GEOCHEMICAL MAPPING OF AGRICULTURAL AND GRAZING LAND SOIL OF EUROPE

EuroGeoSurveys — European Geoscience for Society

GEMAS in Europe

EUROMETAUX — EUROPEAN ASSOCIATION OF METALS

INTRODUCTION TO THE GEMAS PROJECT

With an ever growing world population efficient food production is becoming a major challenge. Efficient agriculture depends on healthy soils. Plant and animal production require sufficient amounts of major and minor nutrients and low concentrations (or availability) of toxic elements in the soil. The GEMAS project documents, for the first time, the concentration of almost 60 chemical elements, and of the parameters determining their availability and binding in agricultural and grazing land soils at the scale of a continent (Europe – 5.6 million km² were sampled). Key observations of the project include:

(1) Well comparable results for the two soil types sampled at the European scale.

(2) A major difference in soil composition is observed between the young northern and the much older southern European soils for many elements.

(3) On average there is a sixfold (and up to a factor of more than 100) difference in the median concentration of elements between the 33 participating countries.

(4) Element distributions depend on geology and climate – the anthropogenic impact is hardly detectable at the European scale. High trace element values in soils are most often related to mineral deposits and districts.

(5) 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 source.

(6) Risk assessment for metals like Cu shows that few samples have such high concentrations that they pose a toxic risk for soil organisms; most of these samples were taken in vineyards.

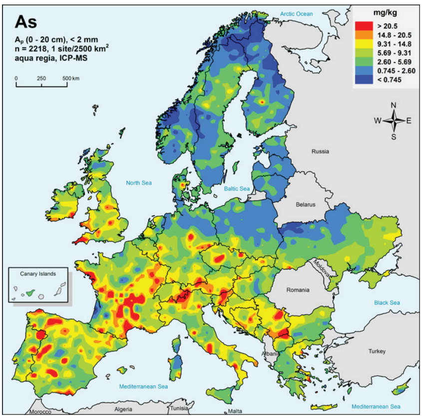
(7) Several important trace elements (minor nutrients, e.g., Cu, Zn) show such low levels over sizeable tracts of land in Europe that trace element deficiency is clearly of concern.

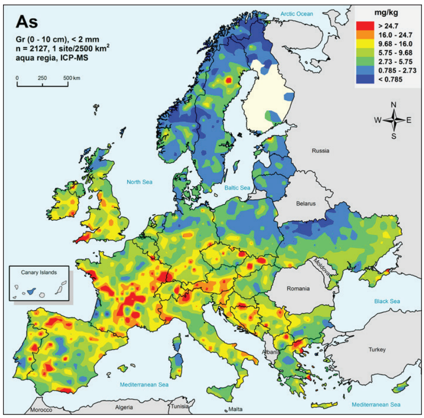
HARMONISED HIGH QUALITY DATA SET

The GEMAS project has produced high quality exposure data for chemical elements across Europe, harmonised with respect to: (1) land-use (agricultural soil, 0-20 cm and grazing land soil, 0-10 cm); (2) spatial scale (homogeneous sampling density: 1 site/2500 km^2 (grid of 50 x 50 km) – described in the publicly available field manual; (3) sample preparation (<2 mm grain size), and (4) analytical methodology: Aqua regia extractable (ICP-MS 53 elements), total (XRF, 41 elements) and mobile metal ion (MMI®, 55 elements) concentrations, lead isotope ratios, pH (0.01M $CaCl_2$), Total Organic Carbon, Total Carbon, Total Sulphur, Effective Cation Exchange Capacity (eCEC at pH of the soil, silver thiurea method), mid-infra red (MIR) spectra, Texture (sand, silt, clay) and Partitioning coefficients (k_D-values) for selected elements.The GEMAS project data sets are made available to the general public with the release of the book "*Chemistry of Europe's agricultural soils*". Quality control of all analytical results is documented in three publicly available reports.

LARGE NORTH-SOUTH DIFFERENCES

A large difference is observed in the concentration of many chemical elements between the soil of northern and southern Europe. The young soil from northern Europe shows that the concentrations for many elements are 2-3 times lower than in older and more weathered southern European soil. The arsenic (As) maps highlight this feature; As concentrations in agricultural soil are clearly higher in southern and western compared to northern Europe.





