

GEMAS: Geochemistry of European agricultural and grazing land soil

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The project Geochemical Mapping of Agricultural and grazing land Soil (GEMAS) was carried out in 33 European countries (5.6 million km²) with an average sampling density of 1 site per 2500 km². The main objective was to assess the chemical quality of productive soils. All collected soil samples were prepared in the same laboratory, and subsequently analysed for the same suite of elements and physicochemical parameters in the same laboratory following a strict quality control procedure. Data interpretation revealed that few soil samples reach element concentrations where toxicity may become of concern. However, more than 10% of samples contain such low element concentrations that deficiency for optimum plant growth and animal health may be a much larger issue warranting attention.

Le projet Cartographie géochimique des sols agricoles et de pâturage (GEMAS - Geochemical Mapping of Agricultural and grazing land Soil) a été mené dans 33 pays européens (5,6 millions de km²) avec une densité d'échantillonnage moyenne de 1 site pour 2500 km². L'objectif principal était d'évaluer la qualité chimique des sols productifs. Tous les échantillons de sol collectés ont été préparés dans le même laboratoire, puis analysés pour la même suite d'éléments et de paramètres physico-chimiques dans le même laboratoire suivant une procédure de contrôle de qualité stricte. L'interprétation des données a révélé que peu d'échantillons de sol atteignent des concentrations d'éléments pour lesquels la toxicité serait préoccupante. A contrario, plus de 10 % des échantillons contiennent des concentrations d'éléments si faibles, que la déficience pour une croissance optimale des plantes et la santé animale forme un problème bien plus préoccupant qui mérite une attention particulière.

El proyecto Cartografía geoquímica de suelos agrícolas y de pastoreo (GEMAS) se llevó a cabo en 33 países europeos (5,6 millones de km²) con una densidad de muestreo promedio de 1 sitio por 2500 km². El principal objetivo fue evaluar la calidad química de suelos productivos. Todas las muestras de suelo recolectadas se prepararon en el mismo laboratorio y, posteriormente, se analizaron para el mismo conjunto de elementos y parámetros fisicoquímicos en el mismo laboratorio siguiendo un estricto procedimiento de control de calidad. La interpretación de los datos reveló que pocas muestras de suelo alcanzan concentraciones de elementos donde la toxicidad puede convertirse en motivo de preocupación. Sin embargo, más del 10% de las muestras contienen concentraciones de elementos tan bajas que la deficiencia para el crecimiento óptimo de las plantas y la salud animal puede ser un problema mucho mayor que merece atención.

Introduction

With an ever growing world population efficient and superior quality food production is becoming a major challenge (FAO, 2019). Well-organised and safe agriculture and

animal husbandry depend substantially on healthy soil. Plants and animals require sufficient amounts of major and minor nutrients and low concentrations (or availability) of potentially toxic elements in soil.

The project Geochemical Mapping of Agricultural and grazing land Soil

(GEMAS) was carried out by the Geochemistry Expert Group of EuroGeoSurveys in cooperation with Eurometaux (Association Européenne des Métaux), and other European and international institutions (Reimann *et al.*, 2014a, 2014b). It documents, for the first time, the concentration of almost 60 chemical elements, analysed by three different methods (total, aqua regia and cold leach concentrations) and physicochemical parameters determining nutrient availability and binding in agricultural and grazing land soil samples at the scale of the European continent (33 countries and 5.6 million km² were covered). In total, 2108 samples were collected from regularly ploughed fields (Fig. 1a), and 2024 samples from land under permanent grass cover (Fig. 1b). The agricultural soil samples were collected from the Ap horizon, the layer that has been disturbed by human activity such as mixing of the upper soil by ploughing in agricultural landscapes. In this case, the 'p' refers to the 'ploughing depth', which is on average down to a depth of 20 cm. The graz-

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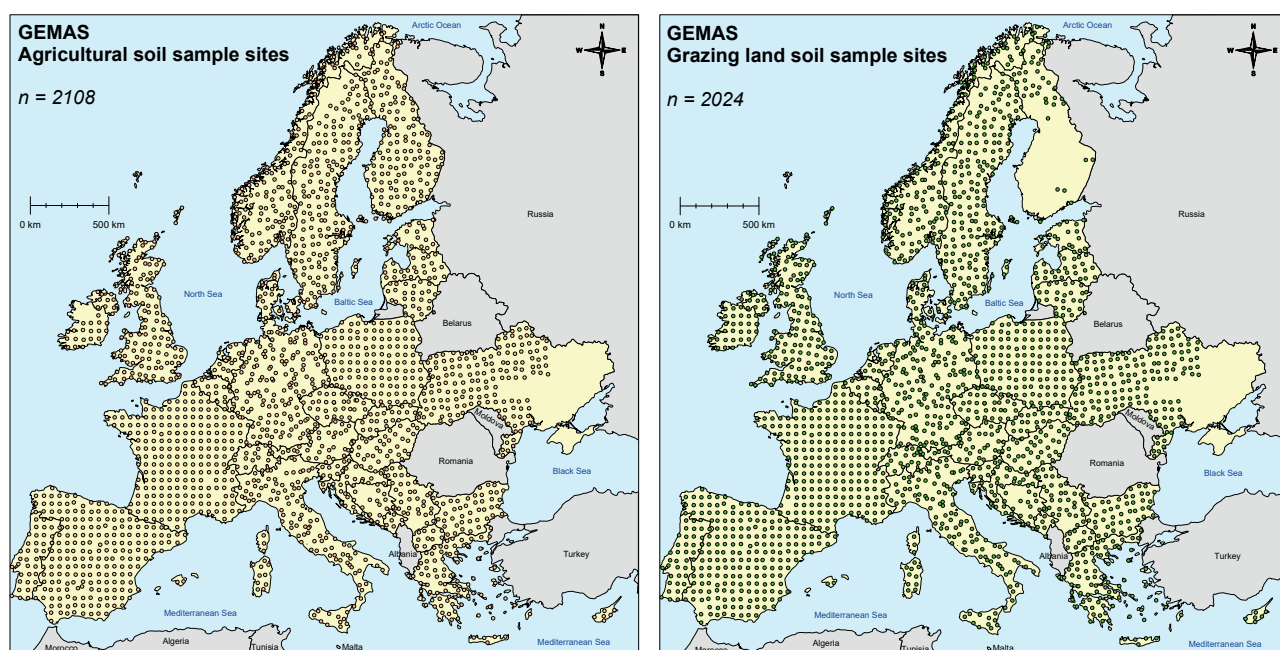


Figure 1: Maps showing the distribution of (a) agricultural soil samples, and (b) grazing land soil samples. A few countries collected samples at the grid nodes of a regular grid of 50×50 km, and other countries used a random sampling scheme within the same grid dimensions, and both retained the nominal sampling density of 1 site/2500 km².

ing land soil samples were collected from land under permanent grass cover or land that has not been disturbed for a period of at least ten years. As the interest is in the grass on which the animals graze, the upper 10 cm of soil was sampled as grass roots are usually concentrated in this section.

