

24. Mapping metallic contamination of soils in the Lower Foyle catchment

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Using the Tellus and Tellus Border geochemistry data, the distribution of metals in top-soils in and around Derry–Londonderry has been mapped and assessed. The concentrations of metals have been compared with the UK Environment Agency's Soil Guideline Values (SGVs). Of 763 samples analysed, only 11 samples exceed the SGV for arsenic and two for that of cadmium. Of these 13 sites, only two were within an urban area. Concentrations of metal in the rural sub-catchments appear to be mainly determined by the underlying geology.

Using a geographic information system (GIS) and multi-element plots (spidergrams) for analysis, the geological background was modelled at a sub-catchment scale in order to determine whether high soil metal concentrations were of natural origin or a consequence of anthropogenic activities. The level of enrichment due to contamination was calculated for 12 metals and metalloids. In the urban area of Derry–Londonderry, levels of arsenic, cadmium and seven other elements are slightly enhanced due to anthropogenic activities. However, as the enrichment factors do not exceed a factor of 3 these enhancements are classified as minor. Possible modern and historic sources of contamination are likely to be buildings, households and waste disposal, hospitals and medical facilities, surface run-off from road traffic, manufacturing industries, coal disposal and sewage works.

INTRODUCTION

It is self-evident that we rely on clean soil for safely growing crops, grazing livestock and outdoor recreation, so it is important that we monitor it for potentially harmful elements. This chapter illustrates how we can use the results of the Tellus and Tellus Border geochemical survey programmes to map the extent and origin of both naturally occurring and anthropogenic metals in a selected area, the cross-border lower catchment of the River Foyle.

Many city environments have been affected by urban and industrial processes over a long timespan. As a result, various substances, such as heavy metals, have often been

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released into the environment. Exposure to high concentrations of heavy metals can have toxic effects, so their occurrence in the environment could have long-term implications for ecosystems and human health. Human exposure to metals may arise through inhalation of wind-blown dust, direct ingestion of soil or consumption of locally grown vegetables. Environmental information, such as that provided by the Tellus Projects, helps to identify this hazard and to reduce potential risks to people, animals and the environment.

In order to assess the impact of anthropogenic activities on soil geochemistry, we need to understand the contemporary baseline chemistry of the natural environment. Important terms in environmental geochemistry are the geochemical baseline and the geochemical background. According to the Forum of European Geological Surveys (FOREGS) Geochemistry Working Group, a geochemical baseline can be defined as the concentration at a specific point in time of a chemical parameter (element, species or compound) in a sample of geological material. It is a fluctuating surface rather than a given value (Johnson and Ander, 2008). A geochemical baseline reports the chemical state of the surface environment, with no interpretation of the data.

In environmental geochemistry, the geochemical or natural background can be defined as the relative measure to distinguish between natural element or compound concentrations and anthropogenically influenced concentrations in real sample collectives (Matschullat *et al.*, 2000). The background may comprise many contributing geochemical populations (caused by compositional variations in underlying parental material) and the anthropogenic contribution, which is likely to be from multiple sources (Johnson and Demetriades, 2011). A detailed review of the numerous studies on approaches to determine background concentrations is beyond the scope of this work, but detailed reviews are given by Matschullat *et al.* (2000) and Reimann and Garrett (2005). More recently, the term Normal Background Concentrations (NBCs) has been used, as defined by BS EN ISO 19258:2011 (British Standards Institution, 2011), which includes both the natural and diffuse anthropogenic contribution to an element concentration in the soil, but excludes point contamination inputs. In studies such as those of Johnson *et al.* (2012) and Ander *et al.* (2013), NBCs were attributed to different regions of the country, where readily distinguishable factors (such as the underlying parent material, metalliferous mineralisation with associated mining activities and the urban environment) control the concentration of an element in soils. The areas showing the most significantly elevated element concentrations in soils were identified as contaminant domains.