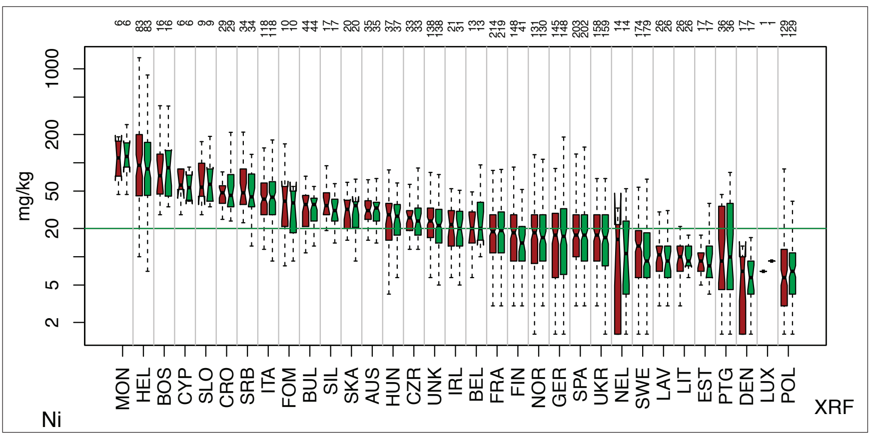
TWO DIFFERENT SAMPLE MATERIALS DELIVER COMPARABLE RESULTS

Two different sample materials, ploughed soil (0-20 cm) and grazing land soil (0-10 cm), taken at different locations at a density of 1 site/2500 km^2 all over Europe, deliver very comparable distribution maps of the chemical elements (see, for example, the maps for arsenic (As)). It is apparent that low sample density mapping results in robust maps.

SUBSTANTIAL DIFFERENCES AMONG COUNTRY SOIL MEDIAN VALUES

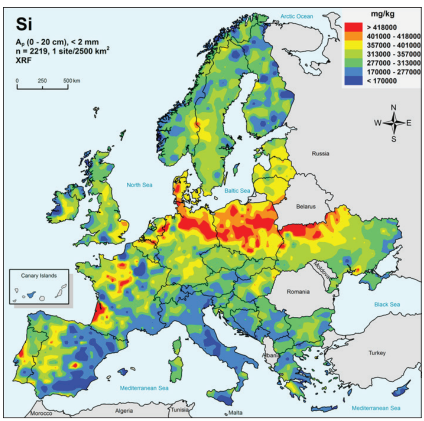
Large differences are observed in elemental median values of soil samples in the different European countries. On average, there is a sixfold difference in the median concentration of the elements among the 33 countries sampled. Several elements show even substantially larger differences up to a factor of more than 100 times. For nickel (Ni) 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 very difficult to define a single European background value for any one element. This regionality is an important factor to consider in soil legislation, which sets out to determine threshold or action levels for chemical elements.

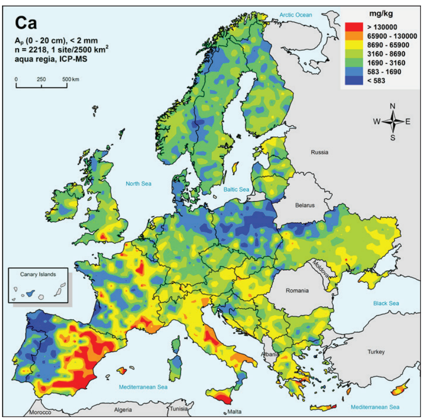
Boxplot comparison of nickel (Ni) concentrations in the agricultural (Ap - dark red) and grazing land (Gr - green) soil of Europe. To focus on the main body of data the boxplots are shown without outliers (extreme values). The boxes are ordered according to decreasing median values. Countries: AUS: Austria, BEL: Belgium, BOS: Bosnia and Herzegovina, BUL: Bulgaria, CRO: Croatia, CYP: Cyprus, CZR: Czech Republic, DEN: Denmark, EST: Estonia, FIN: Finland, FOM: Former Yugoslavian Republic of Macedonia, FRA: France, GER: Germany, HEL: Hellas, HUN: Hungary, IRL: Republic of Ireland, ITA: Italy, LAV: Latvia, LIT: Lithuania, LUX: Luxemburg, 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 red and green lines show the median concentration for Ap (red) and Gr (green) samples.



THE IMPACT OF GEOLOGY

Geology, or better the distribution of parent material for soil formation, plays a key role in determining the patterns observed on the maps. Many maps are dominated by anomalies related to single ore deposits or metal provinces. Soil developed on the sediments of the last glaciation, on chalk and limestone, granite, alkaline intrusions, greenstone or black shale, all have their own characteristic geochemical signature that can be detected on the maps.



