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TU1206-WG2.6-007

Sub-urban geochemistry

A review of good practice and techniques in sub-urban geochemistry;
to ensure optimal information use in urban planning

TU1206 COST Sub-Urban WG2 Report

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Summary

The main need of city planners in relation to the geochemical quality of soils and subsoils is to have reasonable and representative visualisation of the data in a form, which enables them to be used effectively, and in an integrated way with other datasets (socio-economic, health, etc.).

This report, linked to Working Group 2.6 on geochemistry of the COST Action Tu1206 (Sub-Urban) focuses on near surface soils, and deeper subsoils, particularly at the quarter or city scale. It supplements the recent Urban Geochemical Mapping Manual by Demetriades and Birke with contributions from the EuroGeoSurveys Geochemical Expert Group (published in 2015) that details good practice in 2D data acquisition of topsoil.

The current state of knowledge in relation to soil geochemistry (when available) is overwhelmingly based on surface (topsoil) and very near surface sampling of subsoils. This is expressed in the form of 2D mapping, based on interpolation between sample sites. 2D topsoil acquisition is particularly well suited for addressing health issues; deeper acquisitions are needed in relation to urban (re)development, construction work and remediation of contamination. 3D geochemical knowledge, although as yet uncommon, could be very useful in optimizing urban redevelopment projects, anticipating contamination problems, and managing excavated materials (e.g. local reuse possibilities, disposal costs etc.). Because all of these aspects can have important economic, environmental and social consequences, they are considered essential for urban sustainable development. To meet these future 3D and potentially even 4D (temporal and predictive) needs, improved development of data acquisition, management, visualisation and use of these are crucial steps.

Some examples of good practice, or at least of best efforts, are illustrated by case studies. For instance, the Vienna (Austria) and Glasgow (UK) case studies illustrate urban geochemical sampling surveys. The examples of Nantes and of the French BDSolU (Base de données sur les Sols Urbains - French national database on urban soils), may be referred to as good efforts with respect to 3D geochemical databases. The example of Nantes is also suggested as an example of best effort in terms of use of 3D urban geochemical data.

Identified gaps that currently exist include the development of 3D and 4D mapping technology, geochemical data acquisition and management, and 3D representation and use of geochemical data.

Keywords: geochemistry, urban, subsoils, quarter, city, data management, visualization, use, drivers, knowledge, decision aid, 3D, good practice, best effort, recommendations, gaps

Table of content

1-Introduction

Rationale

Context, justification, city needs/use, aims, and links with other subgroups

Urban geochemistry is relevant to a variety of issues including health, contamination, urban planning, urban development, economy, resource management (soil, water), and the use of soils and subsoils (urban agriculture, etc.). It needs to be considered on a wide range of scales - from sample to site, quarter, and city - and in relation to the various components of the urban system: soils, subsoils, deeper sub-surface, watershed, sediments, water, air… The geochemistry of urban soils and subsoils may have natural (geogenic) and/or man-made (anthropogenic) origins (e.g. related to industry, agriculture, traffic, domestic, wastewater, etc.). Urban soils, in close relation to the evolution of the city, display heterogeneity, discontinuities and a dynamic evolution.

This report, linked to Working Group 2.6 of the COST Action Tu1206 (Sub-Urban) on geochemistry, focuses on soils at and near surface, and deeper subsoils, particularly at the quarter or city scale, and aims to:

- identify where, and to what extent, modelling of soil and subsoil geochemistry in 3D is used in European cities in comparison to 2D ,
- assess the extent to which urban managers interact with geoscientists, and geochemists in particular, and use such representations of urban soils/sub-soils, and
- identify examples of good practice.

Such an approach aims to enhance the links between urban geochemistry (2D and 3D mapping) and urban spatial planning (Figure 1). This especially complements the recent work by the EuroGeoSurvey Geochemistry Expert Group on urban geochemistry, whose “Urban geochemical Mapping Manuel” (Demetriades, A. and Birke, M., 2015a) represents a key foundation of this report.

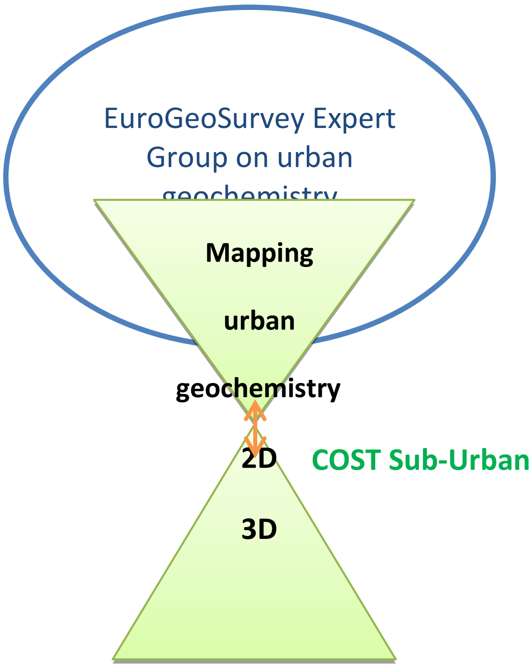

Figure 1. the relationship of COST Sub-Urban to the wider urban geochemistry community.

1.2- Knowledge base

The report is based on: an overview of two comprehensive books produced by the EuroGeoSurvey Expert Group on urban geochemistry (Johnson *et al.,* 2011, Demetriades and Birke, 2015a and b); a survey of good practice by a small group of COST Sub-Urban partners; and some additional discussions with geochemists and urban planners.

1.3- Report structure

In this report, we focus on the geochemical aspects of soil and subsoil at the quarter to city scale; sample and site-scale geochemistry are not addressed. Groundwater geochemistry is not targeted here (see report of Working Group 2.4), and nor is the geochemistry of sediments or dust, although they are included in some of the presented case studies.

Two topics are more particularly developed:

1. Urban soil geochemistry, corresponding to available 2D approaches,

2. Urban subsoil geochemistry within the context of 3D to 4D approaches.

For each of the topics, the following aspects are discussed: databases, visualisation, and uses of results. Some examples of good practice, or at least of best efforts, are illustrated by case studies. Web links are also provided to illustrate the latter. Identified gaps are eventually highlighted

2- Available 2D approaches: urban soil geochemistry

2.1- Databases to manage geochemical information

2.1.1- General introduction

A recent key initiative at European scale has been the acquisition of systematic knowledge on urban topsoil geochemistry. The methods of data acquisition are well described, and results are widely available, but the management of geochemical information is less commonly described in the literature. Management of these data is not commonly described in detail for an external readership, and is largely addressed within organisations.

2.1.2- General discussion

- Data acquisition

Data acquisition includes: definition of a sampling strategy; sampling; sample preparation; analysis; verification of accuracy and precision, and assessment of uncertainty of the data.

- Data description

In addition to the soil geochemical data themselves, the following sample metadata are required: localisation (x,y locality coordinates); method of acquisition; soil description (colour, odour, texture, structure…), and site description (garden, road side, …). Some additional information may be useful, depending on the reason for the acquisition of the data: physico-chemical properties of the soil (pH, grain size, agronomic properties such as C/N, organic carbon, water content, CEC, carbonate content…); soil profile (to interpret the natural/anthropogenic influences of the genesis, and including their contamination); and their historical and environmental context (to understand the origin of contaminants); etc.

- Data storage in databases

Effective database storage enables: accessibility and efficient (re)use of the data (for statistics, mapping…); and integration of new data (update). The database structure needs to enable effective organisation of the data, facilitate different functionalities, such as data extraction and data integration, and also anticipate future uses of the data. Interoperability with other databases is key to facilitate for example, data crossing or comparison.

- Database management and updating

The database needs to be maintained and updated to incorporate new data (new analytical data, and new analyses of stored reference samples…). To ensure the sustainability of the database, a database manager is needed (permanent staff preferred). Long term financial support is thus needed to ensure long term updating and access to the data (digital archives). The COST Sub-Urban Working Group report (WG2.2) on data acquisition and management details these needs. Management by a non-profit / public organisation is often the preferred solution for national/regional scales of data, so as to allow access to data users. For public data, the drive is towards free access (cf. European Inspire Directive) although licensing of the data is often used to protect IPR, and ensure proper use of the data.

2.1.3- Examples/case studies

The key steps in **data acquisition** are very well described by Demetriades and Birke (2015a and b), under the EuroGeoSurveys Urban Soil Geochemical Project (URGE II), the successor to the original URGE Project (Johnson *et al.,* 2011). URGE II has resulted in the development of a rigorous methodology (including sampling strategy, sample preparation, analysis, verification/quality control...) to be applied on a European scale to allow easy and direct comparison of urban soil data. Many examples and case studies describing data acquisition are also available in the literature.

Links to Demetriades and Birke (2015a), kindly made possible by the authors, are available through the COST Sub-Urban website:

http://sub-urban.squarespace.com/new-index-1/#geochemistry-wg-26

A synthesis of some key points from this report are given in Appendix 1.

Data description associated with urban geochemistry of soils is less commonly described in the literature. Gavrilenko (2013), Puskás (2009) and Ramos-Miras (2011) have described particularly sample site details and chemical content, as well as some additional parameters such as grain size or pH. Land use and environmental parameters appear generally to have been added afterwards, based on sample location.

A more complete description of data is available in relation to the French National Database on agricultural soil quality (RMQS, see website link below). It includes the following descriptors: position (x, y, general locality details), depth (lower and upper), layers (surface and deeper), environmental indicators (calculated: land use, lithology, vegetation, hydromorphy), soil characteristics (granulometry, carbon content, total carbonates, nitrogen, pH, cationic exchange capacity), metal contents (total and/or extractable). Further information is available in the online manual by Jolivet *et al.* (2006, in French):

http://acklins.orleans.inra.fr/programme/rmqs/RMQS_manuel_31032006.pdf

There are very few detailed examples of **data storage, management and updating** on urban soil geochemistry in the literature. It is nevertheless partly described in the G-BASE manual (Johnson and Breward, 2004), which accompanies the geochemical data acquired, and stored in an Oracle database managed by the British Geological Survey (BGS, UK). They include urban and non-urban data, which go through a rigorous quality control procedure before being published and standardized. The data are freely available to all BGS and other NERC (Natural Environment Research Council (UK)) researchers for non-commercial research. Otherwise, they are available under license. The following link gives access to the urban geochemistry part of G-BASE http://www.bgs.ac.uk/gbase/urban.html. More information is also available in Fordyce et al. (2005).

London Earth is an example of city-scale good practice in terms of an urban geochemical (2D) database. It holds the data from the systematic high-density geochemical soil survey of the Greater London Area (GLA), which aims to give insight into the environmental impacts of urbanisation and industrialisation as well as to characterise the geochemical baseline of the UK's most populous city (http://www.bgs.ac.uk/gbase/londonearth.html). A set of ten geochemical maps and short interpretations are available to download for a selection of environmentally sensitive elements (As, Cd, Cr, Cu, Ca, Fe, Pb, Se, Ni and Zn). The London Earth soil geochemistry viewer displays interactive geochemical maps for five of these elements (Cu, Ca, Fe, Pb and Ni). *London Earth* is a component of the UK-wide Geochemical Baseline Survey of the Environment (G-BASE) which provides high-resolution geochemical mapping for the whole of the UK, including surveys of many of the UK's cities. 27 urban areas have been sampled to date, including Glasgow, Nottingham, Ipswich and Cardiff (http://www.bgs.ac.uk/gbase/urban.html).

The French web portal on groundwater data (ADES) represents another interesting example of a web service. The database is designed to meet data acquisition, control, management and dissemination requirements. It offers free and open access to various groundwater data, including quality (chemical analyses) and monitoring networks. Sensitive data are nevertheless protected, being accessible only to authorized services. The Metadata conform to the requirements of the INSPIRE Directive. There are various levels of validation (raw to highly validated data), and several research methodologies are used. More information is available at the following links:

http://www.ades.eaufrance.fr/?CInfo=en-GB

http://www.ades.eaufrance.fr/Spip.aspx?page=IMG/pdf/Flyer-ADES-AN-BD.pdf

2.2- Use of geochemical data and information

2.2.1- General introduction

As stated above, the acquisition and use of geochemical data is commonly linked to issues of health, and the need to evaluate health impacts.

2.2.2- General discussion

As observed in the case studies reviewed (see Appendix 2), the acquisition of data is not often carried out to meet the needs of city council/urban planners/decision makers. When this is the case, the key objectives include:

- Knowledge: distribution and sources of contaminants
- Management: flagged area, threshold values, management of contamination and options for remediation with costs

This information, often associated to informative maps, provides the basis for key decision-support tools.

Several types of decision-support tools are recommended for addressing a range of user needs: reports, data, GIS files with geochemical maps, maps synthesizing trace element content and acceptable uses of excavated soils. Effective visualization is vital for communication, meaning from technical discussion to decision support and in public meetings.

The most common use of urban topsoil data is related to health issues. Representations of the data vary according to the objective/specific need. There may be a need for example to identify zones where the population may be at risk of direct exposure to contaminated topsoils (through soil ingestion or inhalation of dust or vapors). It may also be important to establish if the soils are used for urban agriculture or gardening. In this case, potential uptake of contaminants by plants, and so their transfer to the food chain should be considered.

2.2.3- Examples/case studies

The review presented in Appendix 2 gives some examples of users. The main cited user is the municipality or city council (Glasgow-UK, Nantes-F, Oslo-N, Lavrion, GR, Vienna, A). Within the city council, several technical services may be involved, e.g.: garden and green spaces technical service (Nantes, F); Health and Welfare department (Oslo, N). There may also be links with for example the Development and Regeneration Services (Glasgow), urban planners (Nantes, F) and Environmental Protection for soil (Vienna).

The main use is linked to decision support.

In this regard, the urban geochemical sampling surveys carried out for Glasgow (UK) and Vienna (Austria) are considered as examples of good practice. Glasgow was driven particularly by both environmental and health issues, and Vienna by environmental issues. Both surveys also link soil geochemistry with the geochemistry of river/stream sediments and water and airborne dust. In Glasgow, the sediments and waters sampled were in the stream/rivers/estuary within the catchment of the River Clyde which passes through and lies in the general vicinity of the city. The Glasgow case study is presented in Appendix 3 and that for Vienna is presented in Appendix 4.

2.3- Visualisation of geochemical information

2.3.1- General introduction

Visualisation of geochemical information may relate both to statistical and/or spatial treatment of the data, and may illustrate either validated data or interpreted data.

2.3.2- General discussion

Various end-users with no particular expertise in geochemistry (developers, urban planners …) need representations that are easy to understand, and to use. In this context, the use of raw data appears inappropriate, and an interpreted data set should be used instead. The visualisation of data is also linked to the objectives or use of the visualisation (see. § .2.2).

Preliminary statistical treatment allows a general overview: minimum and maximum percentiles, and data distribution (histograms). Data distribution being generally non Gaussian, classical statistics cannot be applied. The most commonly used statistical approaches include: box plots, PCA, and cluster analysis.

Spatial visualisation can show point location data with or without interpretation (e.g. referring to a threshold value). Data interpretation may also be applied to build continuous spatial representations, thanks to interpolation. The advantage of interpolation is that it enables coverage of the whole of the studied area. However the accuracy of such a treatment needs to be verified: the spatial relationship between data must be verified by a geostatistical approach through the use of variographic analysis. An alternative to interpolation is the use of grids, where a sample is represented by a cell (square portion of the territory, supposed to be homogeneous). Due to the heterogeneity of urban soils, the data used for interpolation or grid representation are inferred to be more or less representative of the system under study. Uncertainty maps should therefore be provided in addition to spatial interpretations.

The most common types of spatial visualisations are element/component maps. Indicators of soil geochemical quality can also be mapped by crossing several parameters.

2.3.3- Examples/case studies

There are many examples of subsurface data representations in the literature. Mapping of soil geochemical quality is particularly well developed at the European scale.

Many examples have been compiled by Johnson et al. (2011):

http://eu.wiley.com/WileyCDA/WileyTitle/productCd-0470747242.html.

Examples of grid representations are also available on the internet, e.g. in the advanced geochemical atlas of BGS:
http://resources.bgs.ac.uk/ebooks/AdvancedSoilGeochemicalAtlasEbook/index.html#/1/

The representative examples proposed provided below illustrate element/component maps (Fig. 1 to 4) and "built parameter" maps (Fig. 5). Fig. 2 (Argyraki and Kelepertzis, 2014) shows a mix of punctuated and continuous interpretations. In both representations, the range of content depends only on the data considered and does not correspond to a more general threshold. This corresponds to the continuous representation of given elements presented by Guillén (2011) as baseline maps (Fig. 3). In contrast to this, Acosta and al. (2011) (Fig 4) as well as Poggio and Vrščaj (2009) (Fig 5) have used classes for representation. These may be used as thresholds by developers. Finally, the factors maps (Fig. 6) proposed by Guillén (2011) offer an interesting example of a built parameter map, even if the notion of factor should be presented in a more readable way for end-users.

