceptable baseline concentration for a geochemical province is not based on the highest detected baseline concentration but upper outliers representing the highest concentrations are identified and ignored. The use of regional baseline values for acknowledgement of assessment needs supports the identification of sites requiring detailed site-specific quantitative risk assessment.

5. Conclusions

Geological properties to a great extent determine the distribution of elements in soil. Not only bedrock but also regional variations in

the fine-fraction content of tills reflecting glaciation processes define element concentrations. An anthropogenic impact on baseline levels can be detected especially in man-made soils located in city centers.

The new Decree on the Assessment of Soil Contamination and Remediation Needs (214/2007) has prompted the development of a national database that combines both pre-existing and new soil geochemical baseline observations. Reliable data on baseline concentrations is of particular importance from the viewpoint of site owners in regions where the baseline values may exceed the threshold values given in the Decree (214/2007). This is because according to the Decree (214/2007), the threshold values that are used as trigger values for the assessment process are to be replaced by the baseline concentrations whenever they exceed the threshold values. The recalculations of regional guideline values will give tools to better assess the remediation needs as well as to choose the best available remediation technique for the area in question. The national baseline database, developed in co-operation between Finnish geologists, data providers and the environmental authorities, provides scientifically sound, easily accessible and generally accepted information on the baseline concentrations, thus contributing to rational and transparent decision-making.

Acknowledgments

The authors would like to thank Mr. Heimo Savolainen for calculating the basic statistics in the TAPIR system. Ms. Kati Laakso and Mr. Jari Lehtinen were the key persons involved in developing the TAPIR database. Senior scientist Nils Gustavsson prepared Fig. 8 and assisted with statistical methods. Mr. Harri Kuvonen prepared the scheme in Fig. 1. The authors would also like to thank Dr. Petri Lintinen for commenting on and Dr. Roy Siddall for correcting the English language of the manuscript. Two anonymous referees gave valuable comments to the manuscript.

References

- Arkimaa H, Hyvönen E, Lerssi J, Loukola-Ruskeeniemi K, Vanne J. Proterozoic black shale formations and aeromagnetic anomalies in Finland 1:1,000,000 [map]. Geological Survey of Finland. 2000. Special maps 45.
- Crommentuijn T, Polder MD, Van de Plassche EJ. Maximum permissible concentrations and negligible concentrations for metals, taking background concentrations into account. Bilthoven: National Institute of Public Health and the Environment (RIVM); 1997. [Report no. 601501 001].
- De Vos W (editor), Tarvainen T (editor), Salminen R, Reeder S, De Vivo B, Demetriades A, et al. Geochemical Atlas of Europe. Part 2 – Interpretation of geochemical maps, additional tables, figures, maps and related publications. Espoo: Geological Survey of Finland; 2006. 692 pp.
- Eklund M. National geochemical provinces in the assessment of soil contamination. University of Helsinki, Department of Geology 2008. Master thesis. Finnish.
- Ellison RA, McMillan AA, Lott GK. Ground characterisation of the urban environment: a guide to best practice. Natural Environment Research Council, British Geological Survey, Research Report RR/02/05. Nottingham: ©NERC 2002 British Geological Survey; 2002.
- Galuszka A. A review of geochemical background concepts and an example using data from Poland. Environ Geol 2007;52(5):861–70.
- Goldschmidt VM. The principles of distribution of chemical elements in minerals and rocks. J Chem Soc 1937;655–73.
- Hanski E, Huhma H. Central Lapland greenstone belt. In: Lehtinen M, Nurmi PA, Rämö OT, editors. Precambrian geology of Finland: key to the evolution of the Fennoscandian Shield. Developments in Precambrian geology, Amsterdam: Elsevier; 2005. p. 139–93.
- Hatakka T, Tarvainen T, Jarva J, Backman B, Eklund M, Huhta P, et al. Geochemical baselines in the Pirkanmaa region. Geological Survey of Finland, Espoo. 2010. Report of Investigation 182. [103 pp. Finnish].
- ISO 11466. Soil Quality. Extraction of trace elements soluble in aqua regia. Switzerland: International Standard Organisation (ISO); 1995.
- ISO 19258. Soil Quality. Guidance on the determination background values. Switzerland: International Standard Organisation (ISO); 2005.
- Jarva J, Tarvainen T. Geochemical baseline concentrations in the urban areas of the Tampere region. Geological Survey of Finland, Espoo. 2008. Archive report S41/2008/36. Finnish.
- Kähkönen Y. Svecofennian supracrustal rocks. In: Lehtinen M, Nurmi PA, Rämö OT, editors. Precambrian geology of Finland: key to the evolution of the Fennoscandian