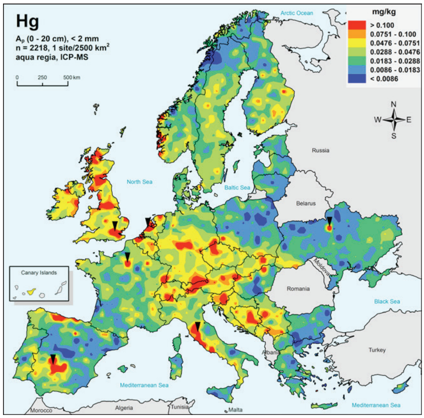


Total concentrations of silicon (Si) and calcium (Ca) in the agricultural (Ap) soil samples: note the high Si concentrations over the thick silica-rich sediments of the last glaciation in northern central Europe, and the high calcium (Ca) concentrations over areas underlain by chalk and limestone. Even the principal geological difference between Scandinavia and the rest of Europe is reflected on the Ca map; on a more local scale the low at the Norwegian/Swedish border marks a sandstone unit.

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 elevated element concentrations in the agricultural soil samples taken in their vicinity. For example, London, Paris and Rotterdam are three European cities that are marked by high values (red colours) in agricultural soil as is shown on many of the geochemical distribution maps. For mercury (Hg), Kiev is also clearly discernible by an anomaly, which is most likely due to the presence of a mercury processing facility right in the city. Otherwise an anthropogenic impact is difficult to detect at the mapping scale of the GEMAS project. The location of most metal smelters or coal-fired power plants remains, for example, invisible on the geochemical maps. Many of the high values observed on the maps are actually related to natural metal occurrences or to specific rock types that are enriched in these elements. In terms of the few existing national soil action levels for agricultural soil in Europe, an important observation is that in general very few samples deliver results that are above any known action level.

The human impact on the quality of the agricultural soils is suprisingly low at the continental scale.

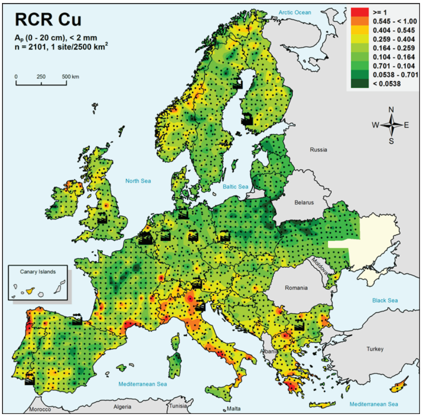


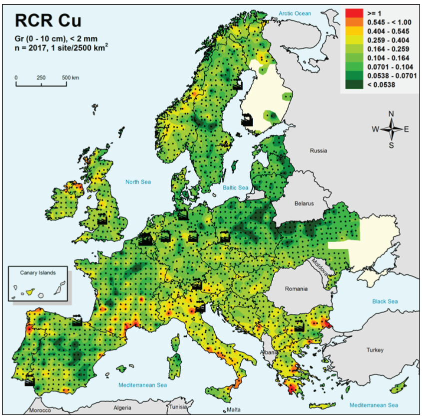
Distribution of mercury (Hg) in the agricultural soil (Ap horizon) of Europe. Some cities are marked by Hg anomalies, e.g., Kiev, London, Paris, Rotterdam. The anomalies in the Rome/Naples area are due to the occurrence of alkaline volcanic rocks. Large European Hg deposits like Almaden in Spain and Monte Amiata in Italy are also marked by distinct Hg anomalies. Many of the anomalies in Scandinavia, along the west coast of Scotland and Ireland are due to the occurrence of organic matter-rich soil.


CLH

RISK ASSESSMENT

Where do we detect toxicologically relevant element concentrations in the soil samples? The existence of harmonised measurements of element concentrations in soil, in combination with results for the parameters determining the availability of the elements in soil, allows for the first time a realistic risk assessment of trace elements in soil at the European scale. It turns out that a very low proportion of the soil samples are at risk due to measured metal concentrations. For copper (Cu), most of the soil samples at risk were taken in vineyards (use of Cu-based pesticides). The 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.





Only a few, isolated sites are predicted at risk (i.e., risk characterisation ratio, RCR > 1): 1.6% and 1.3% of sites for Agricultural and Grazing land, respectively.

IS DIFFUSE CONTAMINATION A SERIOUS THREAT TO SOIL QUALITY?