Element/component maps

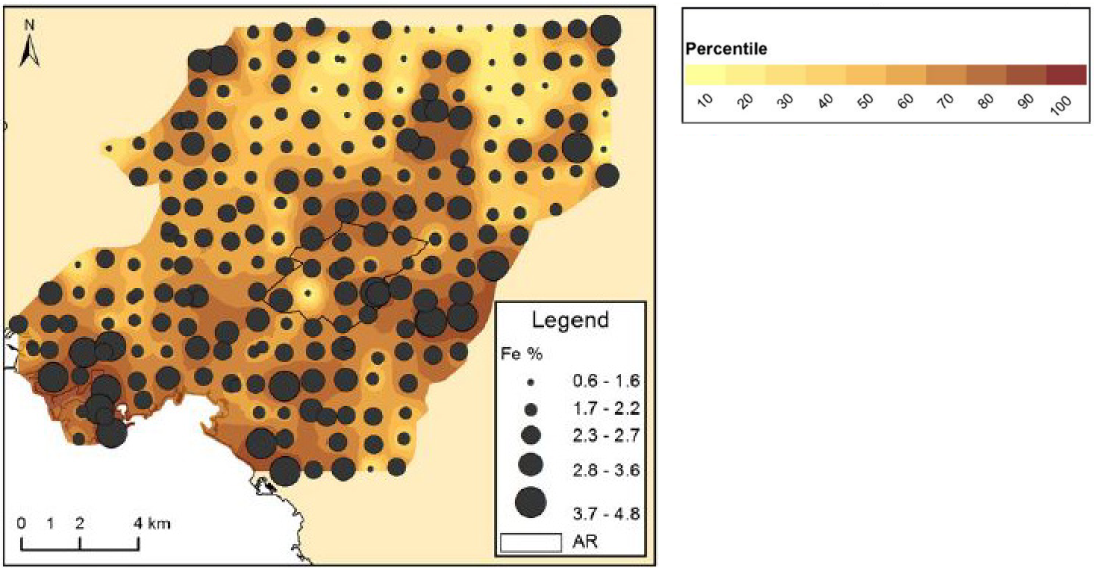

Fig. 2: Geochemical map showing the spatial distribution of iron in urban soils around the city of Athens (Greece) (AR: “Athens Ring”). (Argyraki and Kelepertzis, 2014)

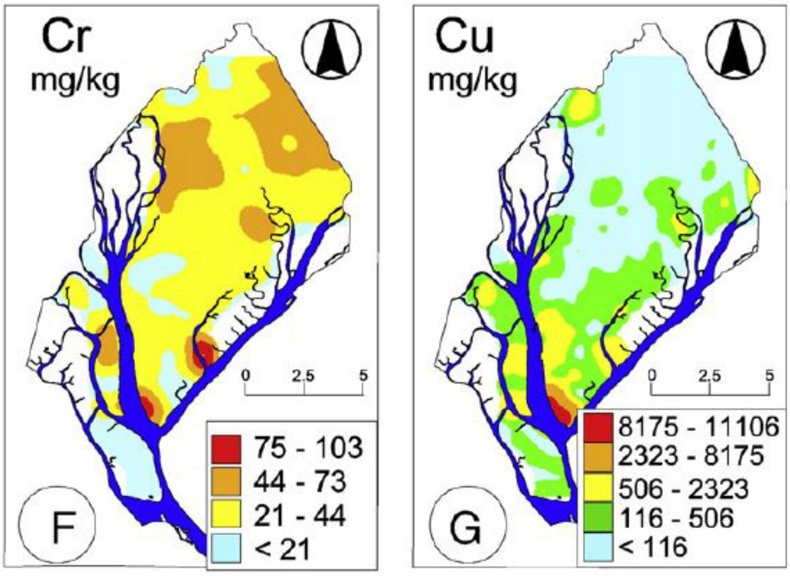

Fig. 3: Baseline maps of chrome and copper obtained from the geochemical samples of soils from Huelva municipality (Spain). (Guillén, 2011)

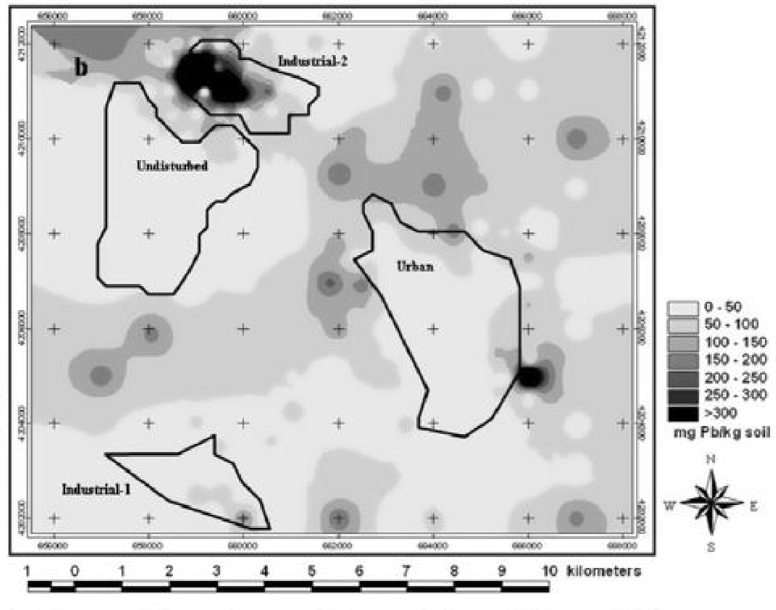

Fig. 4: Spatial distribution of Pb around Murcia city (Spain). Data were interpolated with the Inverse Distance Weighting method. (Acosta *et al.,* 2011)

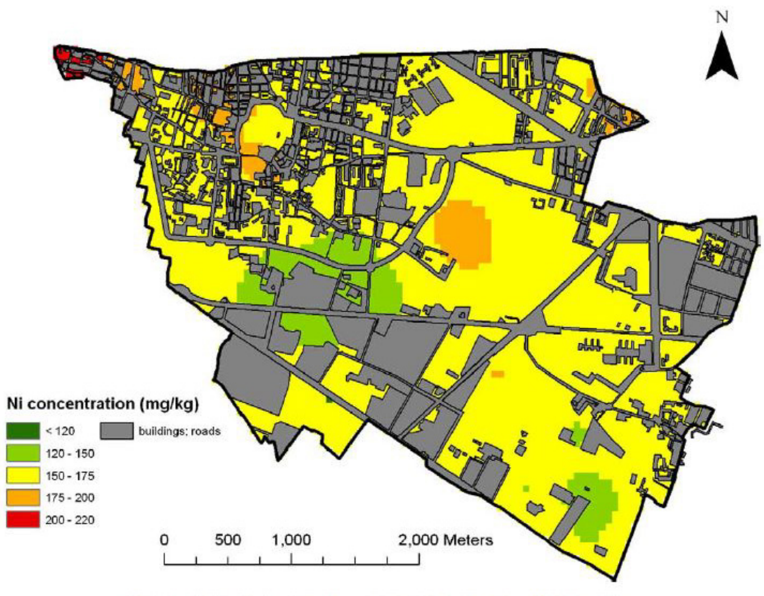

Fig. 5: Spatial distribution of nickel concentrations around Grugliasco (Italy) as calculated by the log-normal ordinary kriging. (Poggio & Vrščaj, 2009)

Build parameter/ indicator maps

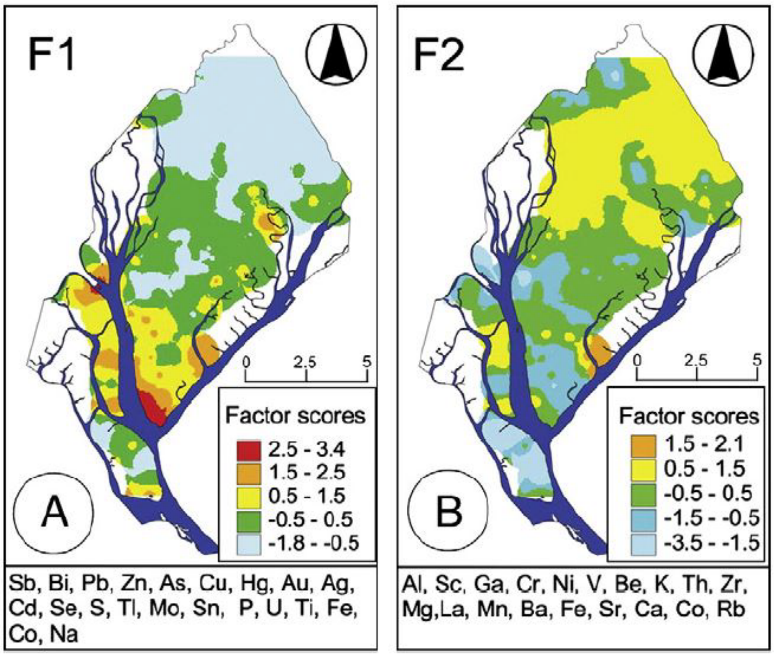

Fig. 6: Maps showing the factor score of the F1 and F2 factors obtained by factorial analysis on the geochemical samples of soil from Huelva municipality (Spain). (Guillén, 2011)

2.4- Knowledge gaps

The following gaps have been identified in regard to 2D geochemical approach:

(i) Soil mapping in the urban environment, including heterogeneity and dynamics. In the urban environment, there is a constant evolution of soils as they are being removed, and new soils are being introduced or even created. This raises the following questions: How to monitor these changes on soils and to confirm whether they remain in situ or not? How and where to observe soil dynamics in the urban environment (evolution of input, transformation, output) and assess associated impacts on the urban system (permeability, geochemistry, etc…)?

(ii) Emerging contaminants: new substances are introduced in existing or new products (e.g. platinoids such as Pt in car catalyitic converters, agrochemicals, pharmaceuticals, flame retardants…) that may impact on the urban environment and related soils.

(iii) Useful representations for end-users: the notion of indicators, which appears to be relatively under developed at the present, offers considerable promise.

3- Towards 3D to 4D approaches

3.1- Databases to manage geochemical information

3.1.1- General introduction

Many 3D geochemical data are currently acquired from urban soils and subsoils to address issues of contamination. However, their acquisition from third parties can be challenging; there can be difficulties in obtaining the data due to their sensitivity, and due to the large number of data owners that may be involved (operators, contractors, private and public …). Also, these data are often very heterogeneous, and so difficult to compare, due to variations in:

- methods of sampling;
- analytical tools;
- detection limits;
- units sampled.

These differences typically can result from variability in the specifications used for ground investigations: by different consultancies; and over time (e.g. as a result of evolution in analytical methods or practices).

Another difficulty may also be caused by the absence of key data. It may be due to a variety of reasons such as the absence of an appropriate, or sufficient, driver to launch their acquisition (health, economy, environment…), or insufficient budget (geochemical data are costly to acquire).

Where data exist, they should be used as much as is possible. Although the protocols of acquisition may not exactly be the same, and the data might not be directly comparable, they do regardless provide some valuable information. Where data have to be acquired, they should be accessible and readily useable with consideration being given to their interoperability, requiring efficient data storage, maintenance and updating in databases designed to facilitate multiple uses.

3.1.2- General discussion

- Data acquisition

Most of the principles and methodologies used in 2D soil geochemical data apply equally to 3D data acquisition (see § above).

Some additional specifications should also be considered:

- adaptations in relation to drilling methodologies (dry),
- sampling according to lithology rather than depth (sometimes carried out).

More generally, the harmonisation of protocols through guides and norms is essential if consistency and comparability/interoperability of data are to be achieved. It is also necessary that these protocols are adapted to suit a range of specific cases/situations. Many norms exist already as regards soil and subsoil characterization (refered to as SOIL QUALITY, ISO Number). The forthcoming European Standard ISO/CD 15175 on Soil Quality – Characterization of contaminated soil related to groundwater protection will be useful in establishing consistency in urban subsoil quality data. In particular, it will give a list of parameters for site and soil description.

- Data description

Appropriate metadata are essential if data are to be useable. In particular, the 3D coordinates (x, y, z) of the samples are vital (and should be based on a national system of coordinates rather than a local site system), as well as a link to the borehole description. The boreholes, as well as the samples should have a unique identifier. Their description should include the lithology but also organo-leptic indicators (colour, odour) as referred in the forthcoming European Standard ISO/CD 15175 on Soil Quality – Characterization of contaminated soil related to groundwater protection.

The following descriptors are also recommended:

- precise depth range of the sample
- use rigorously defined and internationally agreed terms to describe the components of the anthropogenic deposits (including colour/odour…).
- a glossary mass of the sample

For each parameter analysed/characterised, the following should be provided:

- Description of the unit sampled,
- Analytical methods used,
- Sample preparation methodology,
- Detection limits,
- Quantification limit,
- Saturation index,
- Etc.

During data acquisition, it is necessary to anticipate data storage in databases, and thus to acquire all essential observational and other useful data.

- Data storage in databases

The database must have a robust and adaptable structure, enabling multiple uses of the geochemical data over time. The transfer of data by the data producer should be facilitated as far as possible with input file(s) wholly compatible with the database. To reduce the risk of error during transfer, a standardised data transfer template is required. For example, in France, for groundwater analytical results, a specific format (the Edilabo format) has been developed in collaboration with laboratories that report the data.

The verification and validation of data need to be automated as far as possible to save time and money (units, range of result, analytical tool, etc). Once validated, data delivery via a portal should also be largely automated.

- Database management and updating

Long term financial support is needed to ensure long term updating and access to data (digital archives). The COST Sub-Urban WG2.2 report (Watson et al. 2017) on data acquisition and management details these needs. Management by a non-profit / public organisation is often the preferred solution for national/regional scales of data, so as to allow access to data users. For public data, the drive is towards free access (cf. European

Inspire Directive) although licensing of the data is often used to protect IPR, and ensure proper use of the data. To protect the confidentiality of some data, several levels of access to the data may be included (professional, citizen, etc).

3.1.3- Examples/case studies

There are currently few functional examples of good practice with respect to 3D geochemical databases for European cities.

Glasgow GSPEC shows some interesting aspects such as: free access database for data storage, data description format, potential link between geochemical results, sample description and borehole description and locality details. Glasgow City Council has made it obligatory for their own newly acquired data to be fed into the database via the portal, and its use is gradually being extended more widely across Scotland and the UK (see COST WG2.2 report, Watson et al. 2017). The geochemical aspect of GSPEC is 'in development'. In particular, for the management of geochemical data, a set of rules to validate geochemistry data is yet to be defined.

Nantes may be considered as a best effort case for the following reasons:

- a database is built to ensure 3D representation of urban soils and subsoils geochemistry

- it has influenced the national database on urban geochemistry of soils and subsoils (BD-SolU)

- a major effort was made to gather, homogenise and integrate the collected existing data

- a protocol for data acquisition and description has been produced and is now used by urban developers and consultancies firms.

The case study is described in Appendix 5.

The French national database on urban soils analyses (BD-SolU - Base de données sur les Sols Urbains - French national database on urban soils, Rouvreau et al, 2014) may also be considered as a best effort case. Managed by BRGM with the financial support of the French Environment Agency (Ademe), it is developed on PostGreeSQL. It has been used with success to manage and interpret the geochemical background around an industrial site in an Eastern French city in order to determine when the (sub)soils are impacted on (or not) by industrial activities, and to select a redevelopment project that minimise the volumes of excavated impacted (sub)soils. Testing the input of an existing data set (such as the Nantes local database) is the next step. To facilitate the input of newly acquired data, the production of files for data description, compatible with data storage in BD-SolU, is expected to be developed at national scale in relationship with analytical labs (in the same way as the Edilabo format for water quality data-ADES).

3.2- Use of geochemical information

3.2.1- General introduction

The 3D representation of subsoils geochemistry may be a valuable as a decision-support tool for urban planners, developers and managers. It may be used for example to estimate the volume and quality of excavated materials, to adapt a redevelopment project so as to optimise the management of excavated materials, and/or to limit health risks. It may supplement a preliminary 2D approach, or be carried without any preliminary 2D survey in zones where contamination is already suspected. Its general use would allow better management of subsoils as a resource.

3.2.2- General discussion

Use of 3D geochemical information is generally carried out at site scale. To enhance the use of this information at larger scale (quarter to city), close cooperation between scientists and users is necessary. Cooperation with consulting firms may also be profitable (exchange of knowledge/data).

3.2.3- Examples/case studies

3D urban geochemical data are generally used for management of contamination at a site scale. There are relatively few examples of its larger scale use (Rotterdam, Nantes, Oslo…) having been carried out and published; it is therefore difficult to identify examples of good practice.

Nantes might represent a best effort case study for the following reasons:

- In this context of urban redevelopment, knowledge has been established to help anticipate the management of excavated materials (soils and subsoils);

- The 3D model of subsoils has been used to calculate volumes per category, and so management options, for each potential category (landfill, reuse);

- The visualization of geochemical data for operational purposes has been developed with urban developers and urban planners;

- An economic evaluation of benefits related to the various management options available has been carried out;

- Baseline compatibility levels have been produced to facilitate and guide the reuse of excavated materials.

Further details are given in Appendix 5.

Vienna and Glasgow might also be regarded as a best effort case studies because the geochemical data acquired have enabled local background levels to be established, and the anthropogenic and geogenic origins of trace elements to be distinguished. Knowledge of local background levels is useful in the management of excavated materials. The Vienna case study is also interesting because it monitors the evolution of soils within the context of a wider geochemical approach which, like in Glasgow, also encompasses groundwater, dust and sediments. More details are given in Appendices 4 and 3.