The samples were collected according to the specifications of the European Union's REACH regulation (Registration, Evaluation, Authorisation and Restriction of Chemicals; EC, 2006; EGS-GWG, 2008; Reimann, 2014). The REACH regulation aims to improve the protection of human health and the environment from potential risks posed by chemicals.

The GEMAS project data sets were made available to the general public in 2014 with the release of a two-volume atlas with the title "Chemistry of Europe's Agricultural Soils" (Reimann *et al.*, 2014a, 2014b).

As part of GEMAS valorisation, a series of peer-reviewed publications, where detailed interpretation of the continental-scale distribution of single elements or related groups of elements, have been published, e.g., Reimann *et al.* (2012a – Pb); Ottesen *et al.* (2013 – Hg); Tarvainen *et al.* (2013, 2014 – As); Scheib *et al.* (2012 – Nb); Sadeghi *et al.* (2013 – Ce, La, Y); Baritz *et al.* (2014 – C); Birke *et al.* (2014a, 2016, 2017 – Cd); Poňavič and Scheib (2014 – Se); Cichella *et al.* (2014 – U, Th, K); Ladenberger *et al.* (2015 – In); Albanese *et al.* (2015 – Cr, Ni, Co, Cu); Négrel *et al.* (2016

– Ge; 2018a – U, Th; 2018b – Rb, Ga, Cs; 2019 – Sb, W, Li; 2021 – Mg); Fabian *et al.* (2014 – pH; 2017 – Pb); Jordan *et al.* (2018 – Ni); Matschullat *et al.* (2018 – C, N, S); Hoogewerff *et al.* (2019 – 87Sr/86Sr), and Xu *et al.* (2019 – TOC, pH).

Harmonised high quality soil geochemical data sets

The GEMAS project has produced high quality exposure data for chemical elements across Europe that are harmonised with respect to: (1) land-use (agricultural soil, 0–20 cm and grazing land soil, 0–10 cm) – **Figures 1 & 2**; (2) spatial scale (homogeneous sampling density of 1 site/2500 km², i.e., a grid of 50×50 km was used (EGS-GWG, 2008; Reimann, 2014); (3) sample preparation (<2 mm grain size), and sample splitting in the same laboratory (Mackovych and Lucivjansky, 2014),

and (4) analytical methodology: all samples for the same suite of elements and physicochemical parameters were analysed in the same laboratory, namely (a) aqua regia extraction (ICP-MS 53 elements), (b) total (X-ray fluorescence, 41 elements), (c) mobile metal ion cold leach (MMI^o, 55 elements), (d) lead isotope ratios, (e) pH (0.01M CaCl₂), (f) total organic carbon, total carbon, total sulphur, effective cation exchange capacity (eCEC at pH of the soil, silver thiourea method), (g) mid-infrared (MIR) spectra, (h) texture (sand, silt, clay) and (i) partitioning coefficients (k_d -values) for selected elements (Reimann *et al.*, 2009, 2011, 2012b; Birke *et al.*, 2014b). Quality control of all analytical results is documented in three publicly available reports (Reimann *et al.*, 2009, 2011, 2012b).



Figure 2: Photographs of (a) agricultural soil with cabbages, Hellas, and (b) grazing land soil with sheep grazing, Larnaca district, Cyprus.

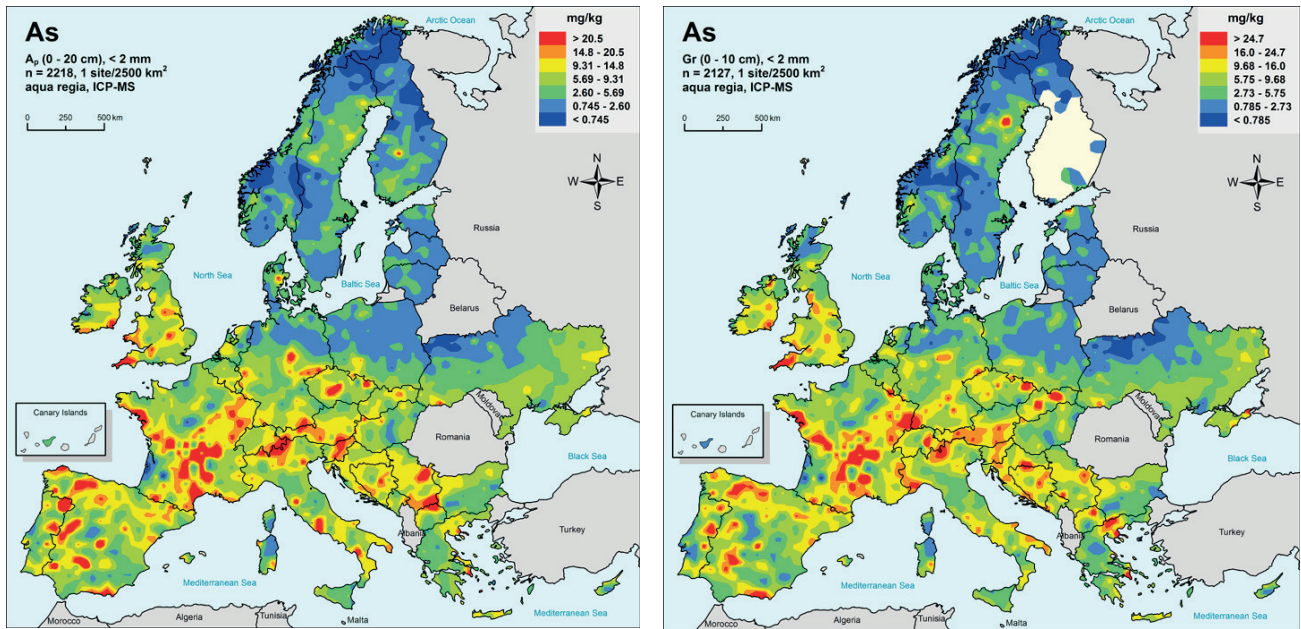


Figure 3: Geochemical maps showing the distribution of arsenic (As) in (a) agricultural soil and (b) grazing land soil (Reimann et al., 2014c, Fig. 11.9.5, p.154). Note the distinct north-south differences, and the comparable results of the two different sample types.