This study presents a detailed approach to characterising the natural background and thus to determining the anthropogenic contribution to overall metal concentrations. The aim of the project was to assess the chemical quality of soils in the lower River Foyle catchment, including urban Derry–Londonderry and the surrounding rural cross-border area, in order to identify sub-catchments where anthropogenic impacts may have had a detrimental effect on land quality. In particular, the project has assessed the influence of the urban area of Derry–Londonderry on the soil environment. In order to determine whether

high soil metal concentrations were of natural (geogenic) origin or resulted from anthropogenic activities, the ‘geological background’ was modelled by taking account of the different geological lithologies of the 31 sub-catchments of the lower River Foyle. Using a GIS and multi-element diagrams, soil quality in the study areas was assessed, and degrees of metal enrichment above the natural geological background and attributed to anthropogenic impacts were quantified. The methodology demonstrated here should contribute to future environmental protection and catchment management strategies.

THE REGULATORY CONTEXT

Source–pathway–receptor model

In the UK, the environmental quality of land is commonly assessed using the Contaminated Land Regulations, which enforce Part IIa of the Environmental Protection Act (1990). Contaminated land is defined by identifying pollutant linkages between a contaminant (a substance that is in, on or under the land and has the potential to cause harm), a pathway (a route by which a receptor can be exposed to, or affected by, a contaminant) and a receptor (something that could be adversely affected by a contaminant, such as people) (DEFRA and Environment Agency, 2004). Each of these elements can exist independently, but together they create a potential risk. All three components must be present for a site to be defined as contaminated land.

The CLEA framework

Under the Contaminated Land Exposure Assessment (CLEA) framework, the Environment Agency (EA), an executive non-departmental public body sponsored by the UK Department for Environment, Food and Rural Affairs (DEFRA), has developed a risk assessment tool for human exposure to contaminated soils. Generic SGVs have been developed for quantitative risk assessment of land contamination (DEFRA and Environment Agency, 2004). These can be used for initial assessment of human health risks arising from long-term and on-site exposure to chemical contamination in soil. They represent ‘trigger values’ – indicators that soil concentrations above this level may pose ‘a possibility of significant harm to human health’ (DEFRA, 2008). They do not represent the threshold at which a ‘significant possibility of significant harm’ could occur but they present a useful starting point for further investigation (Environment Agency, 2009a, 2009b). In the Republic of Ireland the Environmental Protection Agency (EPA) supports the application of the UK EA approach to risk assessment and contaminated land (Doak, 2004). Some important SGVs are shown in Table 24.1.