3.3- Visualisation of geochemical information

3.3.1- General introduction

3D geochemical modelling of urban subsoils is relatively uncomon at quarter to city scale, compared to 2D approaches that map soil geochemical quality. 3D representation, where undertaken, is done so mainly in relation to redevelopment projects, including brownfield sites, where subsoils contamination (e.g. by former industrial or mining activities) may affect the management of excavated materials. As 3D geochemical modelling is very expensive, its use generally has to be determined by economic need. In comparison, health drivers are frequently cited as the key drivers for 2D mapping of soil geochemistry.

3.3.2- General discussion

Most of the reasons used to advocating 2D data mapping of soil geochemistry may also be applied to the 3D modelling of subsoil geochemistry (cf. § above). Similarly, the reasons used to argue for and justify the use of 3D data interpretation, modelling and visualization of subsurface geology/lithology/properties (e.g. data management, interpolation...), as well as many of the existing tools, may also be used for 3D geochemistry as well (cf. COST Sub-Urban Working Group 2.3 report (Schoecker et al., 2017)). As with 3D geological modelling and interpretation, 3D geochemical data interpretation must also be adapted to the specific question(s) to be addressed

3.3.3- Examples/case studies

As yet 3D urban geochemical modelling and visualisation is largely unexplored at quarter to city scale and good practices are yet to be identified.

Best effort is evident in the Nantes case study for the following reasons:

- Data interpretation integrates borehole description and sample analyses,

- Significant quantities of data are available for one of the city quarters, whereas less data are available in the other quarters

- A typology of made ground has been established: the classes take into account contamination potential linked to intrinsic quality of the types of made ground,

- Several forms of data visualisation are available: 3D, 3D to 2D (structure of ground/subsurface according to materials geochemical properties, and classes of subsoil quality according to management options (landfill, reuse),

- Contamination potential has been linked to former land use (in particular, industrial and service activities) and presented in visual form.

More details are given in Appendix 5 and in Le Guern *et al*. (2016a, b).

3.4- Knowledge gaps

In addition to the gaps previously highlighted in relation to 2D geochemical surveys, the following gaps are evident for the 3D to 4D approach.

Development of 3D and 4D mapping technology

A major difficulty in developing a 3D representation of the “geological” structure of urban soils and subsoils lies in their heterogeneity and especially in the lack of geological logic in the internal structure of anthropogenic made-grounds/deposits.

Like urban soils, urban subsoils are also constantly evolving: in situ subsoils may be removed or modified (e.g. removal of contaminated subsoils); new materials may be introduced. The evolution may be particularly rapid in (re)development zones and may result in major changes in the properties of the subsoils (e.g. geotechnics, permeability, geochemistry, organic carbon). Subsoil dynamics should therefore be monitored over time, to providing the basis for their 4D representation.

Geochemical data acquisition and management

There is a need to build a general knowledge on soil and subsoils. It should address the following:

- Consolidation of existing geochemical data in local and/or national databases, taking account of: 3D to 4D data, database structure, management-verification, validation, and updating. In this context, the following key questions arise: how to populate the national databases? What would be the best solution(s) for public and private data respectively: voluntary, contract, legislation?
- Protocols to ensure comparability of data. Measures already in place in relation to 2D geochemical surveys and data (cf. § 2.1.3), could be extended to/tested on 3D data. As mentioned in §3.1.2., protocols should be adaptable to site-specific conditions. Standardisation of descriptions is also essential.
- Because existing data lack consistency and standardisation (different extraction methods and/or detection limits), methods need to be explored to make their comparison more reliable and robust.

3D representation of geochemical data

Geostatistics may be useful in helping to addressing gaps in data, selecting data for interpolation, identifying the best method of interpolation of data, and interpolating data when their spatial correlation is confirmed.

Although there has been considerable research and development in geostatistics for 3D geological modelling (linear, non-linear, voxel - cf. COST Sub-Urban Working Group Report WG 2.3 (Schoekker et al. 2017)), management of heterogeneity, and analysis and management of uncertainty, much research and development remains to be carried out in this field on 3D subsoil geochemistry.

Use of geochemical data

More helpful representations of geochemical data are required for end-users. In this context, the development of indicators of geochemical quality versus potential use of soil and subsoils could be useful. Cost/benefit analysis is another area where further work is required.

3.5- Workflow

User(s): Who?	Urban planners	Urban developer	Urban manager	
Question(s)?	Baseline	Contamination	Excavated soils / subsoils	Biodiversity
Aim(s)?	Knowledge	Decision Aid	Management	Planning
Driver(s)?	Economy	Health	Social	Environment

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- Appendix 1 – Key points of data acquisition for 2D mapping of urban soil geochemistry – synthesis from Demetriades and Birke Urban Topsoil Geochemical Mapping Manual (2015)
- Appendix 2 – Survey : To which extent the 3D modelling of soils and subsoils geochemistry is used in European cities
- Appendix 3 – Glasgow case study
- Appendix 4 – Vienna case study
- Appendix 5 – Nantes case study

APPENDIX 1 – Key points of data acquisition for 2D mapping of urban soil geochemistry – synthesis from Demetriades and Birke Urban Topsoil Geochemical Mapping Manual (2015)

A brief overview of the scope and content only of the Manual is provided here:

(i) The Manual covers all aspects needed to establish the baseline of concentrations of chemical elements and compounds in urban environments and describes “tried and tested” urban geochemical methodologies for: sampling, sample preparation, laboratory analysis, quality control, data conditioning, processing and map plotting. As such, the Manual represents the basis for standardisation of urban geochemical sampling across Europe and globally.

(ii) Given the potential importance of geochemical data in relation to a wide range uses, and major issues such as planning, health and well-being, The Manual emphasises the need for high quality, integrity, and legal defensibility of the data. The geochemical baseline can then serve as a basis: for assessing previous anthropogenic impacts (urbanisation, industrialisation etc.), and; for the timeline for future change.

(iii) The Manual places greatest emphasis on sampling, as any errors at this stage are very difficult to identify, and to rectify, and have knock-on effects throughout the “mapping” process.

(iv) Soil is the most widely used sample medium, in urban areas, and especially so for citywide campaigns (Johnson and Ander, 2008). The emphasis of the Manual is therefore on sampling topsoil, and subsoil to a limited depth. Topsoil is the sample medium most likely to be in direct contact to humans, and child health criteria are of particular importance in this regard (Demetriades and Birke (2015a and b).

(v) Drainage sediments are less widely used than in non-urban studies, in part because of the greater difficulties in their sampling in urban areas culverts etc.). However, drainage sediments (e.g., Fordyce et al., 2004) are better suited than soils for tracking the passage of contaminants through the urban environment.

(vi) Urban topsoil, especially in older city areas, is geochemically (and lithologically and structurally) complex and heterogeneous as a result of anthropogenic influences. This, the cultural layer of Blume (1989) and others, varies from a few centimetres to more than 10 metres and is a significant sink for the legacy of, and any continuing, urban contaminants.

(vii) Of most direct relevance to the Sub-Urban Action Geochemistry Report is the Manual's:

- guidance on sampling emphasises:
    - single spot (rather than composite) sampling,
    - systematic (grid-based) rather than random sampling
    - nominal sample density of 4 samples/km^2 (but can be any density) typically using a 500 x 500 m grid for central city areas up to 1000 x 1000 m grid for suburbs,
    - Topsoil (the medium of most direct contact to humans and the principal sample type) samples from a range of 0-10 cm depth from undisturbed (or least-disturbed), preferably bare, urban soil near grid node, although other depth ranges may be more appropriate, depending on survey objectives,
    - subsoil samples from a range of 50-60 cm depth, although optimum depth range should be determined by an orientation survey,
    - if topsoil and subsoil samples are collected at all sample sites, both should be from the same depth ranges.
    - Duplicate field samples to be collected at every 20th sample site for projects with >400 samples, and every 10th sample site if <400 samples, and

- Emphasis is also placed on
    - preparation of a reference sample or samples, before the project starts,
    - the need for all analysis to be in one laboratory, for the same suite of elements/compound, using a reproducible methodology, and with strict quality control.

(viii) Examples of mapping resulting from such data acquisition avec available in Johsnon et al. (2011).

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APPENDIX 2 - Survey to evaluate to which extent 3D representation of soils and subsoils geochemistry is carried out (compared to 2D) and involvement of city partner

In spring 2015, a survey table was circulated to several COST Sub-Urban partners. It included the following thema:

- City and country, Scientific partners (organisms), City planner involved: Y (who) / N

- Geol context, Aim of project, Topic considered

- Scale, Material, Depth, Representation (2D/3D),

- Presented or mentioned in WG1, Presented or mentioned in WG2.3, Published: Y (where)/N, Contact Person, E-mail of contact

- Driver, Documents used/useful for city partner (other actions), Link with city planning or management (Y/N)

- Contaminants, Geogenic origin considered (Y/N)

- Initial questions of urban planner, Other services brought (expected/unexpected),
- Difficulties/gaps

Examples of 2D representations of urban topsoils geochemistry are summarized in Figure A2.1. Figure A2.2 shows that on the contrary to 2D representation of urban soil geochemistry and 3D representation of urban geology, 3D representation of subsoil geochemistry appear more scarcely carried out. The answers of the survey are detailed in Table A2.1.

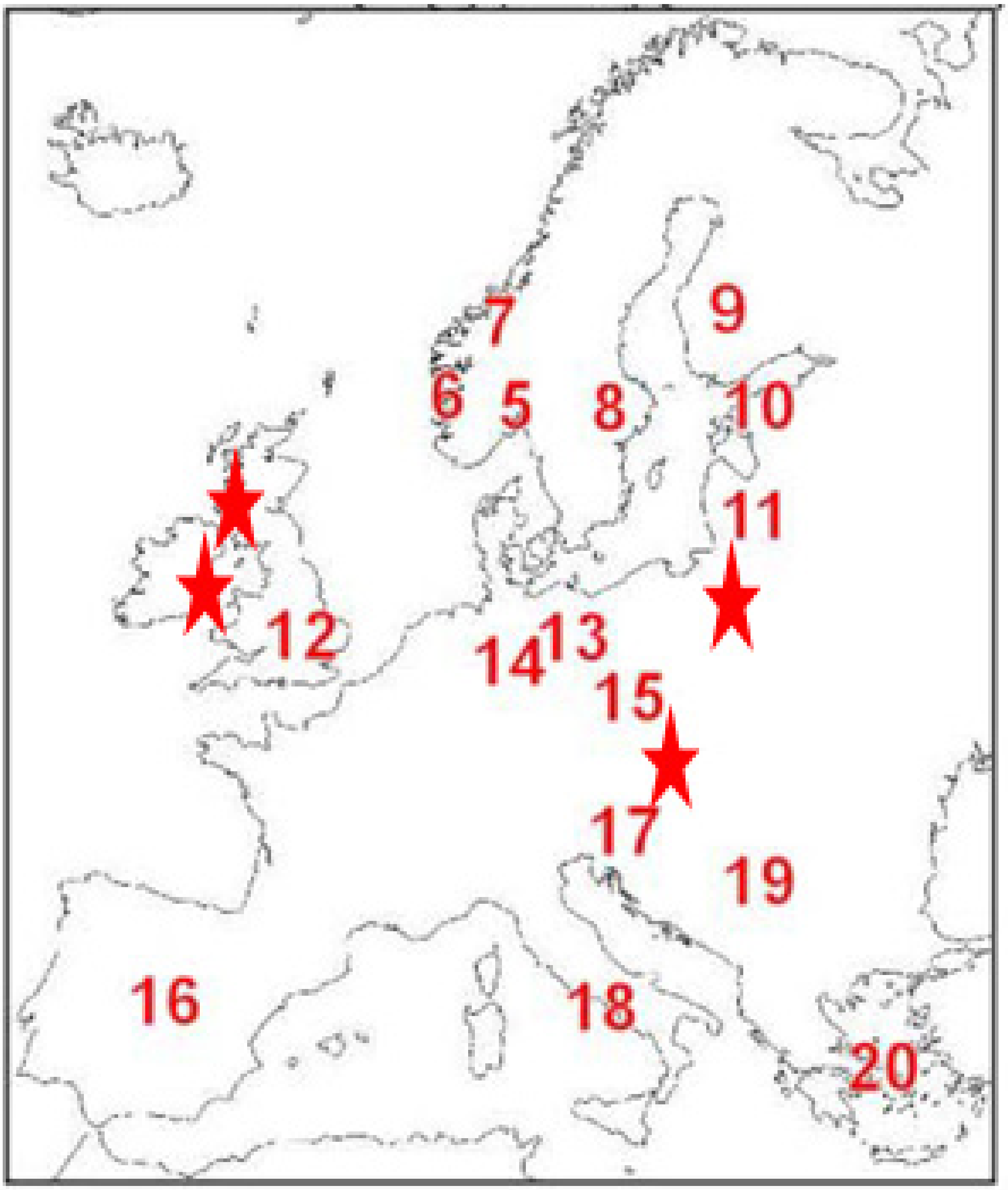

Figure A2.1- Examples of 2D representations of urban topsoils geochemistry (modified from *Johnson and Demetriades, 2011* - http://englishfreemap.jp*).*

Figure A2.2 - Examples of 3D representations of urban soils and subsoils geochemistry

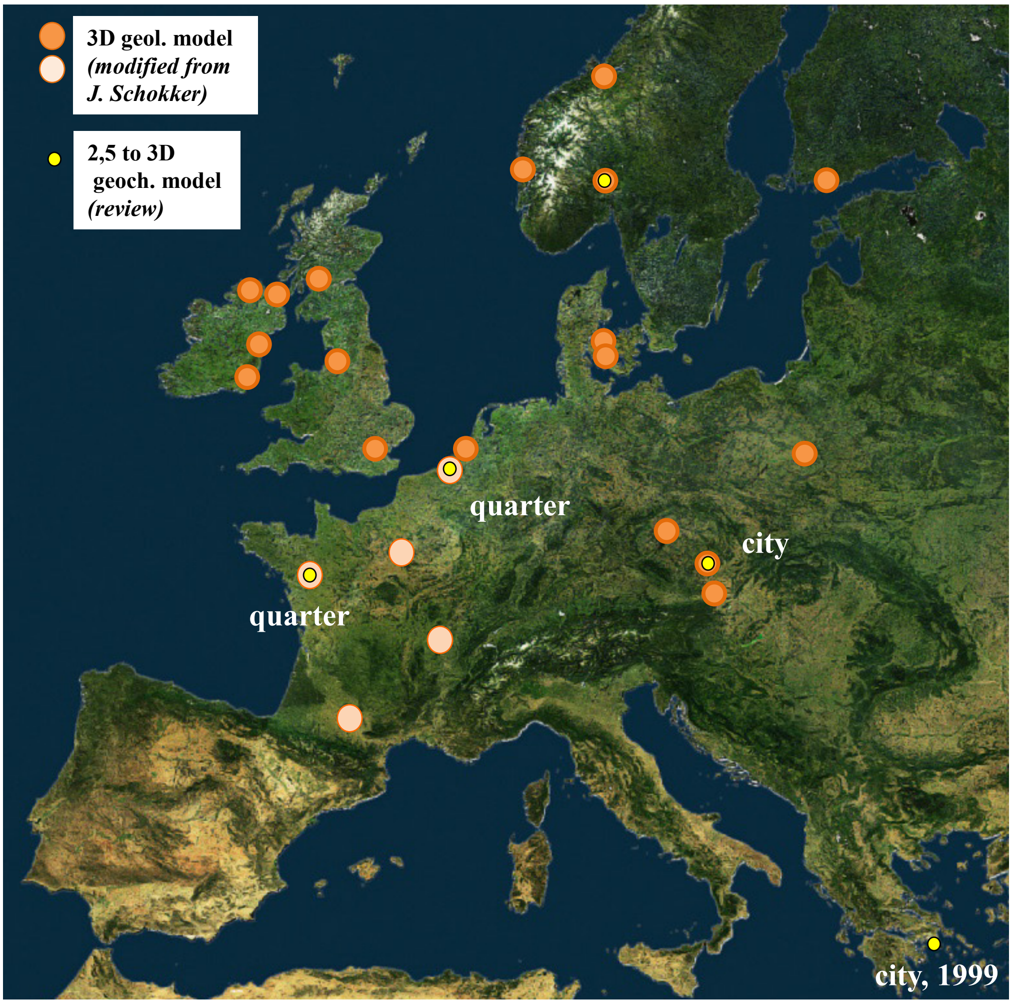

Table A2.1 – Responses from COST Sub-Urban partners to a review of the extent to which 3D representation of soils and subsoils geochemistry is carried out by (compared to 2D), and the involvement of, city partners