Large North-South differences

A major spatial difference in geochemical patterns is observed in the concentration of many chemical elements between the soil of northern and southern Europe. The young soil from northern Europe has 2 to 3 times

lower element concentrations than the more mature, weathered and older soil in southern Europe. The arsenic (As) maps of agricultural and grazing land soil show this feature clearly with higher concentrations in southern and western Europe compared to northern Europe (Fig. 3). When comparing

the geochemical maps with the geological map (Fig. 4a), the boundary between northern and southern Europe coincides remarkably well with the maximum extent of the last glaciation (Fig. 4b).

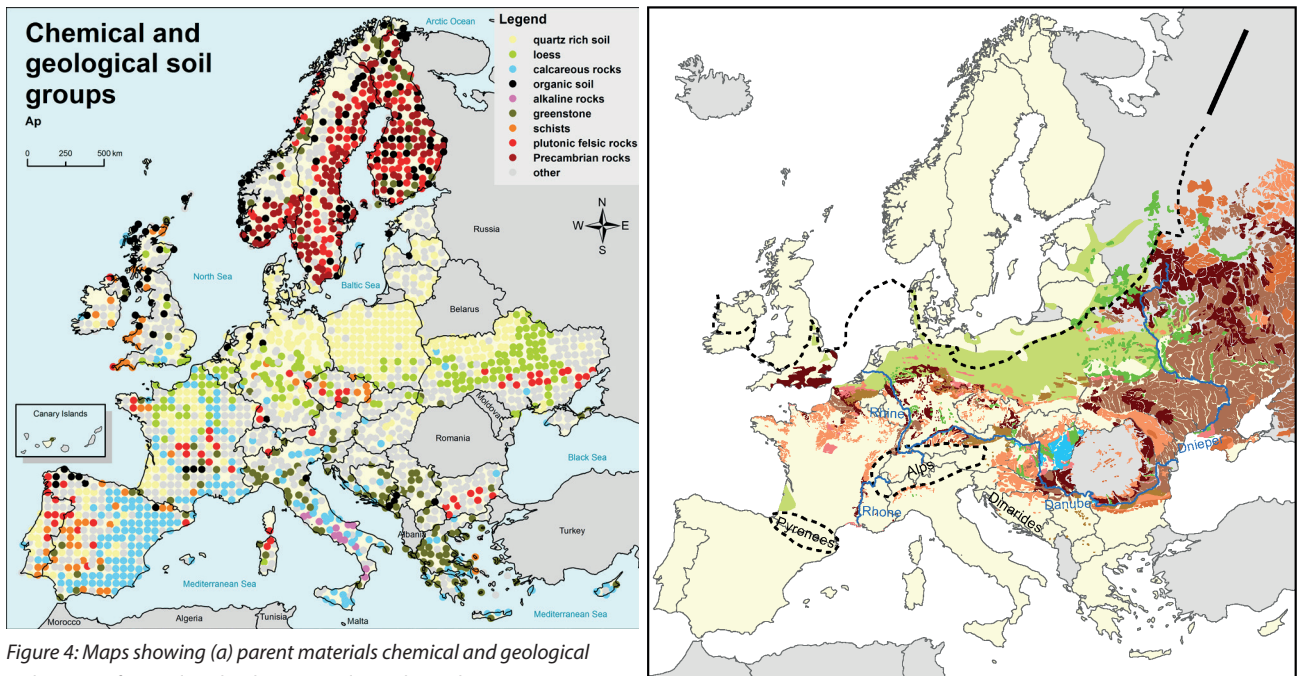


Figure 4: Maps showing (a) parent materials chemical and geological soil groups of agricultural soil (Ap) samples (Birke et al., 2014c, Fig. 10.8, p.98), and (b) distribution of aeolian deposits with maximum extent of the last glaciations (Weichset 18-22 ka) from Scheib (2014, Fig. 9.1, p.162); loess data for continental Europe redrawn from Haase et al. (2007); loess of southern Britain are based on Antoine et al. (2003), and generalised extent of coversand is based on Kasse (1997), Zeeberg (1998), and Bertran et al. (2009).