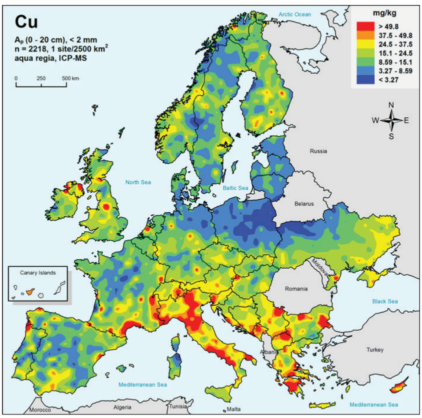
The European Commission has identified diffuse contamination as one of the eight threats to sustainable soil quality in Europe. The GEMAS maps demonstrate that the impact of diffuse contamination on the quality of European agricultural soil is vastly overestimated at present. Contamination from anthropogenic sources plays an important role at a much more local scale (e.g., see above the impact of cities like London and Paris on the mercury (Hg) concentrations in soil), but remains undiscernable at the continental scale. At the continental scale, the GEMAS maps show that it is the occurrence of ore deposits, geology (certain rock types enriched in specific elements) and climate that play the key role in determining the observed element distribution patterns. Surprisingly, neither agriculture nor diffuse contamination plays a key role in determining the chemical composition of European agricultural soil at the continental scale.

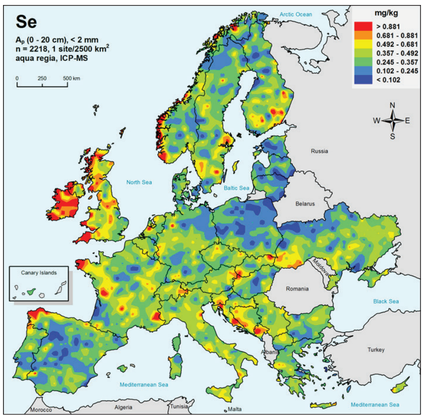
HEALTH IMPLICATIONS: ELEMENT DEFICIENCY NEEDS MORE ATTENTION

Many trace elements play an important role for the health of plants, animals and humans. Molybdenosis is a disease affecting ruminants, especially cattle. It is caused by grazing on land with increased molybdenum (Mo) concentrations in soil. The high intake of Mo results in a copper (Cu) deficiency, which leads to many severe health problems, including organ failure and death. 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, has been observed in Europe, for example, in Ireland (see map) where Se can be enriched in soil due to steady input via marine aerosols. At the continental scale Se-deficiency may be a larger problem than Se toxicity. Other important trace elements are, for example, the metals cobalt (Co), copper (Cu) and zinc (Zn), where contamination is a much discussed issue. However, at the European scale, deficiency of these elements in soil may be a much larger issue warranting attention. While very few soil samples reach concentrations where toxicity may become a concern, more than 10% of the samples contain such low concentrations that deficiency is an issue for optimum plant and animal health and productivity.

FORENSIC APPLICATIONS

The GEMAS data deliver important information for forensic sciences. Multi-element data sets, including some isotope systems can be used to trace the origin of food – or even human bodies. It is thus not surprising that forensic units of, for example, Scotland Yard and the Royal Canadian Mounted Police have already expressed interest in the GEMAS data.





Copper-deficient soil occurs in rather large areas of Europe (blue colours on the map), while potentially toxic levels are rarely reached - see risk maps). For selenium (Se), again large parts of Europe's agricultural soil is deficient in this element, while excessive concentrations can be reached along coastal areas (see Ireland, western Norway) due to the steady input via marine aerosols in combination with a strong affinity to bind to organic matter in soil.

To make the GEMAS project possible 65 organisations, from almost all Geological Surveys of Europe, other State and contract research organisations, universities to industry have cooperated to produce a fully harmonised, strictly quality controlled and freely available data set at the scale of a continent.

CONTACT ADDRESSES & GENERAL INFORMATION ON THE GEMAS PROJECT

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For national contacts and additional information about the GEMAS project consult the project's website: http://gemas.geolba.ac.at/

The projects field manual and three quality control reports can be downloaded from the internet at the following links:

http://www.ngu.no/en-gb/hm/Publications/Reports/2008/2008-038/

http://www.ngu.no/upload/Publikasjoner/Rapporter/2009/2009_049.pdf

http://www.ngu.no/upload/Publikasjoner/Rapporter/2011/2011_043.pdf

http://www.ngu.no/upload/Publikasjoner/Rapporter/2012/2012_051.pdf.

In December 2013 the project results will be published in the form of a book. The data set will accompany the book and be freely available to the general public:

Reimann, C., Birke, M., Demetriades, A., Filzmoser, P., O'Connor, P. (eds.) 2013. Chemistry of Europe's agricultural soils. Geologisches Jahrbuch (Reihe B), Schweizerbarth (available: Dec. 5, 2013).

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