City (country)	Scientific partners	City planner involved Y (who) / N	Geol context	Aim of project	Topic considered	Scale	Material	Depth	Representation	Presented or mentioned in WG1	Presented or mentioned in WG2.3	Published Y/N (where)	Contact Person	E-mail of contact	Driver	Documents used/useful for city partner (other actions)	Link with city planning or management Y/N	Contaminants	Geogenic origin considered Y/N	Initial questions of Urban planner/	Difficulties/gaps
Glasgow (UK)	BGS	Yes Glasgow City Council	Quaternary/Bedrock mainly Carboniferous sediments and volcanics	Characterise urban geochemistry of Glasgow, within the context of the wider River Clyde catchment	Soil quality across the urban area. Systematic sampling for inorganic elements. Limited sampling for persistent organic pollutants (POPs) related to land use types. Urban influence versus rural soils, identification of anomalies and likely sources	Whole city	Top soil and deeper soil	5-20 cm 35- 50 cm	2D	N		First phase published report Fordyce et al 2012	F M Fordyce	fmf@bgs.ac.uk	Legislative: need to understand city environments better to develop brown field sites. Help develop UK contaminated land guidance providing information on urban geochemical baselines. Research to feed into environmental guidance and management.	Report and data provided to city council. GIS files with geochemical maps provided to city council	Link with development and regeneration Dept	Inorganic and some sampling for POPs			
Glasgow (UK)	BGS	Yes Glasgow City Council	Quaternary/Bedrock mainly Carboniferous sediments and volcanics	Characterise urban stream sediment and water quality draining into the River Clyde	Stream sediment and surface water quality in all urban tributaries draining into the River Clyde; sediment and water quality in the River Clyde and the Clyde Estuary; rural stream sediment and water quality in the river catchment. Large suite of inorganic analysis. POPs analysis in selected sediment samples	Whole city	Stream sediment, stream water, river sediment, river water, estuary sediment	Surface. Core sediments in estuary also	2D	N		First phases published Fordyce et al 2004; Jones et al 2004; Vane et al 2011; Vane et al, 2010; Vane et al, 2007	F M Fordyce	fmf@bgs.ac.uk	Glasgow Council has responsibility for river quality draining into the Clyde so were interested in assessments of sediment/water quality	Report and data provided to city council. GIS files with geochemical maps provided to city council	Link with development and regeneration Dept	Inorganic and some sampling for POPs	Y		
Nantes (France)	BRGM	Yes (urban planners)	Alluvial	Adaptation of city planning (quarters) Management of « excavated materials »	Potential sources of pollution (maps) Geochem. baseline 3D modelling of urban geology and associated geochemical quality	Part of city (quarter)	Soil to subsoil and underground	0-5 m 0-20 m	2D / 3D	N		N (AquaConsoil 2015 ?)	C. Le Guern	c.leguern@brgm.fr	Legislative : excavated soil = waste, probable evolution Possibility of reuse will become possible (no law, but guide recently published) : test of applicability of the guide	- Shapefile and associated DB on potential sources of pollution linked to industrial activities '- Geochemical baseline values '- Volume of soils/underground materials per level of quality/possibility of reuse/management	Y (urban planning, direct link)	Organic Inorganic	Y	Where are the potential sources of pollution ? How to optimize the management of excavated soils/materials ? Interest in a physicla platform ? Is it possible to propose an evolution of the treshold values to accept excavated soils/materials in inert waste disposal ?	Lots of data Transfer of excavated soils/ materials

Nantes (France)	IRSTV BRGM IFSTTAR U-Nantes	Y (garden and green spaces management service)	Bedrock (micaschists, granite…)	Compatibility of soil geochemical quality with agricultural use in urban allotment gardens (sanitary purpose)	Soil geochemical quality (trace elements)=> maps of trace element contents Origin of anomalies (natural => geogenic, contamination => industrial, agricultural, man made ground…)	Multi sites across city	Topsoil Soil	0-25 cm 0-1,2 m	2D	Y (city report)		Partly (JSS, 2014)	C. Le Guern	c.leguern@brgm.fr	Sanitary : No real legislativ driver rather environmental and responsability awareness	- Maps synthetizing trace elements content and acceptability vs use of ground '- Origin of trace elements Public meetings	Y (management of allotment gardens)	Trace elements	Y		
Nantes (France)	IRSTV OSUNA BRGM IFSTTAR	Yes (waste management service)	Alluvial	To understand transfer of pollutants in soils and subsoils in urban environment	Impact of a former landfill on groundwater Ground characterisation, GW monitoring, 3D modelling	Site / subcatchment	Soil to subsoil and underground	0-15 m	2D-3D	Y (city report)		Partly (conference papers)	C. Le Guern	c.leguern@brgm.fr	Research :	Advice for GW site monitoring (obligatory part of network)		Organic (of which medical/emergent) Inorganic	Y		
Nantes (France)	IRSTV IFSTTAR			Sustainable urban rainwater management	Retention and infiltration basins - sediments - contaminants - management	Sites / subcatchment	Sediments Soil to subsoil and underground	0-8 m	2D	Y (city report)		Partly (JSS, 2013, 2014…)	F. Rodriguez B. Béchet	beatrice.bechet@ifsttar.fr	Research :						
City (country)	**Scientific partners**	**City planner involved Y (who) / N**	**Geol context**	**Aim of project**	**Topic considered**	**Scale**	**Material**	**Depth**	**Representation**	**Presen-ted or mentio-ned in WG1**	**Presen-ted or mentio-ned in WG2.3**	**Published Y/N (where)**	**Contact Person**	**E-mail of contact**	**Driver**	**Documents used/useful for city partner (other actions)**	**Link with city planning or management Y/N**	**Contaminants**	**Geogenic origin considered Y/N**	**Initial questions of Urban planner/**	**Difficulties/gaps**
Oslo (Norway)	NGU	Yes, Health and welfare department at Oslo municipality	Bedrock (limestone, granitic gneiss, mica schist...)	Identify historical pollution point sources, characterising chemical status 0-3 m depth for Oslo area, defining area of awareness, estimating present and future amount of excavated materials + need for low-grade pollution soil deposit, proposing methods of chemical characterisation of excavated material	Anthropogenically influenced versus natural soil, excavated urban soil, pollution sources	Urban area of Oslo	Soil, one sample per meter	0-3 meter (not on all localities, 484 samples 0-1m, 269 1-2 m and 206 2-3 m)	2D	?		As five Geological Survey of Norway reports (in Norwegian)		Rolf.Tore.Ottesen@ngu.no, Malin.Andersson@ngu.no , Ola.Anfin.Eggen@ngu.no	Problems relating to excavated soil	Awareness area (which is in daily use by city), all geochemical data	Y	Organic/ Inorganic	Y	Identify historical pollution point sources, characterising chemical status 0-3 m depth for Oslo area, defining area of awareness, estimating present and future amount of excavated materials + need for low-grade pollution soil deposit, proposing methods of chemical characterisation of excavated material	Defining amounts of excavated material proved difficult, as well as drilling in urban soil

Lavrion	IGME, Hellas	Y (Municipality)	Bedrock (marble, schist, schistose-gneiss, metamorphosed mafic-ultramafics)	Identify historical pollution and its detailed characterisation; risk assessment, environmental management plan, and proposals for remediation	Impact of ore beneficiation and metallurgical processing, and metallurgical wastes on the health of the local population	Urban and suburban area of Lavrion (7 square kilometres)	Top Soil (0-5 cm; N=224); Rock (N=140); Metallurgical processing wastes (N=72); House dust (N=127); Groundwater (N=15); Drill-hole core samples (N=147); Child blood (N=235); Urine (N=65); Child deciduous teeth (N=82)	Surface soil sampling (0-5 cm); Drill-hole depth varied from 4.30 to 17.20 metres.	2D/3D	N		Y as EU LIFE Programme report (6 volumes published in 1999); Publications in different Journals and textbooks	Alecos Demetriades	alecos.demetriades@gmail.com	Health related problems; High Pb in human blood; High As in urine.	Report and data provided to Lavrion town Municipality and Hellenic Ministry of Environment	Y - Lavrion Municipality	Inorganic chemical elements	Y	Identification of all potential sources of pollution; Site-specific threshold values; Environmental management and rehabilitation plan with costs.	Gaps: organic contaminants. But, major problem is the difficulty of finding the funding for remediation
Nafplion	IGME, Hellas	N	Holocene sediments; Tertiary sediments; Campanian to Maastrictian flysh; Lower to Upper Cretaceous limestone; Upper Jurassic limestone	Geochemical characterisation of urban soil	Soil quality across the urban area with respect to inorganic chemical elements	Urban and suburban area (40 square kilometres)	Top Soil (0-10 cm); N=144	Surface soil (0-10 cm)	2D	N		Y published in two volumes as open file report	Sofia Tassiou	stassiou@igme.gr	To document the quality of urban surface soil	Report and data are available to all interested parties	N	Inorganic chemical elements	y	Identification of all potential sources of soil contamination	Gaps: organic contaminants.
Drama (Greece)	IGME, Hellas	N	Holocene sediments; Pleistocene sediments; Miocene limestone; Rhodope Massif marble	Geochemical characterisation of urban soil	Soil quality across the urban area with respect to inorganic chemical elements	Urban and suburban area (45 square kilometres)	Top Soil (0-10 cm); N=176	Surface soil (0-10 cm)	2D	N		Y published in two volumes as open file report	Sofia Tassiou	stassiou@igme.gr	To document the quality of urban surface soil	Report and data are available to all interested parties	N	Inorganic chemical elements	y	Identification of all potential sources of soil contamination	Gaps: organic contaminants.

City (country)	Scientific partners	City planner involved Y (who) / N	Geol context	Aim of project	Topic considered	Scale	Material	Depth	Represen tation	Presen-ted or mentio-ned in WG1	Presen-ted or mentio-ned in WG2.3	Published Y/N (where)	Contact Person	E-mail of contact	Driver	Documents used/useful for city partner (other actions)	Link with city planning or management Y/N	Contaminants	Geogenic origin considered Y/N	Initial questions of Urban planner/	Difficulties/gaps
Sparti (Greece)	IGME, Hellas	N	Holocene sediments; Upper Pleistocene fluvial sediments; Upper Pliocene conglomerate, sandy and marly sediments; Lower Pliocene conglomerate; Upper Senonian to Upper Eocene limestone; Middle Triassic to Lower Jurassic dolomite and limestone; Permian phyllite	Geochemical characterisation of urban soil	Soil quality across the urban area with respect to inorganic chemical elements	Urban and suburban area (45 square kilometres)	Top Soil (0-10 cm); N=206	Surface soil (0-10 cm)	2D	N		Y published in two volumes as open file report	Sofia Tassiou	stassiou@igme.gr	To document the quality of urban surface soil	Report and data are available to all interested parties	N	Inorganic chemical elements	y	Identification of all potential sources of soil contamination	Gaps: organic contaminants.
Thrakoma kædonæs (Greece)	IGME, Hellas	N	Tertiary sediments, Pleistocene fans of conglomerates, Miocene red silt & marl; lacustrine sediments; Triassic to Jurassic limestone, dolomite; Permo-Carboniferous to Lower Triassic clayey-sandy formations.	Geochemical characterisation of urban soil	Soil quality across the urban area with respect to inorganic chemical elements	Urban and suburban area (45 square kilometres)	Top Soil (0-10 cm); N=173	Surface soil (0-10 cm)	2D	N		Y published in two volumes as open file report	Sofia Tassiou	stassiou@igme.gr	To document the quality of urban surface soil	Report and data are available to all interested parties	N	Inorganic chemical elements	y	Identification of all potential sources of soil contamination	Gaps: organic contaminants.
Rotter-dam	The Netherlands		Harbour site Botlek	Possibility of using natural attenuation to remediate groundwater					3D						GW quality						
	Germany																				
Vienna (Austria)	GSA	Yes (Vienna Municipality, including department of Environmental Protection for soil	Flysh sandstone, terrace gravel (Holocène), loess/marine silt (Neogene)	Urban geochemistry of city (monitoring) + background levels	Origin of trace elements (anthopogenic vs geogenic)	Urban area	Topsoil Tertiary and Quaternary sediments at construction sites Forest soils	0-10 cm several m depth	2,5D (geol. 3D model)	?	Y	SEGH 2011	Sebastian Pfeiderer		geol. Layers: test for compliance with landfill regulations			Trace elements (inorganic) : As, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Pt, Se, V, Zn)	Y		

Idrija (Slovenia)		Yes (who ?)	Carboniferous and Permian slate, quartz sandstone and conglomerate, Discordant Middle Permian quartz sandstone, siltstone and conglomerate Pleistocene fluvio-glacial deposits (carbonate pebbles)	identify historical pollution impact, define levels of metal contents in urban soil & sediment &houshold dust		whole town	soil, sediments, houshould dust	soi:l 0-10 and 20-30 cm	2D			soil: Bavec et al., 2015, Journal of Geochemical exploration; **Sediments**: Bavec et al.., 2014; environmental geochemistry and health,	M. Gosar	mateja.gosar@geo-zs.si		geochemical maps, reports , papers, useful data		mercury and other metals	yes		
City (country)	**Scientific partners**	**City planner involved Y (who) / N**	**Geol context**	**Aim of project**	**Topic considered**	**Scale**	**Material**	**Depth**	**Represen tation**	**Presen-ted or mentio-ned in WG1**	**Presen-ted or mentio-ned in WG2.3**	**Published Y/N (where)**	**Contact Person**	**E-mail of contact**	**Driver**	**Documents used/useful for city partner (other actions)**	**Link with city planning or management Y/N**	**Contaminants**	**Geogenic origin considered Y/N**	**Initial questions of Urban planner/**	**Difficulties/gaps**
Belfast (UK)	GSNI - BGS - NIEA	No	Quaternary	Urban baseline	Shallow (20cm) and Deep (50 cm) soils. 4 samples per sq km; 1 of which analysed for organics	Belfast Metropolitan area	Top soil and deeper soil	5-20 cm 35- 50 cm	2D	N		http://nora.nerc.ac.uk/7486 & http://nora.nerc.ac.uk/9599/	A Donald	awdo@bgs.ac.uk	Baseline survey as part of country wide survey.	See published documents	Not used as yet				
Londonderry (UK)	GSNI - BGS - NIEA	No	Quaternary	Urban baseline	Shallow (20cm) and Deep (50 cm) soils. 4 samples per sq km; 1 of which analysed for organics	whole city	Top soil and deeper soil	5-20 cm 35- 50 cm	2D	N		http://nora.nerc.ac.uk/7486 & http://nora.nerc.ac.uk/9599/	A Donald	awdo@bgs.ac.uk	Baseline survey as part of country wide survey.	See published documents	Not used as yet				
Warsaw (Poland)	PGI	N	Quaternary	Characterise urban geochemistry of Warsaw and its suburbs	Soil geochemical quality, aqueous sediments and surface water quality (maps). POPs analyses in selected topsoil and sediment samples. Identification of anomalies (its origin) and pollution sources.	Whole city and suburbs	Topsoil and subsoil, aqueous sediments, surface water	0-0,3 m 0,8-1,0 m	2D	N		N (not finished yet)	Aleksandra Dusza-Dobek, Tomasz Gliwicz, Hanna Tomassi-Morawiec	aleksandra.dusza@pgi.gov.pl tomasz.gliwicz@pgi.gov.pl hanna.tomassi-morawiec@pgi.gov.pl	Urban planning No real legislative driver Research	Geochemical atlas with maps showing the concentration of elements and some POPs in soils, sediments and surface water, analyses of dataset, comparison to current regulations. All data are related to type of land use.	not yet	Inorganic and some sampling for POPs	Y		

APPENDIX 3 – Glasgow (UK) case study

Context

Glasgow (Figure A3.1) is Scotland's largest city and has, with its surrounding conurbation, a population of approximately 1.8 million. In the 19th and early 20th centuries, Glasgow was a leading centre of industry, famous for its ship building, extensive mining of coal and ironstone, and heavy engineering, steel, chemicals, and other industries. Until the 1960s, the south-east of Glasgow area was also home to the world's largest chromium ore processing plant. These industries declined during the 20th century, and Glasgow's economy, and population declined with them. However, Glasgow is growing again, and its economy is being reborn with new service industries.

In the heart of post-industrial Glasgow, the Clyde Gateway and Clyde Waterfront areas are regeneration priorities, stimulating sustainable development and economic growth, and tackling areas of deprivation. A challenge for regenerating these areas is a need to overcome the legacy of former industrial activities, including the geochemical footprints of former industrial uses in the soils and groundwater, and the extensive, abandoned mine workings, some of which are at shallow depth.

To underpin Glasgow's regeneration, the British Geological Survey (BGS) undertook a major multi-disciplinary project, the Clyde-Urban Super-Project (CUSP; 2009-14), focused on Glasgow's subsurface, and its surrounding catchment (Figure A3.1).