- Shield. Developments in Precambrian geology, Amsterdam: Elsevier; 2005. p. 343–405.
- Kampstra P. Beanplot: a boxplot alternative for visual comparison of distributions. *J Stat Softw* 2008;28(1):1–9.
- Koljonen T, editor. The geochemical atlas of Finland. Part 2: till. Espoo: Geological Survey of Finland; 1992. [218 pp.].
- Kuusisto E, Tarvainen T. Geochemical baseline concentrations from different soil parent materials in the Pirkanmaa region. Geological Survey of Finland, Espoo. 2008. Archive report, S41/2008/30. Finnish.
- Laajoki K. Karelian supracrustal rocks. In: Lehtinen M, Nurmi PA, Rämö OT, editors. Precambrian geology of Finland: key to the evolution of the Fennoscandian Shield. Developments in Precambrian geology, Amsterdam: Elsevier; 2005. p. 279–341.
- Lee L, Helsel D. Baseline models for trace elements in major aquifers of the US. *Appl Geochem* 2005;20(8):1560–70.
- Lintinen P. Origin and physical characteristics of till fines in Finland. Geological Survey of Finland, Espoo; 1995. Bulletin 379. [83 pp.].
- Mäkinen J. A comparison of the geochemistry of aquatic sediments and the fine (<63 µm) till fraction in Finland. *Geochem Explor Environ Anal* 2005;5(2):159–67.
- Mäkinen J, Pajunen H. Correlation of carbon with acid-soluble elements in Finnish lake sediments: two opposite composition trends. *Geochem Explor Environ Anal* 2005;5(2):169–81.
- Ministry of the Environment. Assessment of soil contamination and the remediation need. Environmental Administration Guidelines, 2; 2007 [210 pp. Finnish].
- Peltola P. Multielement urban geochemistry – exploring the expected, the unexpected and the unknown [dissertation]. University of Kalmar: Faculty of Natural Science; 2005
- Räisänen ML, Tenhola M, Mäkinen J. Relationship between mineralogy and the physico-chemical properties of till in central Finland. *Bull Geol Soc Finland* 1992;64(1): 35–58.
- Reimann C, Garrett RG. Geochemical background – concept and reality. *Sci Total Environ* 2005;350:12–27.
- Reimann C, Filzmoser P, Garrett RG. Background and threshold: critical comparison of methods of determination. *Sci Total Environ* 2005;346:1–16.
- Reimann C, Arnoldussen A, Englmaier P, Filzmoser P, Finne TE, Garret RG, et al. Element concentrations and variations along a 120-km transect in southern Norway – anthropogenic vs. geogenic vs. biogenic element sources and cycles. *Appl Geochem* 2007;22:851–71.
- Reimann C, Matschullat J, Birke M, Salminen R. Antimony in the environment: lessons from geochemical mapping. *Appl Geochem* 2010;25:175–98.
- Reinikainen J. Derivation basis of threshold and guideline values for soil. The Finnish Environment, 23. Helsinki: Finnish Environment Institute; 2007. [164 pp. Finnish].
- Reinikainen J. Experience on risk-based assessment of soil contamination and remediation needs. Nordrocs, Short Papers and Abstracts, 2nd Joint Nordic Meeting on Remediation of Contaminated Sites, Helsinki, Finland, September 24–25; 2008. p. 86–8.
- Salla A. Background levels of harmful substances in the soils of Helsinki. Environment Centre of City of Helsinki; 1999 [Publications 15/1999. Finnish].
- Salminen R, editor. Regional geochemical mapping in Finland in 1982–1994. Geological Survey of Finland, Espoo, Report of Investigation 130; 1995. [47 pp.].
- Salminen R, Gregorauskiene V. Considerations regarding the definition of a geochemical baseline of elements in the surficial materials in areas differing in basic geology. *Appl Geochem* 2000;15:647–53.
- Salminen R, Tarvainen T. The problem of defining geochemical baselines. A case study of selected elements and geological materials in Finland. *J Geochem Explor* 1997;60(1): 91–8.
- Salminen R, Chekushin V, Tenhola M, Bogatyrev I, Glavatskikh SP, Fedotova E. Geochemical atlas of the Eastern Barents region. Amsterdam: Elsevier; 2004 [548 pp.].
- Salminen R, Batista MJ, Bidovec M, Demetriades A, De Vivo B, De Vos W, et al, editors. Geochemical atlas of Europe. Part 1 – background information, methodology and maps. Espoo: Geological Survey of Finland; 2005. [526 pp.].
- Salonen V-P, Korkka-Niemi K. Influence of parent sediments on the concentration of heavy metals in urban and suburban soils in Turku, Finland. *Appl Geochem* 2007;22(5): 906–18.
- Sorjonen-Ward P, Luukkonen EJ. Archean rocks. In: Lehtinen M, Nurmi PA, Rämö OT, editors. Precambrian geology of Finland: key to the evolution of the Fennoscandian Shield. Developments in Precambrian geology, Amsterdam: Elsevier; 2005. p. 19–99.
- Tarvainen T, Hatakka T, Kumpulainen S, Tanskanen H, Ojalainen J, Kahelin H. Geochemical baseline concentrations from different soil parent materials in the Porvoo region. Geological Survey of Finland, Espoo. 2003. Archive report, S41/3021/2003/1. Finnish.
- Tarvainen, T (editor), Eklund M, Haavisto-Hyvärinen M, Hatakka T, Jarva J, Karttunen V, et al. Geochemical baselines around the Helsinki metropolitan area. Geological Survey of Finland, 2006, Espoo. Report of Investigation 163 [40 pp. Finnish].
- USEPA Method 3051A. Microwave assisted acid digestion of sediments, sludges, soils and oils. Washington D.C: U.S. Environmental Protection Agency (USEPA); 1998 [24 pp.].