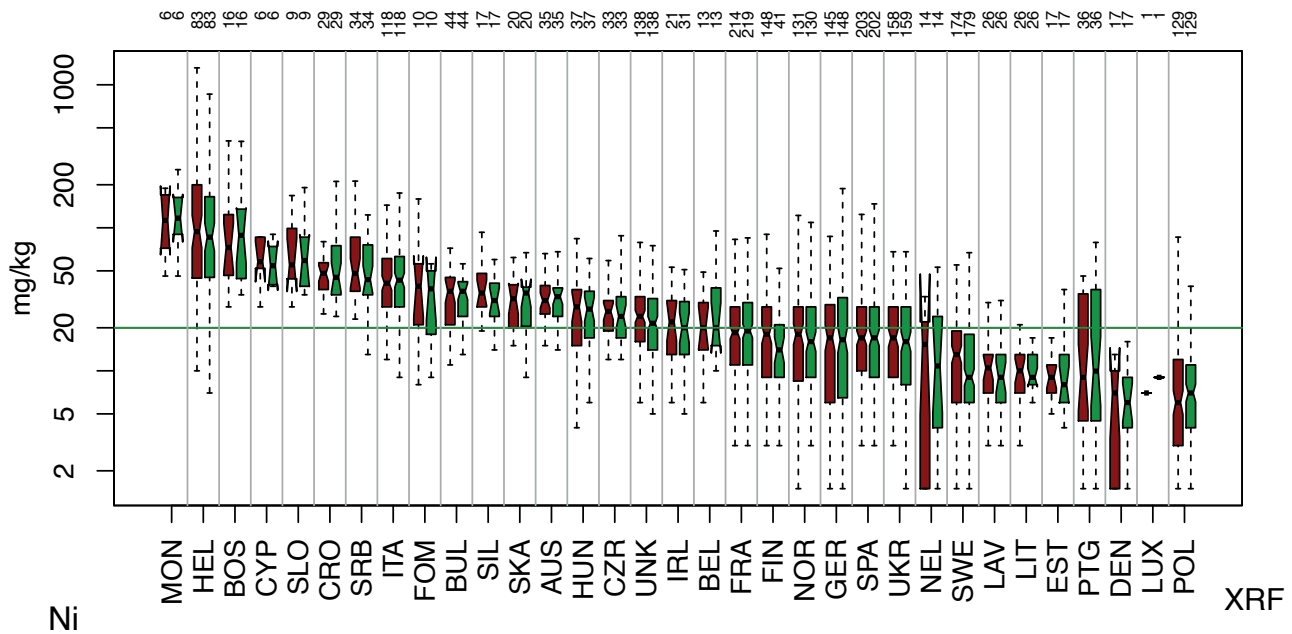


Figure 5: Boxplot comparison of nickel (Ni) concentrations in agricultural (Ap - dark red) and grazing land (Gr - green) soil samples of Europe (from Reimann et al., 2014c, Fig. 11.39.4, p.327). To focus on the main body of data the boxplots are shown without outliers (i.e., values 1.5 times the interquartile range above the upper quartile and below the lower quartile). The boxplots are ordered according to decreasing median values. The number of samples collected in each country is indicated on the top of the diagram. Countries: AUS: Austria; BEL: Belgium; BOS: Bosnia and Herzegovina; BUL: Bulgaria; CRO: Croatia; CYP: Cyprus; CZR: Czechia; DEN: Denmark; EST: Estonia; FIN: Finland; FOM: North Macedonia; FRA: France; GER: Germany; HEL: Hellas (Greece); HUN: Hungary; IRL: Republic of Ireland; ITA: Italy; LAV: Latvia; LIT: Lithuania; LUX: Luxembourg; MON: Montenegro; NEL: The Netherlands; NOR: Norway; POL: Poland; PTG: Portugal; SIL: Switzerland; SKA: Slovakia; SLO: Slovenia; SPA: Spain; SRB: Serbia; SWE: Sweden; UKR: Ukraine; UNK: United Kingdom. The green line shows the median concentration at 20 mg/kg Ni for both Ap and Gr soil samples.

Two different sample materials deliver comparable results

Two different sample materials, ploughed soil (0–20 cm) and grazing land soil (0–10 cm), taken at separate locations at a density

of 1 site/2500 km² all over Europe and with different depth sampling ranges, deliver very comparable distribution maps of chemical elements. The two maps of arsenic (As) distribution in agricultural and grazing land soil samples illustrate this feature very

well (Fig. 3). It is apparent that low sample density mapping results in robust maps.

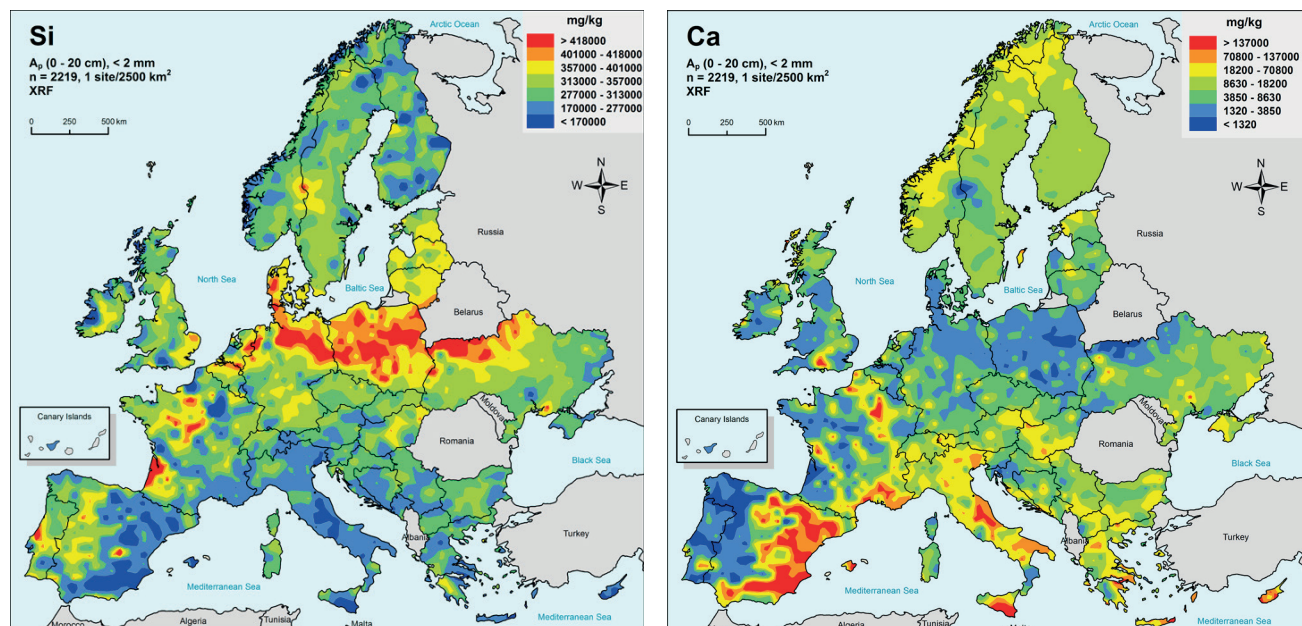


Figure 6: Total concentrations of (a) silicon (Si) and (b) calcium (Ca) in agricultural (Ap) soil samples, determined by X-ray fluorescence (XRF). From Reimann et al., 2014c, Figs. 11.51.5, p.399 & 11.16.5, p.200, respectively.