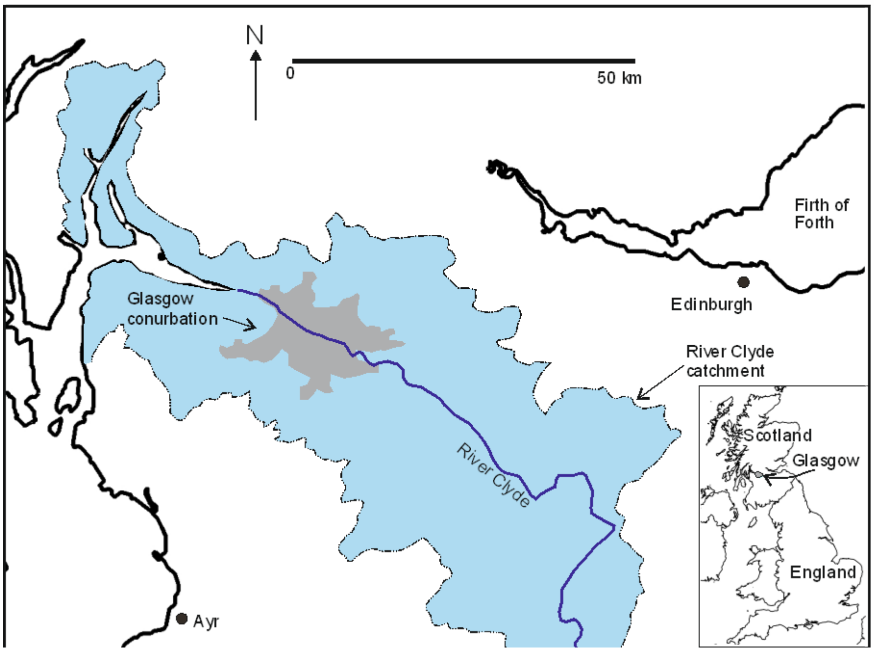

Figure A3.1.: Location of the Glasgow conurbation within River Clyde catchment, Scotland, United Kingdom. (Topography Crown Copyright. All rights reserved. BGS 100017897/2012)

Methodology

CUSP adopted a whole systems geoscience approach (Merritt et al, 2007; Campbell et al., 2009, 2010, 2015Farmer). Multi-attributed, dynamic shallow-earth, multi-scalar 3D models were developed to characterise the complex superficial deposits and faulted bedrock which underlie Glasgow and its associated conurbation. These help to address various geo-environmental issues e.g.: identifying sources, migration pathways and sinks of contaminants, resulting from a multiplicity of industrial legacies; and the extent of, and potential geohazards associated with, former widespread of coal, ironstone, etc. within the urban environment. Various other CUSP datasets, related to groundwater, and importantly geochemistry of surface/near surface soils and waters, have been acquired to inform decision-making in planning, regulation, remediation and construction of the regeneration and other areas. Glasgow City Council (GCC) has been a key strategic partner throughout CUSP, helping to implement new approaches to data acquisition (GSPEC), and to establish, with BGS and others, a pioneering sub-surface knowledge exchange network (ASK) (Barron, 2011; Bonsor et al., 2013).

Results: Geochemical baseline surveys and studies of Glasgow and the Clyde basin

Pollution from past industrial developments pose current and future environmental threats, as many substances are toxic in high concentrations, and could have long-term implications for ecosystems and human health.

As with all cities, urban land quality in Glasgow is the result of complex interactions between man-made inputs and the natural concentrations of substances in soil, which are influenced by the geology and soil forming processes. Therefore, comparisons with rural soils can help elucidate the level of anthropogenic input to soils in urban areas. Therefore, given its intensive industrial legacy, BGS has carried out extensive surveys both in the Glasgow area (2001-02; 2010-11) and throughout the surrounding catchment of the River Clyde, which runs through the heart of the city, and its estuary (Figure A3.1).

These surveys were intended to aid land and water management/protection, and included surveys of:

- rural and urban soil, as part of the BGS Geochemical Baseline Survey of the Environment Project (G-BASE: a major BGS project covering the UK and providing baseline data and geochemical mapping relevant to many environmental issues), and

- rural and urban stream waters and sediment quality in the Clyde Basin (Clyde catchment, Glasgow conurbation, and Inner Clyde Estuary).

An integral part of the G-BASE geochemical mapping programme is the establishment of soil geochemical baselines of urban areas (http://www.bgs.ac.uk/gbase/urban.html; Fordyce et al.(2005), Johnson and Ander (2008)). These data provide unique soil chemical information for the urban environment and are used to:

- Assess the condition of soils within populated areas.

- Identify and quantify human impact on soils in urban areas through comparison with the rural, natural soil geochemical background.
- Indicate elevated concentrations of potential harmful elements

Applications of G-BASE data are also relevant to human health, land-use planning and development, urban regeneration and contaminated land legislation.

Glasgow is one of 27 urban areas in the UK that have been sampled by BGS's G-BASE project. Others include Manchester, Nottingham, Ipswich, Cardiff, Belfast, and the largest study to date covering the Greater London Authority area (London Earth).

- Earlier Geochemical Surveys (2001-02)

Earlier extensive geochemical surveys of Glasgow and the Clyde Basin included:

1. rural stream sediment samples collected by the G-BASE project in the 1980s

2. urban soil samples from the Glasgow conurbation from 2001-2002 (Fordyce et al. (2012))

3. urban sediment and water samples collected in conjunction with Glasgow City Council from all tributaries draining into the River Clyde within Glasgow City (the BGS Clyde Tributaries project (Fordyce et al., 2004)), and
4. river water and sediment samples collected from the Clyde Estuary in collaboration with Glasgow City Council and SEPA as part of the BGS Estuarine Contamination project (Jones et al., 2004).

Fordyce et al. (2012) described the G-BASE survey between 2001 and 2002. 1381 urban soil samples were collected at a density of 1 per 0.25 km2 and 241 rural samples at a density of 1 per 2 km2 on a systematic grid. The distribution of soil parameters are presented as a series of geographic information system (GIS)-generated graduated symbol geochemical maps.

Top (5 - 20 cm) and deeper (35 - 50 cm) soil samples underwent analysis for approximately 46 chemical elements including contaminants such as As, Al, Cd, Cu, Cr, Ni, Pb, Se, V and Zn according to standard G-BASE procedures. In addition, pH and loss on ignition (LOI) as an indicator of organic matter content were determined in the samples.

As an indication of anthropogenic (man-made) pollution, the results revealed (Fordyce et al., 2012), on the basis of median values, that Cd, Cr, Ni and Zn concentrations are 2-3 times, and Cu and Pb 5-7 times, higher in Glasgow than the national average in Scottish soils. Ag (x 3.5), As, Co, Ge, Mo and P_2O_5 (~ x2) are also enhanced in Glasgow urban soils relative to world averages. Similarly, Pb (x 7.5), Cu, Ni, Sb, Sn and Zn (~ x2) and Se (x3) are enriched in Glasgow urban soils relative to world averages. This may in part reflect anthropogenic pollution and in the case of As, Co, Mo, Ni, and Se the presence of coals and volcanic bedrock in the Glasgow area.

Comparisons between Glasgow median values and those from other UK urban areas surveyed by G-BASE show that:

- Cr and Ni are higher in Glasgow soils - attributed to Cr-processing, heavy industry, coals underlying the city (Figure A3.2), and nearby volcanic bedrock

- As, Cd and Pb are lower in Glasgow soils than in most other urban areas.

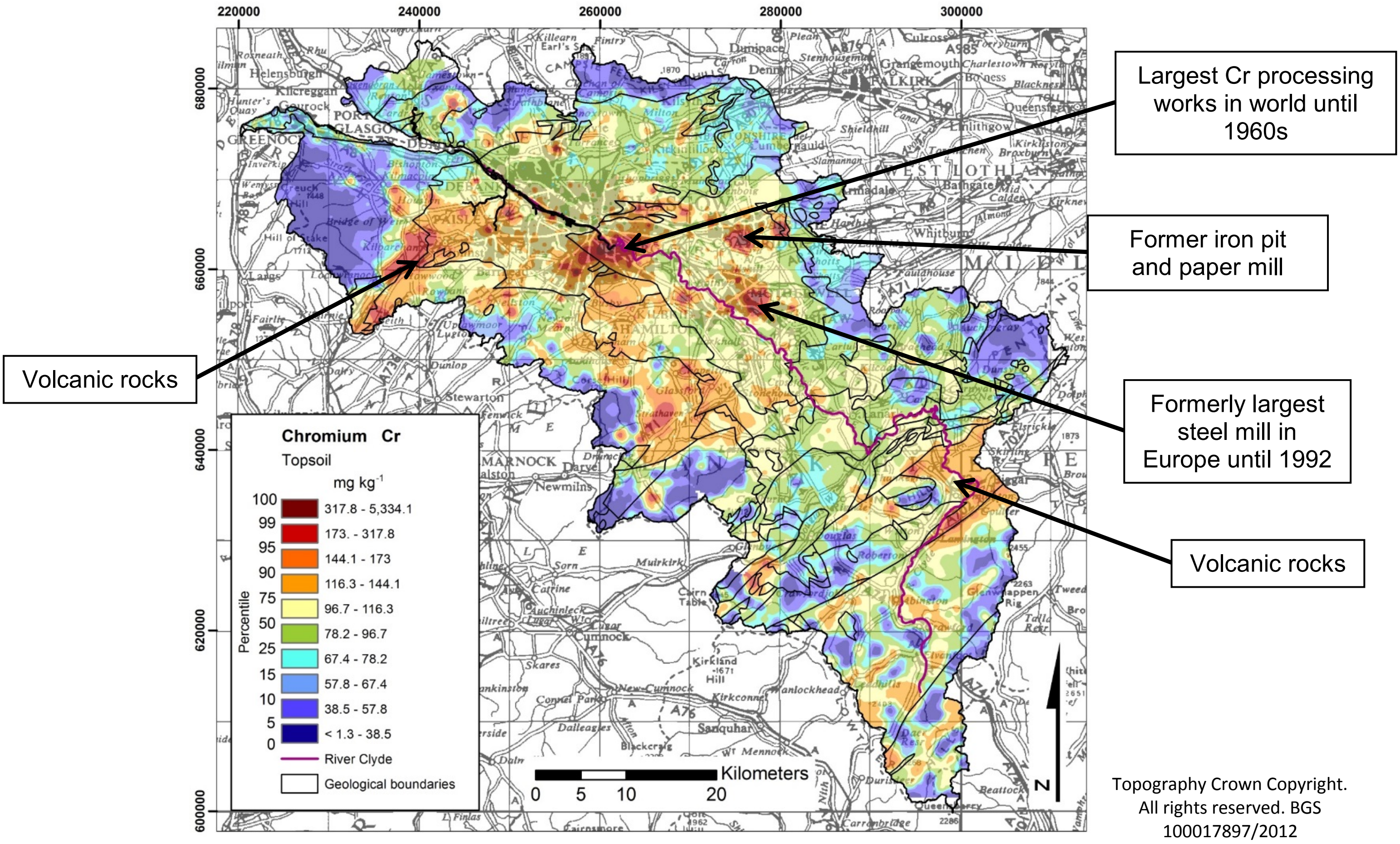

Figure A3.2. Chromium content in (near-surface) soils in the Glasgow area, and the River Clyde catchment, reflecting combined influences of geology (volcanic bedrock) and urban pollution (metal processing) (after Fordyce et al., 2012) (Topography Crown Copyright. All rights reserved. BGS 100017897/2012)

- Geochemical Surveys and Studies linked to the Clyde-Urban Super-Project (2010-11)

During 2010 and 2011 the G-BASE project carried out a further geochemical survey of the Clyde Basin to supplement the earlier G-BASE study (2001-02), particularly focussed on urban soil samples from across much of the Glasgow conurbation.

During 2010, water samples were also collected from small streams (first and second order) from the same sites as an existing survey of stream sediment samples carried out across the area during the 1980s (BGS, 1993). Soils were also collected from rural areas across the whole of the Clyde Basin (~3100 km^2) at a sample density of 1 per 2 km^2. This resulted in approximately 1800 stream water and 1000 soil samples, analysed for over 50 chemical elements. An additional 60 sediment and water samples were collected from the River Clyde and its major tributaries. At these sites, sediments were collected also for organic contaminant (OC) analysis (PAHs, PCBs etc.).

In 2011, the geochemical survey of the Clyde Basin was completed with collection of over 1800 urban soil samples (Lanarkshire and Inverclyde conurbations), which together with the data from 2001-02completed systematic coverage of the Glasgow conurbation. Additionally, 80 urban soils were collected from the City of Glasgow for organic contaminant (OC) analysis.

In total, the geochemical data characterise sediment, water and soil quality for some 2000 stream and river sediments; 1800 stream and river waters; 1460 rural soils and 2450 urban soils across the Clyde catchment.

The results have applications and benefits to studies of a wide range of topics such as biodiversity, land and water quality, agriculture, human and animal health.

Particular interest has been shown, for instance, in possible identification of areas over which trace element imbalances may lead to disease in livestock or affect the growth of crops.

Fordyce et al. (2013) present an additional case study of urban diffuse pollution.

Soils

The soils were collected by the BGS using standard G-BASE protocols (Fordyce et al., 2012), using an auger, on a systematic grid, where 4 samples were collected per km^2 in urban areas, and 1 per 2 km^2 in rural areas. The soils (again sampled at two depths, the upper at 5

– 20 cm depth) were analysed using XRF and assessed for pH and LOI (Loss on Ignition) as organic matter indicators.

The two phases of G-BASE survey have revealed (Fordyce et al., 2012 and unpublished data) that regardless of geological parent material, metal concentrations in Glasgow urban soils (especially Cu, Pb, Sb, and Sn, show the greatest levels of enrichment (2.6-3.3 times based on median values) compared to those of surrounding rural soils. These, together with enhanced CaO (x2.1, based on median values in deeper urban soils), Mo, Ni and Zn, are a typical indicator suite of urban anthropogenic pollution. CaO enrichment probably reflects calcareous buildings, coal and industrial waste in fill materials. Concentrations of As, Bi, Ba, Ce, Co, Cr, Ge, Mo, Ni, Se, Sr, Th, Y, Zn, and pH are also all higher in the urban soils.

The datasets demonstrate impacts of urbanisation and a legacy of urban/industrial pollution on environmental quality that is still evident 40 years after its industrial decline (e.g. Fordyce et al., 2012; Morrison et al., 2014). Indeed, Glasgow has the highest Cr concentrations of all UK's cities. These are typically high in the man-made soils, especially around Ravenscraig site, home to the largest steel mill in Europe until 1992, and in Rutherglen, which hosted the largest Chrome-processing works in the world until the 1960s (Figure A3.2). Similarly, Pb values are also elevated in former industrial sites and in Glasgow city centre. High lead concentrations are related to former use of lead in petrol, lead in coal burning, and lead in paint.

Conversely (Fordyce et al., 2012), levels of organic matter are lower in urban than rural soils; several elements closely associated with organic matter are also lower (particularly Br, I, U and W, and also Hf, SiO_2, TiO_2 and Zr which are more closely associated with the detrital mineral composition of natural soils.

Despite the over-riding influence of urban anthropogenic pollution on soil geochemistry of many elements, geology and geogenic processes still exert a fundamental control on soil composition.

Fordyce et al. (2012) also report systematic geochemical variations between the top and deeper soils sieved to the same <2 mm size fraction:

- Organic matter (LOI) is 1.4-1.6 times higher in top than deeper soils, as are Br (x1.3 rural; x1.5 urban) and I (x2.0 rural; x 1.5 urban), interpreted as reflecting mainly atmospheric deposition of marine aerosols,

- Sn (x2.3); Bi, Pb (x2.0); Cs, Ge (x1.5) and As, Cu, Se, Zn (x1.3) are enhanced in top versus deeper rural soils probably reflecting greater organic matter content,

- Pb, Sb, W and Zn are enhanced c. 1.3 times in urban top soils and As, Ba, Cd, Cu, Ge, Mo, Ni and Se are also generally higher, suggested as reflecting atmospheric deposition; urban surface run off and/or waste disposal,

- Phosphorus median contents in top soils are higher than deeper soils in urban (x1.3) and rural (1.9) probably as a result of fertiliser use, and

- evidence of much greater heterogeneity of urban than rural soils (laterally and vertically) has implications for presentation of urban geochemical data. Care should be taken in quantifying variability before interpolating data between sample points.

Sediments and Waters

In order to assess sediment and water quality in the post-industrial River Clyde catchment, the BGS (as part of CUSP) collected:

- rural stream sediments sampled at 1 sample per 1.5 km^2, across the entire Clyde Basin (G-BASE; see above);

- stream sediment and water samples, sampled at 1 sample per 1km^2, from selected urban tributaries draining into the Clyde within Glasgow (Clyde Tributary Geochemical Project co-sponsored by Glasgow City Council), and

- sediment and water samples, sampled via the grab and core method, in the Clyde Estuary (Clyde Estuarine Contamination Project co-sponsored by Glasgow City Council and the Scottish Environment Protection Agency (SEPA)). These were analysed for 29 chemical elements.

Fordyce et al. (2004) reported on the earlier (June 2003) urban drainage geochemical survey. This comprised 118 stream sediment and 122 surface water samples. The stream sediment and surface water samples underwent analysis for approximately 46 chemical elements including contaminants such as As, Al, Cd, Cu, Cr, Ni, Pb, Se, V and Zn. In addition, parameters such as ammonium, asbestos and Hg as well as organic contaminants such as total petroleum hydrocarbons (TPH), polycyclic aromatic hydrocarbons (PAH), poly-chlorinated biphenyls (PCB) and organo-tin compounds were assessed.

The sediment and water datasets have been integrated, enabling element distribution maps to be produced for the whole of the Clyde Basin (Lass-Evans et al., 2012) to assess human impacts on environmental quality in the Clyde catchment (Figure A3.3).