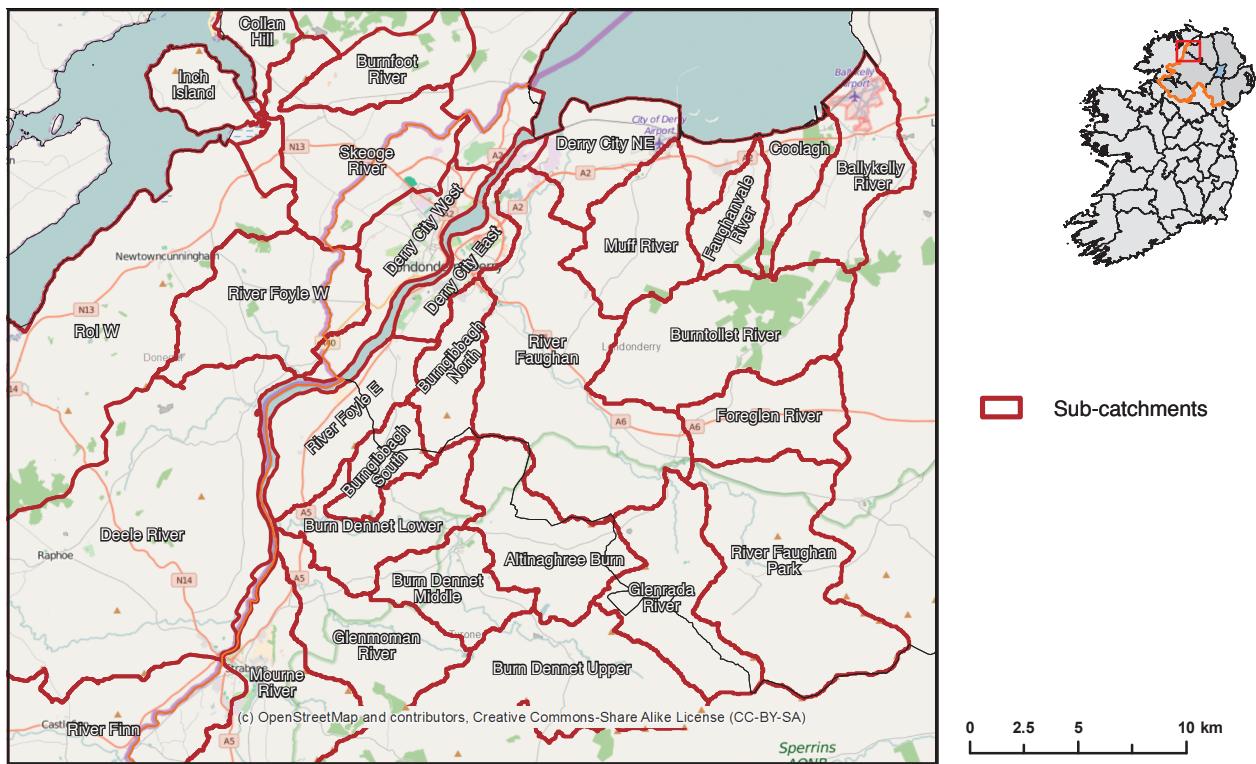


TABLE 24.1. CLEA GENERIC SGVs FOR SPECIFIC LAND USE TYPES (IN mg kg^{-1}) (ENVIRONMENT AGENCY, 2009B)

Land use	As	Cd	Hg	Ni	Se
Allotment	43	1.8	80	230	350
Residential	32	10	170	130	120
Commercial	640	230	3600	1800	13,000

Figure 24.1. Study area sub-catchments.

TOPOGRAPHY, GEOLOGY AND SOILS DATA

The project modelled the geological background of 31 sub-catchments (Fig. 24.1) to distinguish high metal element concentrations of natural origin from those of anthropogenic origin by:

1. mapping the spatial distribution of soil metal in the study area;
2. assessing soil quality with respect to soil quality guidelines;
3. modelling the naturally occurring (geogenic) chemical background values of the major geological units on a sub-catchment scale;
4. distinguishing natural from anthropogenic metal concentrations and thus determining the extent of the anthropogenic contribution.