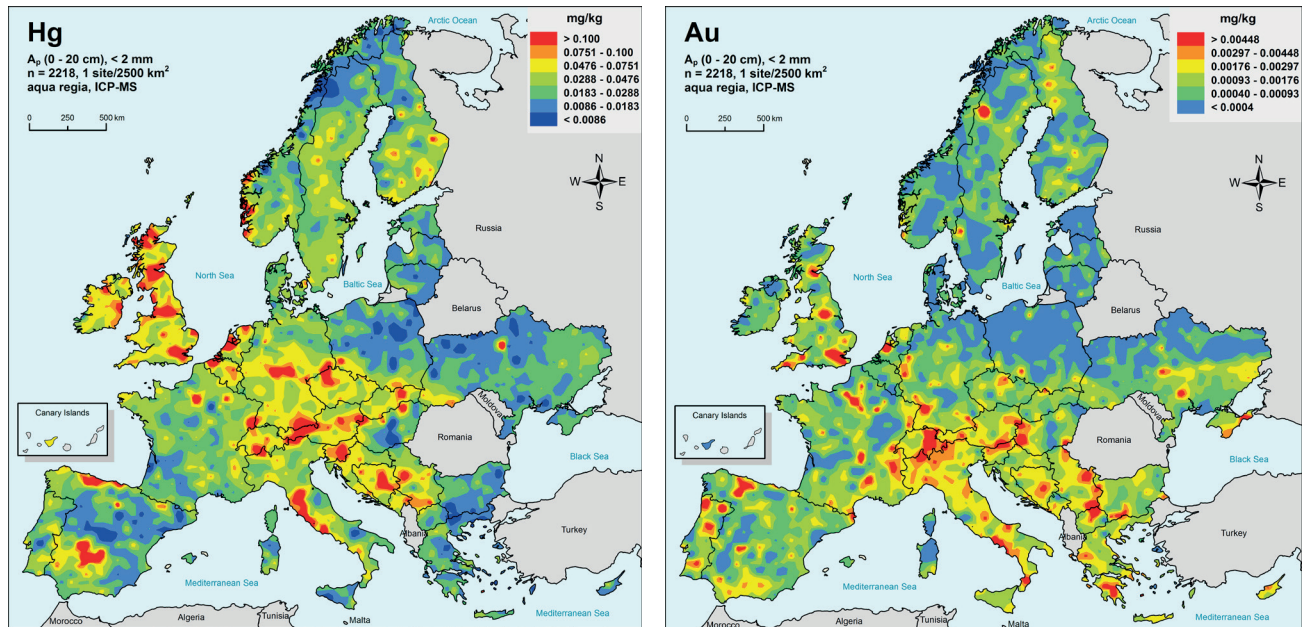


Figure 7: Geochemical maps showing the distribution of (a) mercury (Hg) and (b) gold (Au) in agricultural soil samples (Ap horizon) of Europe. From Reimann et al., 2014c, Figs. 11.29.5, p.269 & 11.10.5, p.161, respectively.

Substantial differences among country soil median values

Major differences are observed in elemental median values of agricultural and grazing land soil samples in the different European countries (Fig. 5). On average, there is a sixfold difference in the median concentration of the elements among the 33 countries sampled. Several elements show even substantially larger differences, up to a factor of more than 100 times. For nickel (Ni) (Figure 5), the lowest median value is observed in Poland (about 5 mg/kg), and the highest in Montenegro (almost 100 mg/kg).

Given these large natural differences, it is exceedingly difficult to define a single European background value for each element. This regionality is a crucial factor to consider in soil legislation, which sets out to determine threshold or action levels for chemical elements for all European Union countries.

The impact of geology

Geology, or better the distribution of parent materials for soil formation, plays a key role in determining the patterns observed on the geochemical maps. Most geochemical maps for metals are dominated by anomalies related to single ore deposits or metallogenic provinces. Soil developed on the sediments of the last glaciation, on chalk and limestone, felsic and mafic igneous rocks (e.g., granite, alkaline igneous

intrusions) or black shale, all have their own characteristic geochemical signature that can be detected on the maps. For example, the high Si concentrations in soil are observed over the thick quartz-rich sediments of the last glaciation in north-central Europe, derived from the erosion of Fennoscandian silica-rich bedrock (Fig. 6a). Areas underlain by calcareous rocks (chalk, limestone, marble) are indicated by high calcium (Ca) concentrations on the map (Fig. 6b), e.g., southern England, Paris basin, Cevennes and Provence-Alpes-Côte d'Azur in southern France, eastern Spain and the Apennines in Italy. Even the principal geological difference between Fennoscandia and the rest of Europe is reflected on the Ca map, i.e., the minor occurrence of carbonate rocks in the Archaean and Precambrian rocks in Fennoscandia and their widespread occurrence in the Palaeozoic-Mesozoic-Tertiary formations of the rest of Europe. On a more local scale, the area with low Ca concentrations at the Norwegian/Swedish border (Fig. 6b) marks a sandstone unit, which is indicated by elevated Si concentrations (Fig. 6a).

The impact of human activities

For a few elements, typically those associated with human activities (e.g., mercury (Hg), lead (Pb) but even silver (Ag) and gold (Au)), some (but far from all) European cities are noticeable by the elevated element concentrations in the agricultural soil samples taken in their vicinity. For

example, the surrounding areas of London, Paris and Rotterdam are marked by high Hg values in agricultural soil (Fig. 7a), a feature shown on other geochemical distribution maps, e.g., Pb, Ag, Au. Kiev is also clearly discernible by a Hg anomaly, which is most likely due to the presence of a mercury processing facility right in the city. London, Paris and Amsterdam are indicated by Au anomalies (Fig. 7b). Otherwise, an anthropogenic impact is difficult to detect at the mapping scale of the GEMAS project (1 sample site/2500 km²). The location of most metal smelters or coal-fired power plants remains invisible on the continental-scale geochemical maps.

The Hg anomalies in the Rome/Naples agglomerations in Italy are presumably of natural origin and due to the occurrence of alkaline volcanic rocks (Fig. 7a). Large European Hg deposits like Almadén in the Spanish province of Ciudad Real, the Asturias mining district in NW Spain, and Monte Amiata in the southern Tuscany region of Italy are also marked by distinct Hg anomalies (Ottesen et al., 2013). Many of the Hg anomalies in Scandinavia, along the west coast of Scotland and Ireland are due to the occurrence of organic matter-rich soil and the natural enrichment of Hg in humus.

Generally, most of the high element values observed on the GEMAS geochemical maps are clearly related to natural metal occurrences or to specific rock types that are enriched in these elements. Overall, the human impact on the quality of agricultural

and grazing land soils is remarkably low at the continental-scale of the GEMAS project (1 sample site/2500 km²).

In terms of the few existing national soil action levels for agricultural soil in Europe, an important observation is that in general very few soil samples deliver results that are above any known action level.

Risk assessment

How can toxicologically relevant element concentrations in soil samples be detected?

The answer to this question is the existence of harmonised and validated measurements of element concentrations in agricultural and grazing land soil samples, in combination with results for parameters (such as pH, CEC, TOC) determining the availability of the elements in soil, allowing for the first time a realistic risk assessment of trace elements in soil at the European scale (Fig. 8). The generated data sets have been used by several European metal industries under the European REACH regulation to assess the risks of the metals they produce to organisms living in agricultural and grassland soils in Europe (Oorts & Schoeters, 2014; Oorts *et al.*, 2016). In fact, an exceedingly small proportion of the GEMAS project soil samples exhibit a risk due to high metal concentrations.

Risk characterisation ratios (RCRs) are calculated as the ratio of measured aqua regia-extractable Cu concentration over the

corresponding predicted no-effect concentration for risk characterisation (PNEC). The PNECs, or ecological soil standards, can be compared with prevailing exposure concentrations in soil to identify areas with potential risk (Oorts *et al.*, 2016). For copper (Cu), most of the agricultural soil samples at risk were taken in vineyards (use of Cu-based pesticides) (Oorts & Schoeters, 2014).