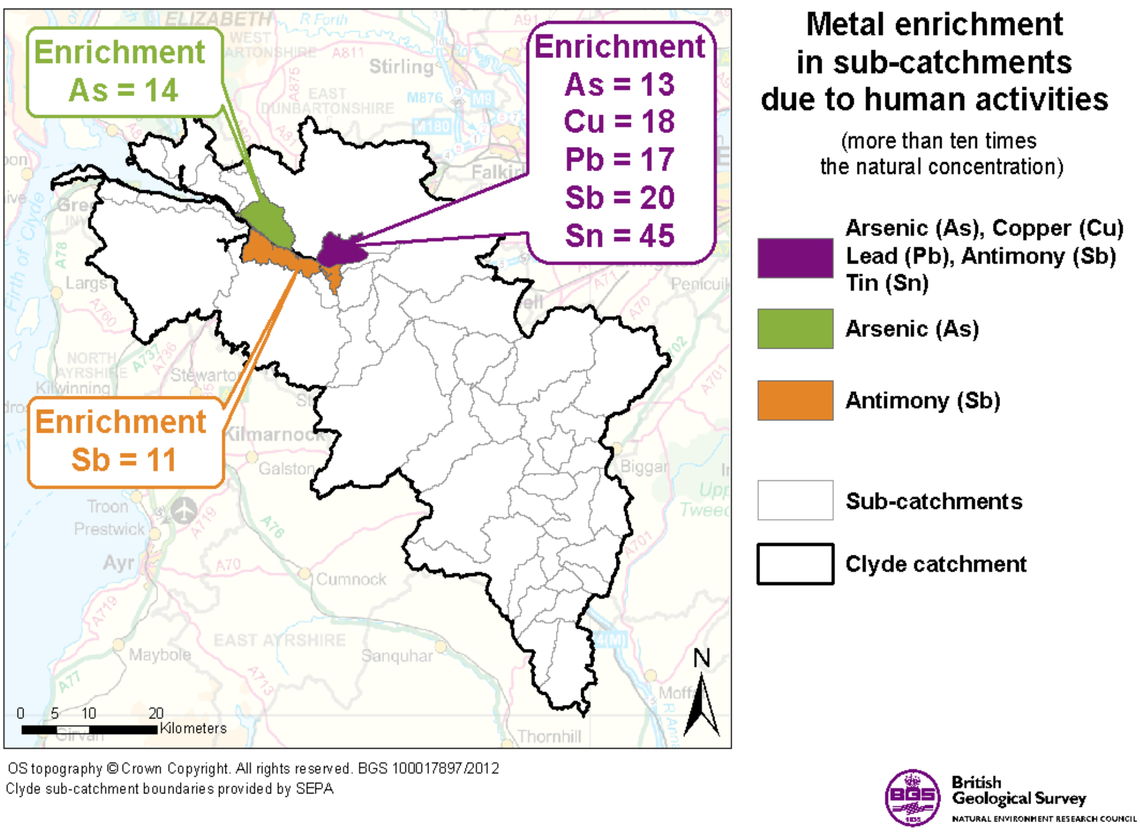

Figure A3.3. Metal enrichments (As, Cu, Pb, Sb, Sn) in sediments of tributaries of the River Clyde. All sub-catchments with enrichments which are >10 times that of natural concentrations reflect human activities within the Glasgow area. (after Lass-Evans et al., 2012) (Topography Crown Copyright. All rights reserved. BGS 100017897/2012)

To distinguish natural variations in sediment element concentrations and calculate the impact of human sources and past industrialisation on overall pollutant levels, it was necessary to model the natural geochemical background. With the exception of mining areas (e.g. lead mining in the Leadhills), in rural parts of the Clyde catchment, the sediment composition is largely determined by the underlying geology and rock type (Figure A3.3). Crucially, it is possible to use these rural results to model the natural background composition in urban areas with similar geology. This has revealed that stream sediments in central Glasgow have been enriched in metals (Sb, As, Cu, Pb, Sn) more than ten times and locally up to 45 times the natural concentration (and exceeding sediment quality guidelines), are as a consequence of human activities, and reflect Glasgow's mining and industrial history (Figure 3). The high urban enrichments extend from Glasgow down the River Clyde and into its estuary. Enrichment factors for lead of up to ten, and locally up to 45, were also found in and around the conurbation (Lass-Evans et al., 2012; Lass-Evans and Fordyce, 2012).

The mapping of the chemistry of the Clyde Basin Drainage Network has served both to characterise the water quality and to assess the dominant control of quality. The surveys, undertaken between 2003 and 2010, generated data encompassing rural and urban streams, rivers, and estuarine water.

The mapping displays the large spatial variability in chemical composition across the Basin and the varying influences of controls such as rainfall, land cover and geology. The maps also display the chemistry of the urban area within the context of the wider drainage network. An online atlas and database of surface-water chemistry are both at an advanced state of preparation. These data characterise the Clyde drainage network and will provide a new resource for stakeholder organisations.

Soil Quality and Health/Deprivation Indicators in Glasgow

The environment plays an important role in moderating health and wellbeing, but the relationships between environmental factors and health and wellbeing are complex, with many interactions. Exposure to environmental risk factors is not equally distributed, and links between poor health and environmental inequalities (e.g. inferior housing, crime and industrial emissions) form part of the Environmental Justice Agenda.

There is an historical legacy of potentially harmful trace element (e.g. Cr, Pb) contamination in Glasgow soils (Figure A3.2). Therefore, the spatial associations between soil metal content, air pollution (NO_2/PM10), deprivation and health (respiratory cases and lung cancer incidence) across Glasgow have been assessed.

To assess the oral bioaccessibility of Cr, the Unified Bioaccessibility Method (Broadway et al., 2010), which mimics the chemical environment of the human gastrointestinal system, was applied to 27 of the BGS G-BASE soil samples. These included several with Cr(VI), the most toxic form of Cr, in secondary minerals arising from disposal of chromite ore processing residue (COPR). The extraction was employed in conjunction with the subsequent determination of the bioaccessible Cr by ICP-OES and Cr(VI) by the diphenylcarbazide complexation colorimetric procedure (Broadway et al., op cit.). Cr(III)-containing species were determined by (i) HPLC-ICP-MS and (ii) ICP-OES. Similar analytical procedures were applied to the determination of Cr and its species in extracts of the < 10 µm fraction of soils subjected to a simulated lung fluid test to assess the inhalation bioaccessibility of Cr. The studies established that:

- oral bioaccessible Cr was higher in the COPR-affected soils,
- oral bioaccessibility ('stomach') was 5% of total soil Cr and, overall, similar to the soil Cr(VI) concentration,
- oral bioaccessibility of Cr was typically greater by a factor of 1.5 in the 'stomach' (pH ~ 1.2) compared with the 'stomach + intestine' (pH ~ 6.3) simulation, but
- Cr(VI) was reduced to Cr(III) during ingestion, a consequence of pH- and soil organic matter-mediated reduction in the 'stomach'.

Insertion of oral bioaccessible fraction data into a human health risk assessment model identified site-specific assessment criteria (for residential land without plant uptake) that were exceeded by the soil total Cr (3680 mg kg^{-1}) and Cr(VI) (1485 mg kg^{-1}) concentration at only the most COPR-Cr(VI)-contaminated location. However, the presence of measurable Cr(VI) in the < 10 µm fraction of the two most highly Cr(VI)-contaminated soils demonstrated that inhalation of Cr(VI)-containing dust remains the most potentially harmful exposure route.

Farmer et al. (2011) determined the human bioaccessibility of lead (Pb) in Pb-contaminated soils from the Glasgow area by the Unified Bioaccessibility Research Group of Europe (BARGE) Method (UBM). This in vitro, physiologically-based extraction scheme mimics the chemical environment of the human gastrointestinal system and contains both stomach and intestine compartments. For 27 soils ranging in total Pb concentration from 126 to 2160 mg kg− 1, bioaccessibility as determined by the 'stomach' simulation (pH ~ 1.5) was 46–1580 mg kg− 1, equivalent to 23–77% (mean 52%) of soil total Pb concentration. Corresponding bioaccessibility data for the 'stomach + intestine' simulation (pH ~ 6.3) were 6–623 mg kg− 1 and 2–42% (mean 22%) of soil Pb concentration. Soil 206Pb/207Pb ratios ranged from 1.057 to 1.175 and are intermediate between values for source end-member extremes of imported Australian Pb ore (used in formerly used petrol additives (1.06–1.10)), and indigenous Pb ores/coal (1.17–1.19).

Morrison et al., (2014) and Fordyce et al. (2012) assessed associations between soil metal content; air pollution (NO2/PM10) and deprivation and health (respiratory case incidence) across Glasgow. This was the first UK city-wide assessment of both chemical land quality and air pollution in the context of deprivation and health. Using dataset 'averages' for intermediate geography areas, generalised linear modelling of respiratory cases showed significant associations with overall soil metal concentration (p=0.0367) and deprivation (p<0.0448). Only nickel of the soil metals showed a significant relationship with respiratory cases (p=0.0056). Importantly, this study demonstrated a statistically significant correlation

(-0.213; $p<0.05$) between soil metal concentration and deprivation across Glasgow. This suggests that despite numerous regeneration programmes, there is still a legacy of environmental pollution in post-industrial areas of Glasgow, decades after the decline of heavy industry. The results suggest that poor soil quality warrants greater consideration in future health and socio-environmental inequality assessments, but further epidemiological investigations would be needed to determine causality, if any, between soil quality and population health/well-being.

Current UK environmental legislation considers soil quality in terms of potential concern for human health from exposure to contaminated soils. Revised UK contaminated land soil guideline values (SGVs) provide a general indication of soil quality (Fordyce et al., 2012; only 2% of Glasgow G-BASE top soils exceed current As residential SGVs of 32 mg kg^{-1}, and 2% exceed current Ni residential SGV (130 mg kg^{-1}). However, the guidelines are land use specific and only two of the G-BASE soils collected were from residential gardens.

Estuary and Marine Contamination in the Clyde Catchment

Estuaries are important habitats for fish, shellfish, birds and mammals, but they are also sinks for sediment and contaminants from urban, industrial and recreational activities upstream, along shore and in the adjacent coastal zone. There have been relatively few detailed studies of sediment contamination the estuaries around the UK. The study of the Clyde estuary, carried out in conjunction with Glasgow City Council and the Scottish Environment Protection Agency (SEPA), has shown the areal extent of different potential contaminants in the sediments and their distribution with depth. From the latter, a contamination history has been deduced, especially using organic contaminants, lead isotopes and radionuclides.

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APPENDIX 4 – Vienna (A) case study

Context

In urban areas, natural background levels of heavy metals in soils, sediments, or groundwater are often overprinted by anthropogenic emissions. Through wet or dry deposition of fine dust from industry or traffic, heavy metal contents in soils can be elevated, particularly in industrial and downtown areas and along major roads. Urban soils collect diffuse fallout of contaminants and act as sinks of pollutants over decades or even centuries. In addition, localized high concentrations of pollutants can occur near old waste sites or spills. Therefore, regional and local anomaly thresholds are usually distinguished in urban geochemical mapping or baseline studies (Albanese et al., 2008). Background reference values for urban soils are ideally defined by analyzing soils samples of similar paedological and geological nature away from urban areas.

In urban groundwater, anomalies of heavy metals can also occur e.g. through leakage of waste sites or contaminated areas. In contrast to locally polluted soil, contamination in groundwater is often transported over wider areas downstream of a local source. As for soil characterization, background reference values are ideally derived from groundwater collected in similar geological settings at a distance from urban areas.

Urban geochemical studies often strive to establish baseline and background reference values for soils and groundwater but also to determine the possible origin of potentially harmful chemical compounds. To this effect, they look at both anthropogenic and geogenic sources of individual elements. In many cities, air quality, especially particulate matter suspended in air, is monitored and data can be used to identify anthropogenic input. As for geogenic sources, geo-scientists can deliver natural background values for soils, underlying soft and hard rocks, and groundwater.

The city administration of Vienna operates monitoring networks for air quality / wet deposition (17 / 4 stations), soil quality (286 sites) as well as groundwater levels (850 wells) and quality (45 wells). Concerning air quality, the amounts of SO_2, NO_2, CO, O_3, PM_{10} and $PM_{2.5}$ (particulate matter smaller than 10 or 2.5 µm in diameter) are recorded continuously while Pb in PM_{10}, heavy metals in PM_{10}, BaP, benzene, wet deposition of fine dust, Cd and Pb content in fine dust are measured sporadically. In addition, concentrations of NH^{4+}, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, NO_3^- and SO_4^{2-} are measured in rain water. In soils, heavy metal contents of As, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Pt, Se, V and Zn were determined at three-year regular intervals up until 2003 and again in 2016. Groundwater levels are recorded monthly at approximately 850 wells, and weekly at 180 wells. 45 wells are regularly sampled for hydro-chemical analysis. To a large extent, data are publicly available in reports or published online by the Vienna city administration, the Environment Agency Austria or the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management.

In a study commissioned by the Vienna Municipal Departments 45 (Water Management) and 29 (Bridge Construction and Foundation Engineering), the Geological Survey of Austria carried out an urban geochemical study which used the aforementioned data, complemented by new analyses of Quaternary and Neogene sediments, stream sediments as well as additional soil and dust samples. The objective was to investigate the current state of heavy metal content, to establish background reference values and to distinguish geogenic from anthropogenic sources (Pfleiderer et al., 2012).

Methodology

The study included chemical analyses of soils, Quaternary and Neogene sediments, stream sediments, dust and groundwater.

- *Soil samples*: The data sets included 286 samples of urban topsoil (0-10 cm), analyzed for As, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Pt, Se, V and Zn (Kreiner, 2004), 355 samples of urban topsoil (0-35 cm) analyzed for As, Cd, Cr, Cu, Hg, Ni, Pb, S and Zn (Wruss, 2004) and 94 samples of (undisturbed) forest soil (A-, B- and C-horizons) analyzed for Al_2O_3, C_{tot}, FeO, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5, SiO_2, SO_3, TiO_2, Ag, As, Ba, Cd, Ce, Cl, Co, Cr, Cs, Cu, Ga, Hg, La, Mo, Nb, Ni, Pb, Rb, Sb, Se, Sn, Sr, Th, U, V, W, Y, Zn and Zr (Pfleiderer et al., 2012). Sampling locations are shown in Figure A3.1, and further information on sample preparation and analytical methods can be found in the cited literature.
- *Sediments*: The data sets included 21 sediment samples, analyzed for As, Cd, Cr, Co, Cu, Hg, Ni, Pb and Zn (Wruss, 2000) and 321 samples of uncontaminated Quaternary and Neogene sediments, analyzed for As, Cd, Co, Cr, Cu, Hg, Ni, Pb and Zn (Pfleiderer et al., 2009).
- *Stream sediments*: As a proxy for hard rock geochemistry, but also as indicators of anthropogenic deposits, 56 stream sediment sample were collected within Flysch sandstone areas and analyzed for Ag, Al, As, Ba, Be, Ca, Cd, Ce, Cl, Co, Co, Cr, Cu, Cu, F, Fe, Ga, Hg, K, La, Li, Mg, Mn, Mo, Mo, Na, Nb, Nb, Ni, P, Pb, Rb, S, Sb, Sc, Se, Si, Sn, Sr, Th, Ti, U, U, V, W, W, Y, Zn and Zr (Pfleiderer et al., 2009). Grain size fractions of < 180 µm and < 40 µm were analyzed separately; the heavy mineral fraction was additionally studied with respect to mineralogical / micro-chemical phases.
- *Groundwater samples*: The data sets included 2960 analyses at 66 wells from the groundwater quality monitoring network, situated mainly in recent floodplains and terraces of the Danube river, analyzed for Ca, Mg, Na, K, HCO_3, SO_4, Cl, NO_3, NO_2,

PO_4, Al, As, B, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb and Zn and 145 analyses at 12 forest springs, situated in the western Flysch zone, analyzed for Al, As, Ba, Ca, Cd, Cl, Cr, Cu, F, Fe, H_2SiO_3, HCO_3, K, Li, Mg, Mn, Na, NH_4, NO_2, NO_3, Pb, PO_4, SO_4, Sr and Zn (Pfleiderer et al., 2009).

- *Dust samples*: The data set included 11 samples collected downwind from chimneys of waste incinerators, caloric power stations and metalworking industry, or in areas with heavy traffic (Pfleiderer & Neinavaie, 2012). Mineralogical / micro-chemical phases were identified and classified according to origin, emitting source and their potential to release heavy metals into the environment through weathering.

In addition to geochemical data, the study was based on a lithological map of Vienna (Hofmann & Pfleiderer, 2003), a 3D geological model of Vienna (Pfleiderer & Hofmann, 2004) and land use data of the GMES Urban Atlas (http://www.eea.europa.eu/data-and-maps/data/urban-atlas) (Figure A41).