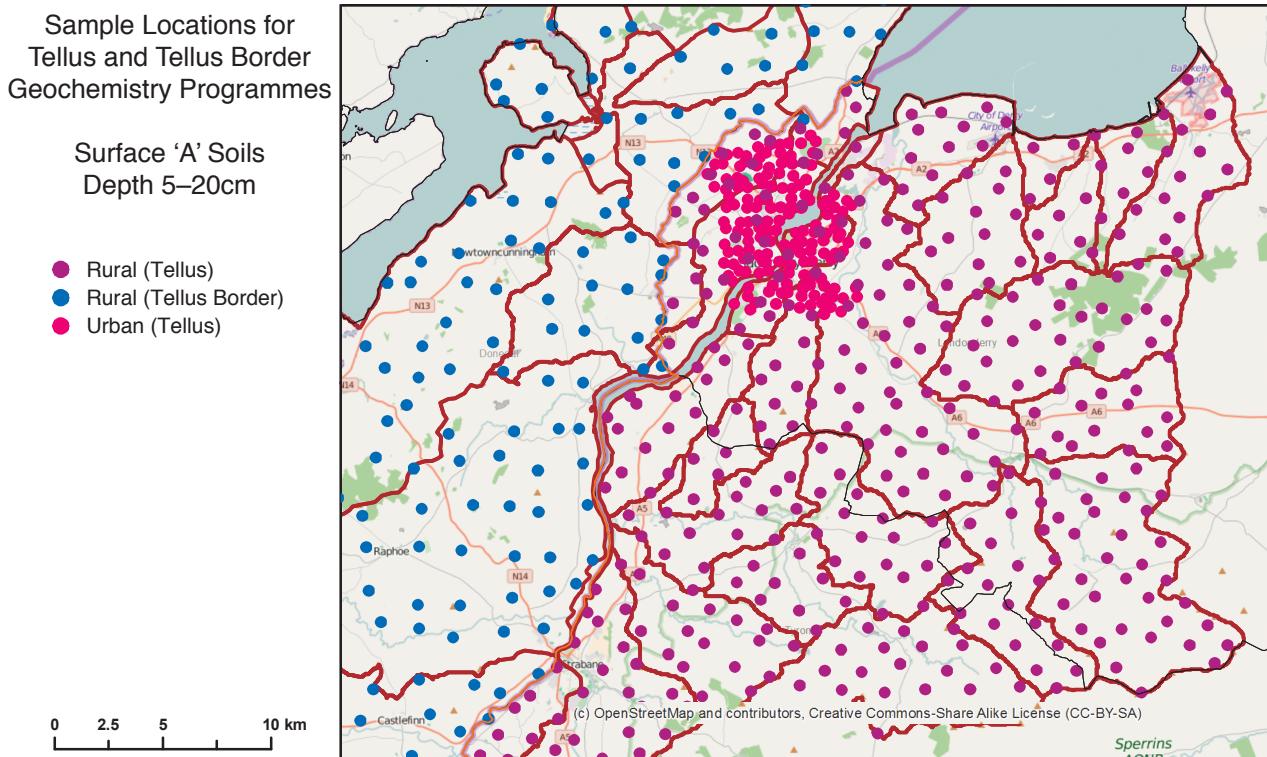


Figure 24.2. Map of the Derry–Londonderry study area showing the Tellus and Tellus Border soil sample locations.

TELLUS AND TELLUS BORDER SOIL GEOCHEMISTRY DATA SETS

The study was based on three topsoil geochemistry data sets (Fig. 24.2):

- 468 samples, one site per 2 km^2 , collected 2004–6 (rural surroundings of Derry–Londonderry, Tellus Project);
- 162 samples, four sites per km^2 , collected 2004–6 (urban Derry–Londonderry, Tellus Project);
- 133 samples, one site per 4 km^2 , collected 2011–12 (rural surroundings of Derry–Londonderry, west of Lough Foyle, Tellus Border Project).

These sampling surveys and analysis are described by Young *et al.* (Chapter 3, this volume). The urban samples were collected as part of the British Geological Survey's programme of mapping major British cities (Johnson and Ander, 2008). Derry–Londonderry was sampled as part of a project that included a survey of Belfast, described by Knights (2007). More recently, an urban geochemical survey of Dublin has been undertaken (Glennon *et al.*, 2014); although not part of the Tellus Border Project, these results provide an interesting comparison with those of Belfast and Derry–Londonderry.

TABLE 24.2. POSSIBLE CURRENT SOURCES OF ANTHROPOGENIC CONTAMINATION IN SELECTED SUB-CATCHMENTS

Sub-catchment	Possible anthropogenic contamination sources	No. samples (observed)	No. samples (model)	Elements with higher values in observed signature compared to geological background
Burngibbagh North	Urban; industrial estate, railway, road	20	13	Cu, Ni, Pb, Sb, Sn, Be, Bi
Burngibbagh South	Close to sewage works but high organic content	7	6	Co, Ni
Derry City East	Urban; construction site, brownfield site, sewage works; road	50	8	Ag, As, Cd, Co, Cu, Hg, Ni, Pb, Sb, Sn, Be, Bi, Mo
Derry City NW	Urban; road	21	14	Pb, Sn
Derry City West	Urban; industrial estate; coal depot; road	70	16	Ag, Cu, Hg, Ni, Pb, Sb, Sn, Zn, Be, Bi, Mo
Mourne River	Urban; sewage	20	19	Cu, Hg, Pb, Sn
Skeoge River	Urban; road; sewage; soil dump?	50	29	Ag, As, Cu, Hg, Ni, Pb, Sb, Sn, Bi, Mo