Is diffuse contamination a serious threat to soil quality?

The European Commission has identified diffuse contamination as one of the eight threats to sustainable soil quality in Europe (EC, 2002). The GEMAS geochemical maps demonstrate that the impact of diffuse contamination, especially long-range transboundary air pollution, on the quality of European agricultural soil is vastly overestimated at present. Contamination from anthropogenic sources plays a key role at a much more local scale (e.g., see above the impact of cities like London and Paris on the Hg concentrations in soil), and sometimes at the regional scale but remains undiscernible at the continental scale. At the European scale, the GEMAS geochemical maps show that the occurrence of ore deposits, geology (certain rock types enriched in specific elements) and climate play the key role in determining the observed element spatial distribution

patterns. Surprisingly, neither agriculture nor diffuse contamination have affected the (semi-) total chemical composition of European agricultural soil at the continental scale (Fabian *et al.*, 2017; Reimann & Fabian, 2021). However, the weak cold extraction (MMI[®]) method showed potential effects of, for example, Cd concentrations from fertilisers in some agricultural areas of Europe (Reimann *et al.*, 2014c; Mann *et al.*, 2015). These observations indicate that diffuse contamination is a more complex issue than one might expect, and the superimposed effects of anthropogenic activities on soil should always be calibrated against the local natural geochemical background.

Health implications: element deficiency needs more attention

The interplay between element toxicity and deficiency has important consequences for health implications. Many trace elements play a vital role in the health of plants, animals and humans (Kabata-Pendias & Mukherjee, 2007; Alloway, 2013). For instance, molybdenosis is a disease affecting ruminants such as cattle and sheep but also wild grazing animals, mainly deer and moose. It is caused by grazing on land with increased molybdenum (Mo) concentrations in soil (Fig. 9a). The high intake of Mo results in a copper (Cu) deficiency, which leads to many severe health prob-

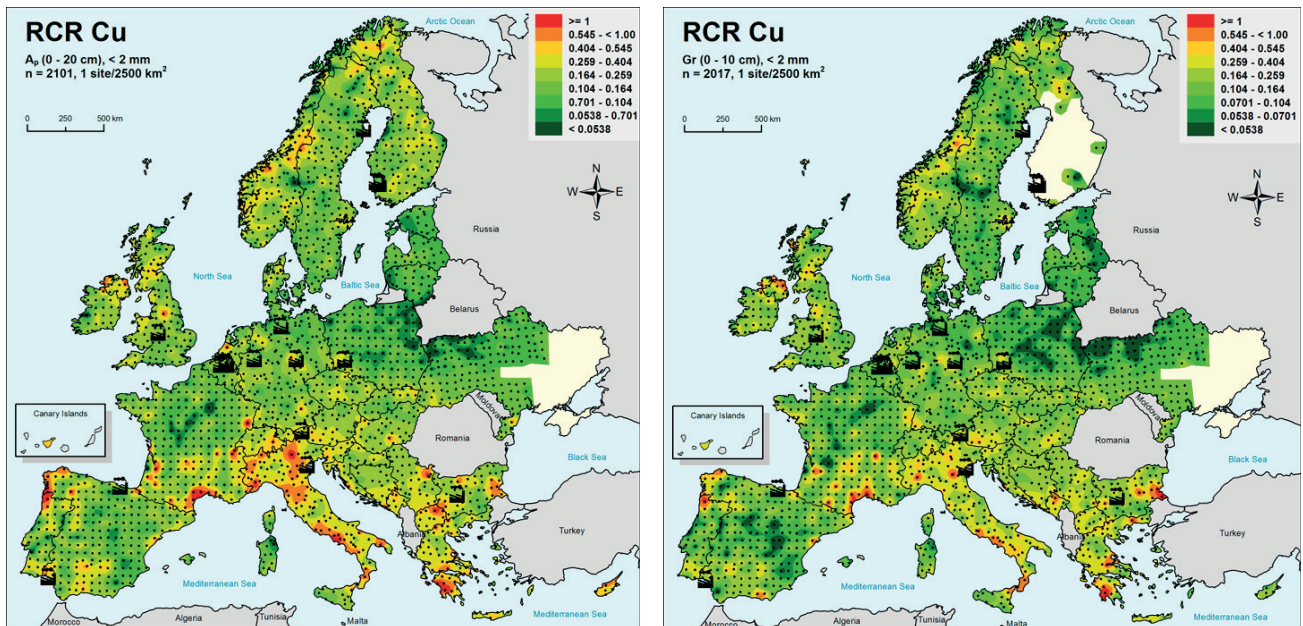


Figure 8: Distribution of risk characterisation ratios (RCR), calculated as the ratio of measured aqua regia extractable concentration of Cu with respect to the corresponding predicted no-effect concentration for risk characterisation (PNEC) for (a) agricultural soil, and (b) grazing land soil. Only a few isolated sites are predicted to be at risk for Cu (i.e., risk characterisation ratio, RCR > 1). About 1.5% and 1.3% of sample sites for (a) agricultural and (b) grazing land soil, respectively, were predicted to be at risk. From Oorts & Schoeters, 2014, Fig. 12.7, p.198, with addition of large smelters.