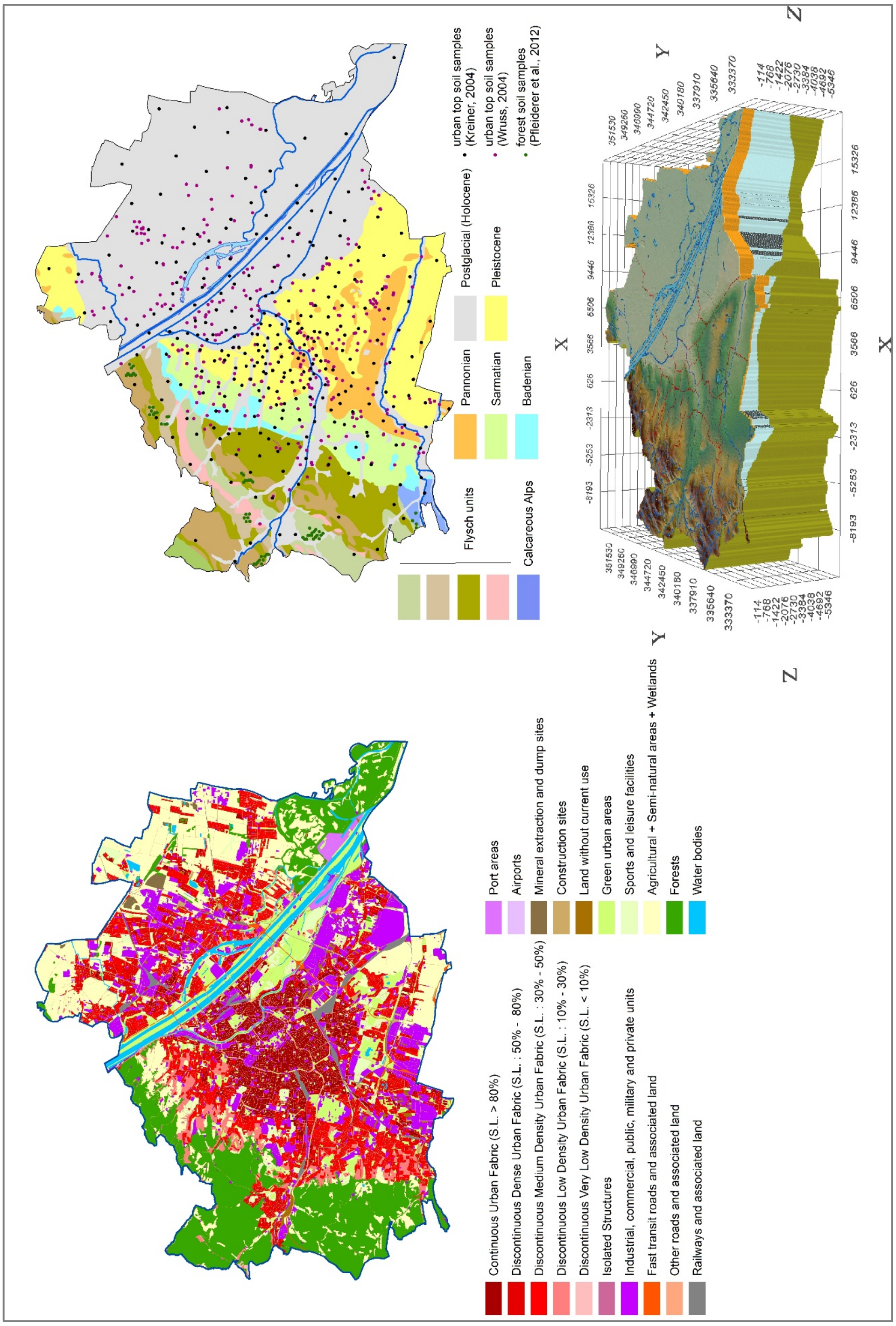

Figure A4.1: Land use (GMES Urban Atlas HTTP://WWW.EEA.EUROPA.EU/DATA-AND-MAPS/DATA/ URBAN-ATLAS), simplified geological map (after Schnabel et al., 2002), soil sample locations and 3D geological model of Vienna (Pfleiderer & Hofmann, 2004).

Results

Table A4.1 compares baseline values of heavy metal concentrations in Flysch sandstone, Quaternary and Neogene sediments and in urban soils. Values for Flysch sandstone were derived from stream sediments and from direct measurements on rock faces using a mobile XRF instrument.

Heavy metal contents in urban soils do not correlate with the underlying geological material. Instead, a direct correlation exists between soil chemistry and land use. Pb, Zn and Cd contents are lower in green spaces as compared to areas of industrial, residential or traffic use. This points to anthropogenic sources for these elements. Local baseline values of elements Cu, Hg, Pb and Zn exceed national guideline values for uncontaminated urban soils and according to Austrian legislation fall into the category ‘‘anthropogenic contamination present but no damage to plants, animals or humans detectable’’ (Eikmann & Kloke, 2004). Local baseline values also exceed background reference values for Austrian top soils on Quaternary and on Neogene sediments (Schwarz & Freudenschuss, 2004) (Tab. A4.2) with respect to Cd, Cu, Hg, Pb and Zn concentrations.

In undisturbed forest soils, the distribution of major oxides clearly reflects the geological parent material. With respect to heavy metals, concentrations of the aforementioned elements are low, whereas geogenic element assemblages (Co, Cr, Cu, Ni and V) are slightly elevated and controlled by the geological setting. Baseline values exceed background reference values for Austrian top soils on Flysch sandstones and on limestones (Schwarz & Freudenschuss, 2004) (Tab. A4.2) with respect to Co, Cr, Cu and Ni concentrations.

Table A4.1: Baseline values of heavy metal concentrations in urban soils, Quaternary and Neogene sediments and in Flysch sandstone

	As (ppm)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Hg (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)
Urban soils - local baseline	9-10	0,8	10	25-45	43-60	0,5	23-33	80-100	150-200
Urban soils - regional baseline	5-6	0,3	4	28	20-24		18	10-20	60-80
Forest soils on Flysch sandstone	9-16		9-19	77-125	18-50	0,09-0,15	23-72	23-43	76-121
Forest soils on limestone	12-22		19-22	111-125	46-61	0,11-0,19	70-85	34-36	103-118
Recent river floodplain sediments	9	0,6		27	46	0,19	62	39	146
Prater river terrace sediments	11		10	19	23		26	11	31
Pannonian sediments	18-25	0,5 - 0,7	11-15	47-61	29-40	0,22-0,4	50-61	22-24	94-119
Flysch sandstone	9,1	0,5	17	119	60	0,17	72	76	159

Table A4.2: Background reference values for top soils in Austria (Schwarz & Freudenschuss, 2004)

		As	Cd	Co	Cr	Cu	Hg	Ni	Pb	Zn
Grazing land soil on quaternary sediments	ppm	27,7	0,7	15,6	48	40	0,26	40	52	132
Grazing land soil on neogene sediments	ppm	16,2	0,3	16,2	50	30	0,27	34	31	104
Forest soils over Flysch sandstones	ppm		0,5	15,8	26	35		31	47	83
Forest soils over limestone	ppm		3,4	20	39	21		37	151	178

Comparison between geological materials (Tab. A4.1) reveals that apart from As, Cd and Hg contents, Flysch sandstones contain higher concentration of heavy metals than soft sediments.

With respect to hydro-chemistry, groundwater mineralization generally increases from younger to older river terraces. This trend can also be observed in heavy metal concentrations. Apart from elemental Cu, groundwater in Flysch sandstones displays much lower contents of heavy metals than groundwater in river terraces. Table A4.3 lists median values of heavy metal concentrations in groundwater within quaternary sediments and in Flysch sandstone.

The median value of Ni concentrations in groundwater of the Prater river terrace exceeds the background reference value for surface groundwater in Austria (Hobiger & Klein, 2004) (Tab. A4.4), while in groundwater in Flysch sandstones the element Cu displays higher median concentrations than the background reference value. Concerning Austrian drinking water quality guidelines, only some forest springs in Flysch sandstones exceed the guideline values with respect to the element Mn.

Table A4.3: Median values of heavy metal concentrations in groundwater within Quaternary sediments and in Flysch sandstone.

Geological unit	As [µg/l]	Cd [µg/l]	Cr [µg/l]	Cu [µg/l]	Fe [µg/l]	Hg [µg/l]	Mn [µg/l]	Ni [µg/l]	Pb [µg/l]	Zn [µg/l]
Recent river floodplain	1,3	0,8	1,8	2	20	0,2	20	3	1,7	14,25
Prater river terrace	1,3	0,65	1,3	1,75	20	0,2	16	4	2	27,5
Flysch sandstone	0,22-0,78		0,2-0,3	1,9-5,7	6-62		0,7-77,5		0,3-0,75	8,5-24

Table A4.4: Background reference values for surface groundwater in Austria (Hobiger & Klein, 2004)

Hydrogeological unit	As [µg/l]	Cd [µg/l]	Cr [µg/l]	Cu [µg/l]	Fe [µg/l]	Mn [µg/l]	Ni [µg/l]	Pb [µg/l]
Quaternary sediments east of Vienna	6,1	0,9	5,7	5	100	50	3,5	2,7
Quaternary and Neogene sediments south of Vienna	4,1	0,2	3,5	4,1	470	44	3,7	3
Flysch sandstone	1,4	0,5	2	3	120	160	2	2

Dust samples reveal slag particles (spherical magnetite and hematite) originating from caloric power stations and occurring in the vicinity of the plants. Abrasion products from brake pads and tyres (cast iron, white alloys) are associated with traffic deceleration sites (intersections, bus stops). The heavy mineral fraction in stream sediments shows an ubiquitous occurrence of mafic rock fragments (titanomagnetite, pyroxene, plagioclase) and of slag particles from waste incinerators (acicular anorthite and melilite) which may be due to road gritting in winter (Pfleiderer & Neinavaie, 2012).

Applications and further use

Landfill regulations in Austria require any material taken out of the ground to be analyzed chemically before (even temporary) re-deposition. The material must comply with chemical guideline values defined for material with and without geogenic preloading. The baseline values of heavy metal concentrations in urban soils, Quaternary and Neogene sediments and in Flysch sandstone, presented in this study, permit for the first time to identify for which elements geogenic preloading exists naturally in Vienna's subsoil.

The baseline values were subsequently used to parametrize the geological units in the Vienna 3D model with respect to heavy metal concentrations. In this process, one background value for each element was attributed to each unit. Geochemical modelling has so far not been performed to describe spatial variations within geological units. Although the aforementioned chemical analyses come with 3D spatial references and the corresponding geological units can thus be deduced from the 3D geological model, a 3D visualization of the current distribution of heavy metal contents has until now not been undertaken due to sensitivity issues.

Thanks to Austrian landfill regulations, the number of geochemical analyses of Vienna's subsurface grows continuously. Equally, regular chemical analyses of soils and hydro-chemical analyses of groundwater ensure ever growing data sets. Regular updates and maintenance of the data sets lies with the municipal departments of Vienna's city administrations (MA22 - Environmental Protection for soil, MA45 - Water Management for groundwater and MA29 - Bridge Construction and Foundation Engineering for sediment). The study presented here describes the status of heavy metal contents as of 2010. Similar to much needed updates of the 3D geological model on the basis of newly drilled boreholes, new compilations and interpretations of current geochemical data are not routinely stipulated by the city administration.

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APPENDIX 5 – Nantes (F) case study

Context

For economic and environmental issues, the reuse of excavated soil in urban development needs to be considered. Urban redevelopment projects occur more and more on brownfield sites, so as to allow urban densification and limit urban sprawl. They must therefore deal with contamination problems. To anticipate the management of excavated soils, it is necessary first to assess their quality and potential volumes. This requires the acquisition of preliminary knowledge of the structure and quality of soils and subsoils, as well as on the potential sources of contamination (made grounds, industrial and service activities). Because urban redevelopment projects occur at a larger scale than a single site, a quarter approach appears better suited to obtaining an integrated knowledge useful for the whole redevelopment project, and a city scale approach for urban planning.

As part of the R&D partnership with an urban developer, BRGM characterized the soil and subsoil geochemical quality on the Island of Nantes (337 ha) (Figure A5-1). More details on the city of Nantes are given in COST Sub-Urban WG1 city report (Rodriguez et al, 2014).

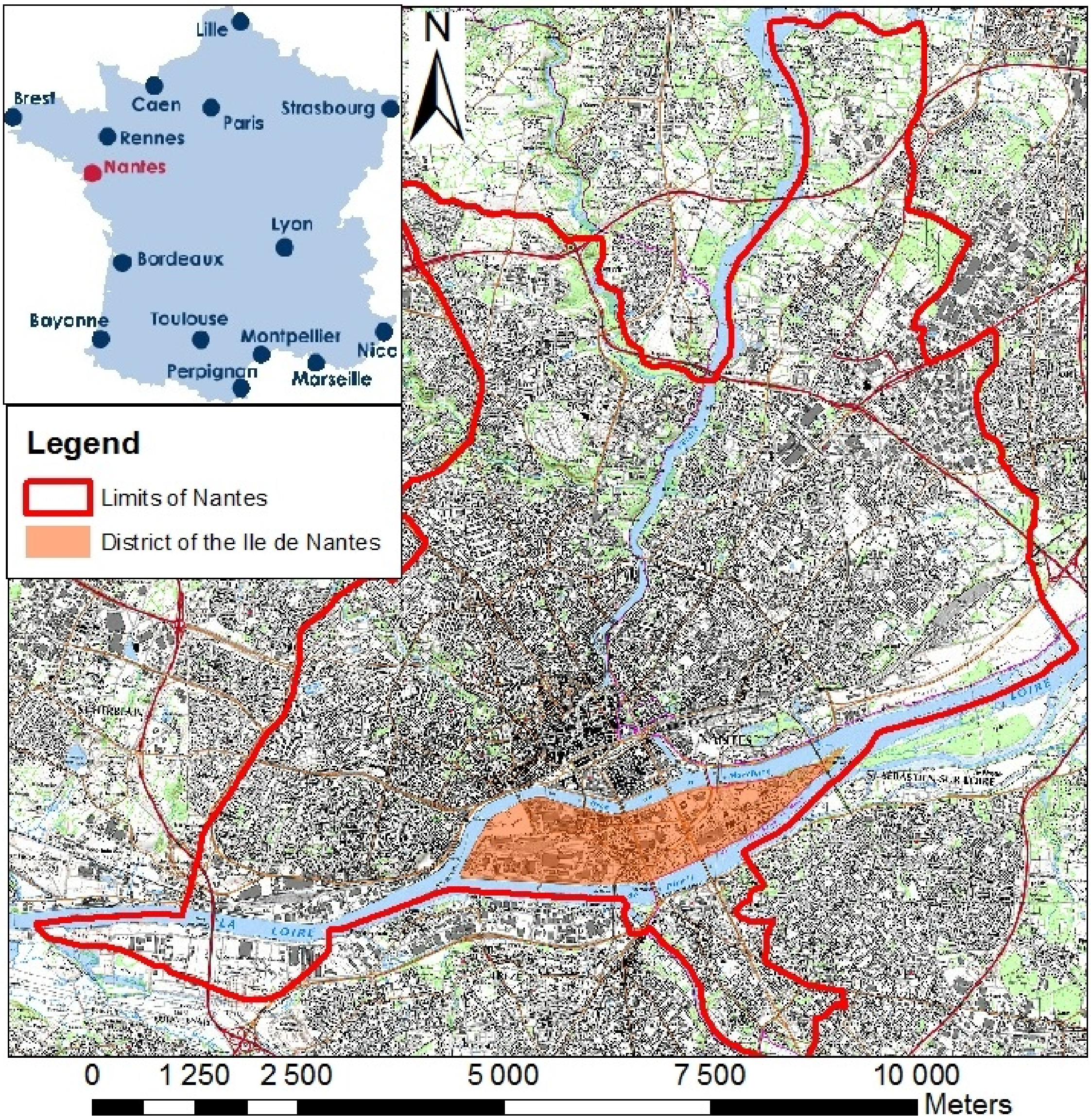

Figure A5.1 - Location of the Ile de Nantes in the city of Nantes (France)

Methodology

To characterize soil and subsoil geochemical quality on the Island of Nantes, complementary and iterative approaches were carried out as described in Le Guern et al. (2016a). In particular, they:

- Gathered soils/subsoils/underground descriptions from boreholes (geotechnical studies, environmental diagnostics) (Figure A5.2) in a structured database,

- Developed a typology of made ground according to intrinsic contamination potential (Le Guern et al, 2016b),

- Interpreted the borehole description (integrating the above typology) to build a 3D visualization of subsoils,

- Gathered the chemical analyses (most coming from contamination diagnostics) in a structured database to validate the developments,

- Mapped the extension of former industrial and service activities through a historical approach, and identified the associated potential sources of contamination and potentially associated contaminants,

- compared potential contamination linked to industry and made-ground with those established.