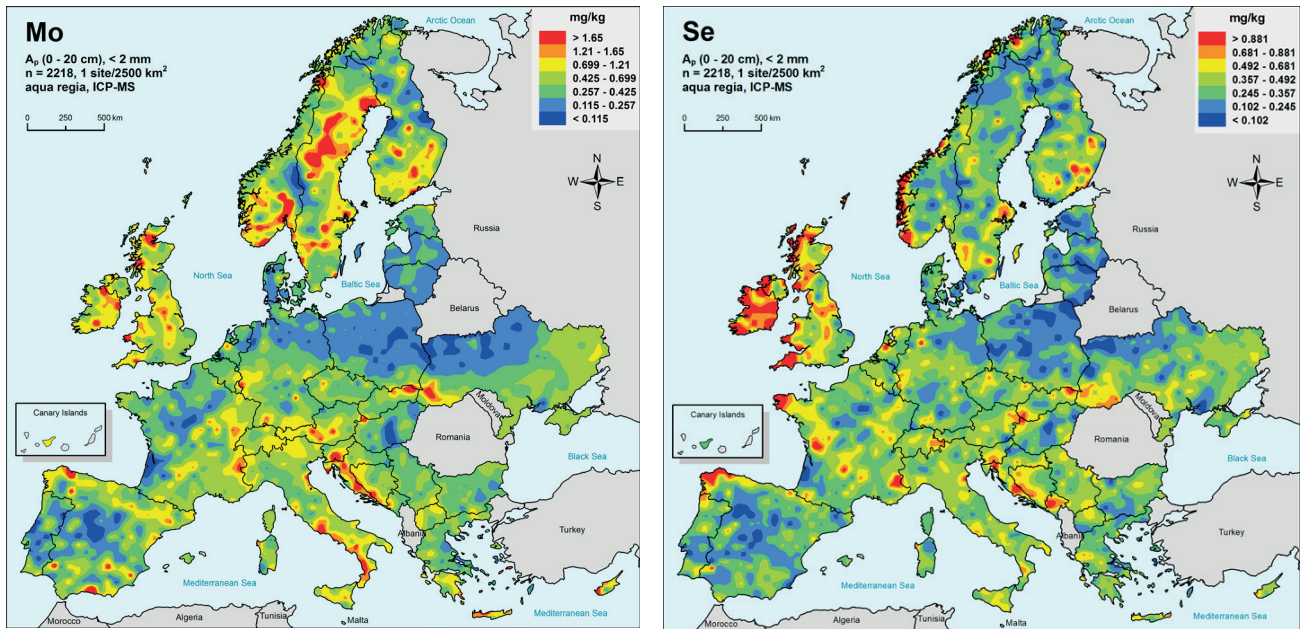


Figure 9: Geochemical maps showing the distribution of (a) molybdenum (Mo) and (b) selenium (Se) in agricultural soil samples. From Reimann et al., 2014c, Figs. 11.36.5, p.311 & 11.50.5, p.393, respectively.

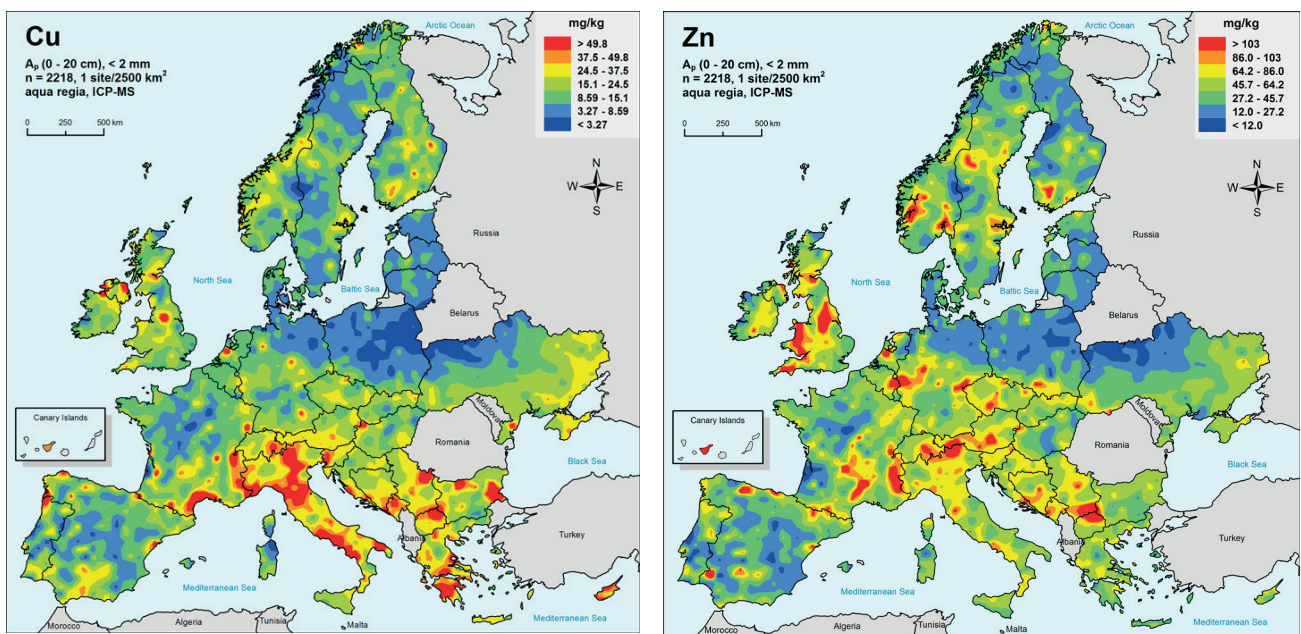


Figure 10: Geochemical maps showing the distribution of (a) copper (Cu) and (b) zinc (Zn) in agricultural soil samples. From Reimann et al., 2014c, Figs. 11.23.5, p.237 & 11.63.5, p.467, respectively.

lems, including organ failure and death. The massive death incidents of moose in Sweden in the 1980s and 1990s were likely caused by liming to prevent acidification of forest soil, which resulted in Mo mobilisation, which in turn reduced Cu uptake in the diet of the moose (Broman *et al.*, 2002).

Another example is selenosis, a poisoning of livestock caused by the ingestion of selenium (Se), which can be enriched in some plants by microorganisms or in soil due to specific climatic conditions. In

Europe, excessive Se concentrations occurring along coastal areas of United Kingdom, NW Spain, NW France and Norway are due to the steady input via marine aerosols in combination with a strong affinity to bind to organic matter in soil (Fig. 9b). The highest Se enrichment in European agricultural soil occurs in Ireland. However, at the continental scale Se deficiency may be a larger problem than Se toxicity.

Copper (Cu) and zinc (Zn) are two metals that are usually of concern when they occur

at high levels, whether their origin is natural or anthropogenic (Fig. 10). Both Cu and Zn are, however, important nutrients and at the European scale deficiency of these elements in soil may be a much larger concern warranting attention than their toxicity (e.g., Cu and Zn have high statutory action values, which are rarely observed in agricultural and grazing land soil – see Appendix A in Reimann *et al.*, 2014d).

Overall, very few agricultural and grazing land soil samples reach alarming con-

centrations where toxicity may become of concern. However, more than 10% of the GEMAS soil samples contain such low concentrations that deficiency is an issue for optimum plant and animal health and productivity may be of much greater concern.

Forensic applications

The GEMAS data sets deliver valuable information for forensic sciences and intelligence. Multi-element data sets, including some isotope systems, can be used to trace the origin of food or even human bodies (Morgan & Bull, 2006; Pye, 2007; Hoogewerff *et al.*, 2019; Caritat *et al.*, 2021). It is, thus, not surprising that forensic units of, for example, Scotland Yard and the Royal Canadian Mounted Police have expressed interest in the GEMAS data sets.

Discussion and conclusions

To make the GEMAS project possible 65 organisations – from almost all of the Geological Surveys of Europe, other State and contract research organisations, universities to industry – have cooperated to produce fully harmonised, strictly quality controlled and freely available data sets at the scale of a continent. For the first time, the GEMAS project provides fully harmonised data for chemical element concentrations and soil properties known to influence their bio-availability and toxicity in agricultural and grazing land soils, the productive soils of Europe. Society has, therefore, a valuable reference data set, a 2008 timeline, to monitor future changes in its agricultural and grazing land soils, caused by both human or natural causes, and a set of reference soil samples for future research. Such an archive is invaluable for land use planning, industrial development, environmental protection, risk assessment, forensic science, agriculture and food tracing. In the case of a major disaster, natural or human-induced, the European authorities have a reference data and a sample set to assess the impact of such an event. Furthermore, a better awareness of element deficiency levels can lead to an increase in productivity and animal health.

To validate the veracity of the GEMAS data sets, results have been compared with residual and alluvial soil samples collected by another pan-European project, carried out by the Geochemistry Expert Group of EuroGeoSurveys, the FOREGS Geochemical Atlas of Europe (Salminen *et al.*, 2005; De Vos, Tarvainen *et al.*, 2006), which displays similar geochemical patterns.

Moreover, the European Commission's Joint Research Centre confirmed that high variation in Hg concentrations across Europe can be mostly explained by soil organic carbon content, vegetation, soil parent material and other natural soil-related processes rather than large scale diffuse pollution. Based on the results of the LUCAS project soil samples (0-20 cm), it was found that some mining activities and coal combustion sites have a regionally important role in the Hg distribution (Ballabio *et al.*, 2021).

The patterns displayed on the geochemical maps discussed in this study are mainly related to the soil parent materials, with distinct differences observed between the lithology of northern and southern Europe. The concentration break for most elements coincides with the southern limit of the last glaciation, i.e., lower element values to its north and elevated values to its south. Of course, for some elements (e.g., Se) their spatial distribution depends on other factors, such as proximity to the sea and soil organic matter.

The recent FAO and UNEP report about the "Status of soil pollution in Europe" (FAO and UNEP, 2021) refers to a European Environmental Agency report (EEA, 2019) and states that "agriculture significantly contributes to diffuse soil and water pollution in Europe" (Eugenio and Ronzan, 2021, Chapter 8), which according to the citation has been taken from a European Environmental Agency report (EEA, 2019). Two metals are given as examples: Cd from mineral fertilisers and Cu from fungicides. This short statement does not consider the results of the GEMAS, FOREGS and LUCAS projects that show the importance of understanding geology, soil parent material and other soil properties, as well as the analytical method applied while assessing soil contamination at the European scale. Anomalies of Cu in vineyards and Cd in heavily fertilised areas of Europe are actually visible on the maps of the GEMAS project but certainly not at the continental scale; at best they are limited to the regional and rather the local scale.

As diffuse contamination is a much discussed topic, it is worth quoting Fabian *et al.* (2017), who make the following introductory statements:

"On the basis of experience from the local scale, for example from the proximity of a metal smelter, it is widely assumed that contamination always results in unusually high concentrations of the emitted element in soil, and monitoring activities are focusing on extreme values. However, dependent on signal intensity local contamination becomes indistinguishable from the natural

background variation at a characteristic distance from the source, usually measured in metres to some kilometres, and in extreme cases 100–200 km. It is therefore a major challenge to identify and quantify diffuse contamination in soil as distinguished from local or regional contamination, because it cannot be clearly separated from a large natural background variation" (p. 6719).

In their conclusion, Fabian *et al.* (2017) state that "diffuse soil contamination at the continental-scale remains invisible in continental scale geochemical maps because the natural variation is still considerably larger and dominates spatial patterns of high concentrations. This solves the puzzle that in spite of substantial anthropogenic emissions, geochemical maps of Pb at the continental scale consistently reflect natural conditions, usually both geology and climate. Pb contamination therefore is rarely marked by high total Pb concentration, but rather by overabundant lower and medium concentrations of Pb" (p. 6725).

Hence, international organisations such as EEA, FAO and UNEP should be extra careful about reporting 'global pollution analyses' in their reports. The scale of anthropogenic induced contamination can be either overlooked or overestimated if the natural geochemical background is not taken into account.

As concluding remarks, the GEMAS project, has produced data sets with well comparable results for two soil types, agricultural (0-20 cm) and grazing land (0-10 cm) sampled at the European scale, leading to several major findings.

- A major difference in soil chemical composition is observed between the young northern and older southern European soil;
- On average there is a sixfold difference in the median concentration of elements among the 33 participating countries (up to a factor of more than 100-fold);
- Spatial element distributions depend mainly on geology and climate;
- High trace element concentrations in soil are most often related to mineral deposits and metallogenic provinces;
- The anthropogenic impact is hardly detectable at the European scale;
- Some cities (e.g., London, Paris) cause anthropogenic trace element anomalies (e.g., Au, Pb, Hg) in their near surroundings and element concentrations decrease rapidly with distance from the source;

- Risk assessment for metals like Cu shows that few soil samples have such high concentrations that they pose a potential toxic risk for soil organisms; most of these samples were taken in vineyards;
- Several important trace elements (minor nutrients, e.g., Cu, Zn) show such low levels over sizeable tracts of land in Europe that trace element deficiency is clearly an issue of concern.

Acknowledgements

The GEMAS project is a cooperative project of the EuroGeoSurveys Geochemistry Expert Group with a number

of outside organisations (e.g., Alterra, The Netherlands; Norwegian Forest and Landscape Institute; Research Group Swiss Soil Monitoring Network, Swiss Research Station Agroscope Reckenholz-Tänikon, several Ministries of the Environment and University Departments of Geosciences, Chemistry and Mathematics in a number of European countries and New Zealand; ARCHE Consulting in Belgium; CSIRO Land and Water in Adelaide, Australia). The analytical work was co-financed by the following industry organisations: Eurometaux, European Borates Association, European Copper Institute, European Precious Metals Federation, International Antimony Association, International Lead Association-Europe, International Manganese Institute, International Molybdenum Asso-

ciation, International Tin Research Institute, International Zinc Association, The Cobalt Development Institute, The Nickel Institute, The (REACH) Selenium and Tellurium Consortium and The (REACH) Vanadium Consortium. The Directors of the European Geological Surveys and the additional participating organisations are thanked for making sampling of almost all of Europe in a tight time schedule possible. The Federal Institute for Geosciences and Natural Resources (BGR), the Geological Survey of Norway and SGS (Canada) are thanked for special analytical input to the project. Review and editing comments by Magnus Johansson and Robin Nagano have improved the manuscript.

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