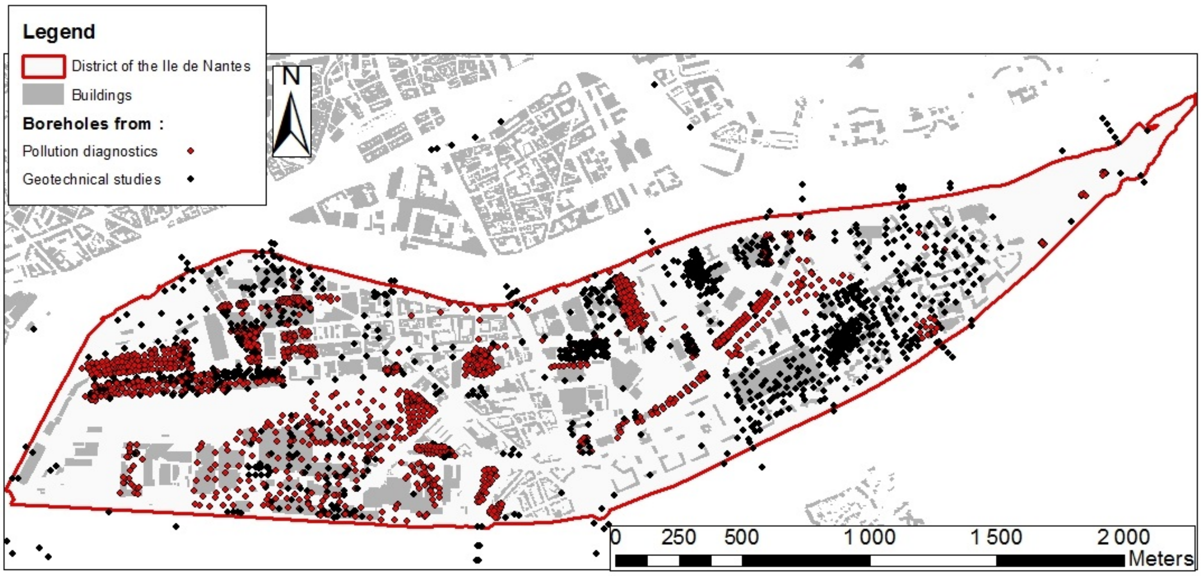

Figure A5.2. – Set of boreholes gathered according to their initial objective – Ile de Nantes, France (Le Guern et al, 2016a, b)

Results

The obtained results (Le Guern et al, 2016a and b) include maps of the potential sources of contamination and associated contaminants linked to industrial activities (Figure A5.3) and land-fill. The 3D model (Figure A5.4) integrates the classes of made grounds defined according to their intrinsic potential of contamination. This was used to map the extent of the made-grounds at various depths (Figure A5.5). The quantities of excavated subsoils according to their geochemical properties (potential degree of contamination) and possible management options (landfill, reuse) were also calculated on the bases of their representation (Figures A5.6 and A5.7). Finally, baseline compatibility levels were proposed to guide the reuse of excavated materials.

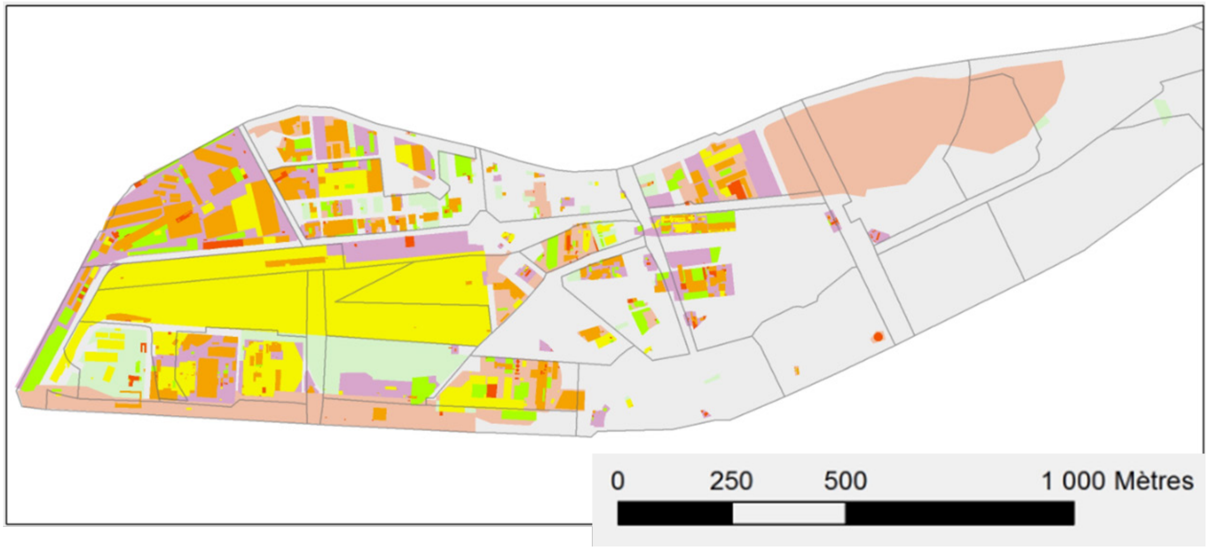

Figure A5.3 – Indicator of potential historical contamination of subsoils by Lead linked to former industrial and service activities (from very low to absent in green to very high in purple) – Ile de Nantes, France (Le Guern et al, 2016b)

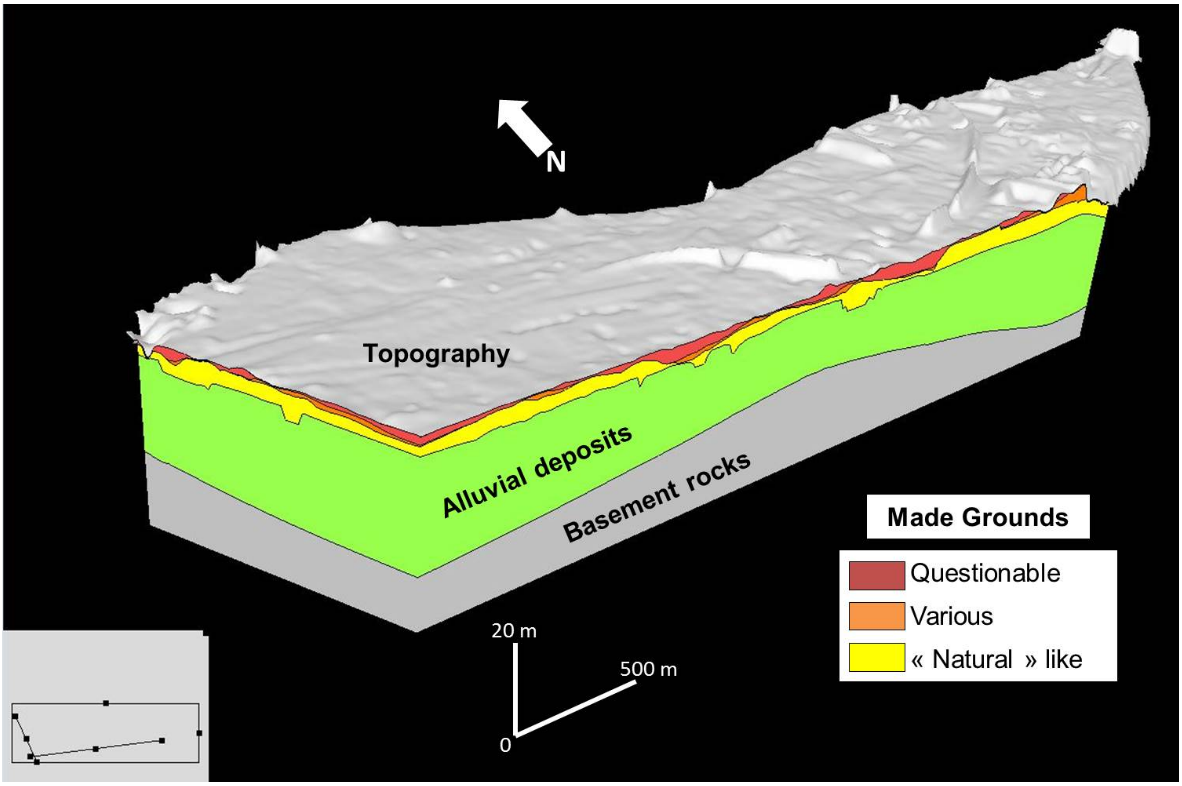

Figure A5.4 – 3D model integrating several classes of made ground defined according to their intrinsic potential of contamination (from high for questionable made grounds to low for the natural-like present on the island) – Ile de Nantes, France (Le Guern et al, 2016a, b)

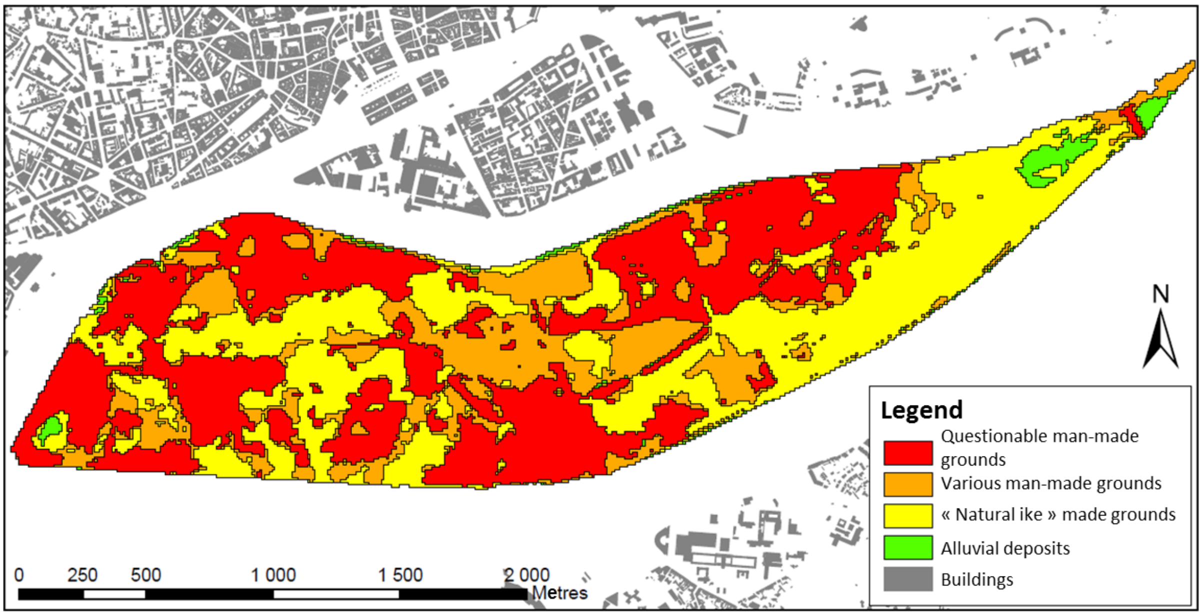

Figure A5.5 – 2D representation of made grounds at 1 m depth, according to their intrinsic potential of contamination, extracted from the 3D model – Ile de Nantes, France (Le Guern et al, 2016a,b)

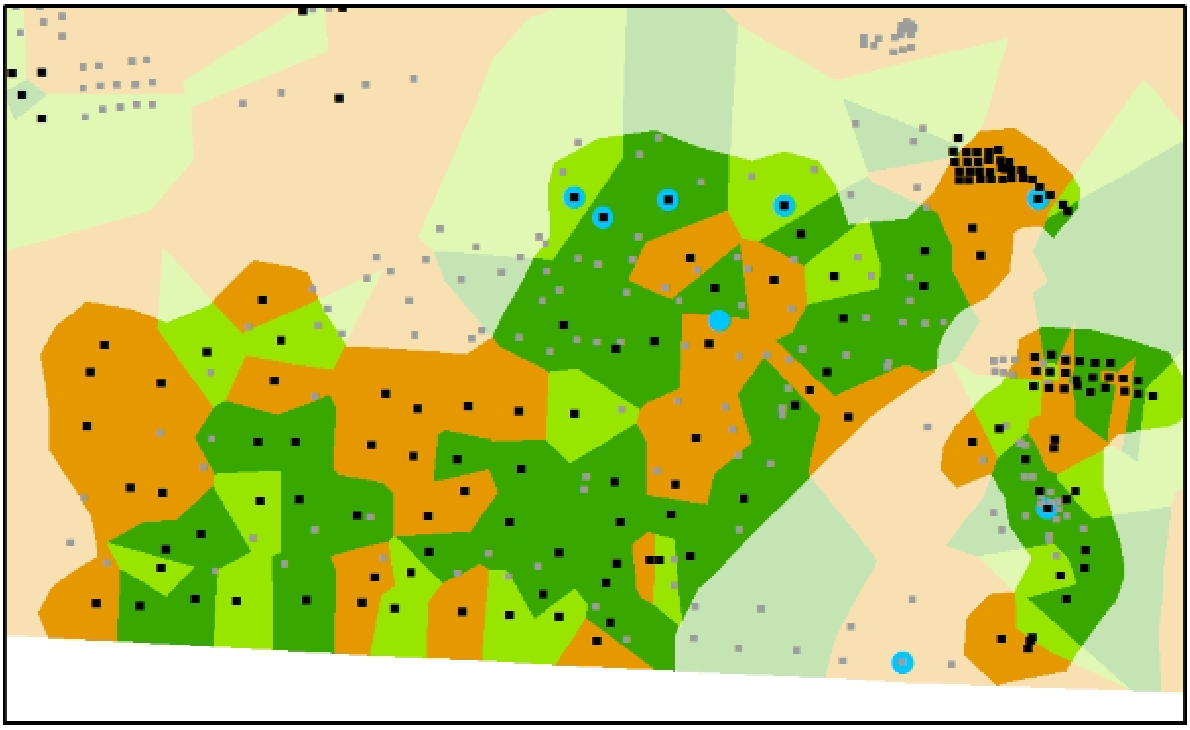

Figure A5.6 – First indication of compatibility of subsoil quality for local reuse for the 1 to 2m deep potentially excavated subsoils at the scale of one redevelopment operation, obtained by comparison with the local geochemical baseline determined for subsoils – Ile de Nantes, France (Le Guern et al, 2016b)

Figure A5.7 – First indication of compatibility of subsoil quality for deposit in a landfill dedicated to inert waste for the 1 to 2 m deep potentially excavated subsoils at the scale of one redevelopment operation – Ile de Nantes, France (Le Guern *et al.,* 2016b)

Applications and further use

The data management, interpretation and visualisation carried out within this study provide useful results for the end-user. They show potential for reuse of the materials to be excavated and help anticipate pollution problems. The developer can also adapt the redevelopment project on the basis of this knowledge. In addition, the baseline compatibility levels proposed can be used to draft a management scheme for excavated materials to enhance their local reuse and reduce management costs.

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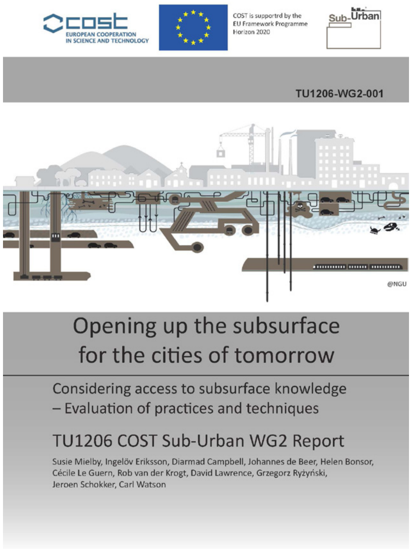

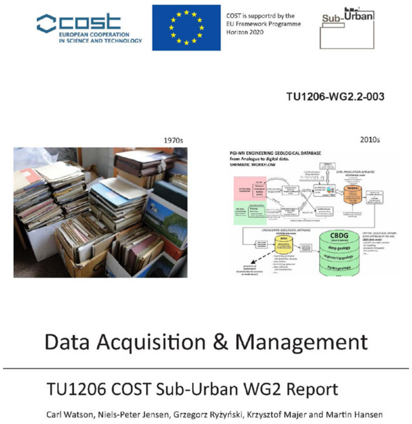

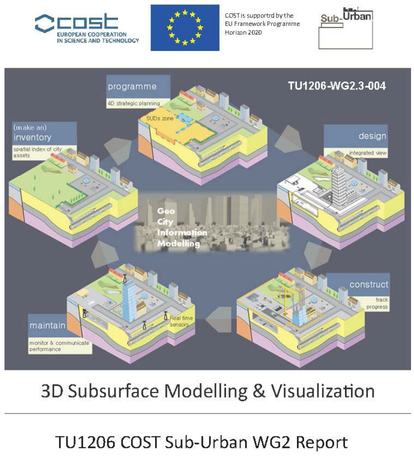

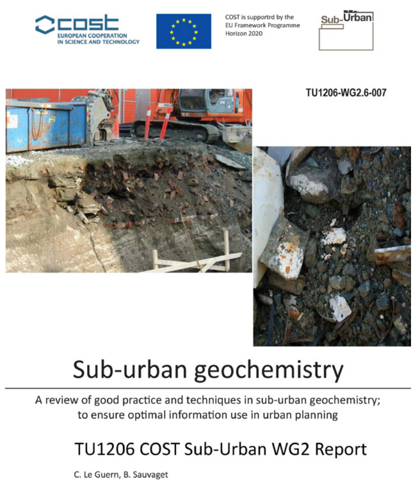

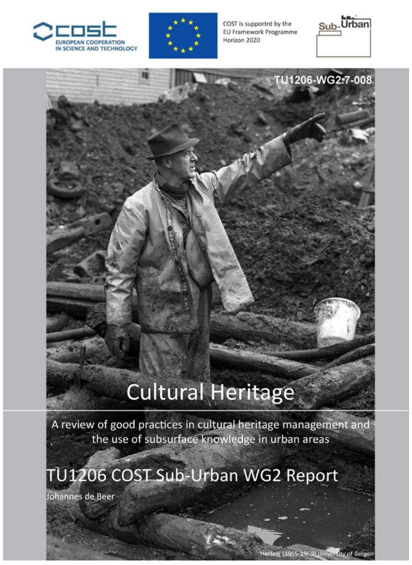

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