The Lower Foyle study area

The project studied an area of approximately 1050 km², extending from Strabane and the Sperrin Mountains in the south to Derry–Londonderry and the surrounding rural cross-border area in the north. Apart from a few towns, the area is largely rural. Historically, the textile industry was prominent here, notably shirt making, which started in 1831. For a time Derry–Londonderry was the most prolific centre of this industry in the UK and exported all over the world, with a peak in the 1920s.

Geology and soil type

Figure 24.3 summarises the bedrock geology of the area (GSNI, 1997), which has been described by Cooper and Johnston (2004). Most of the study area is underlain by mid-

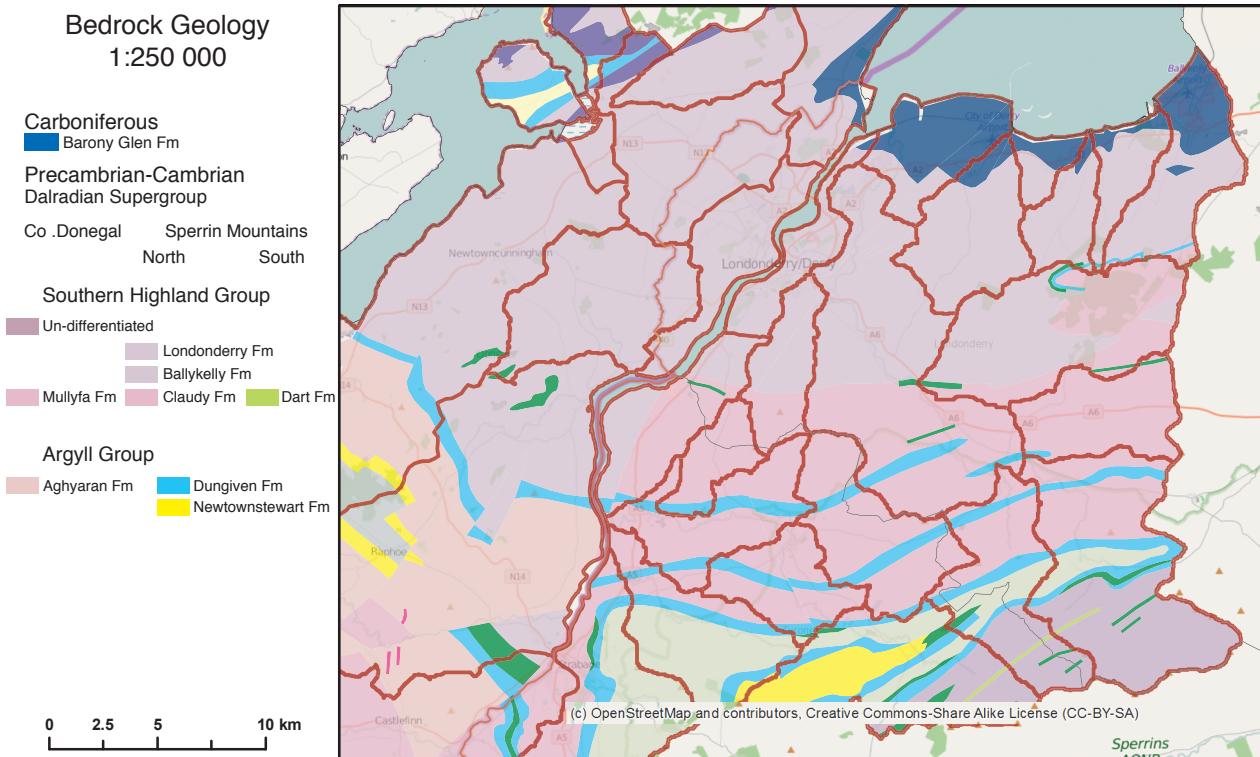


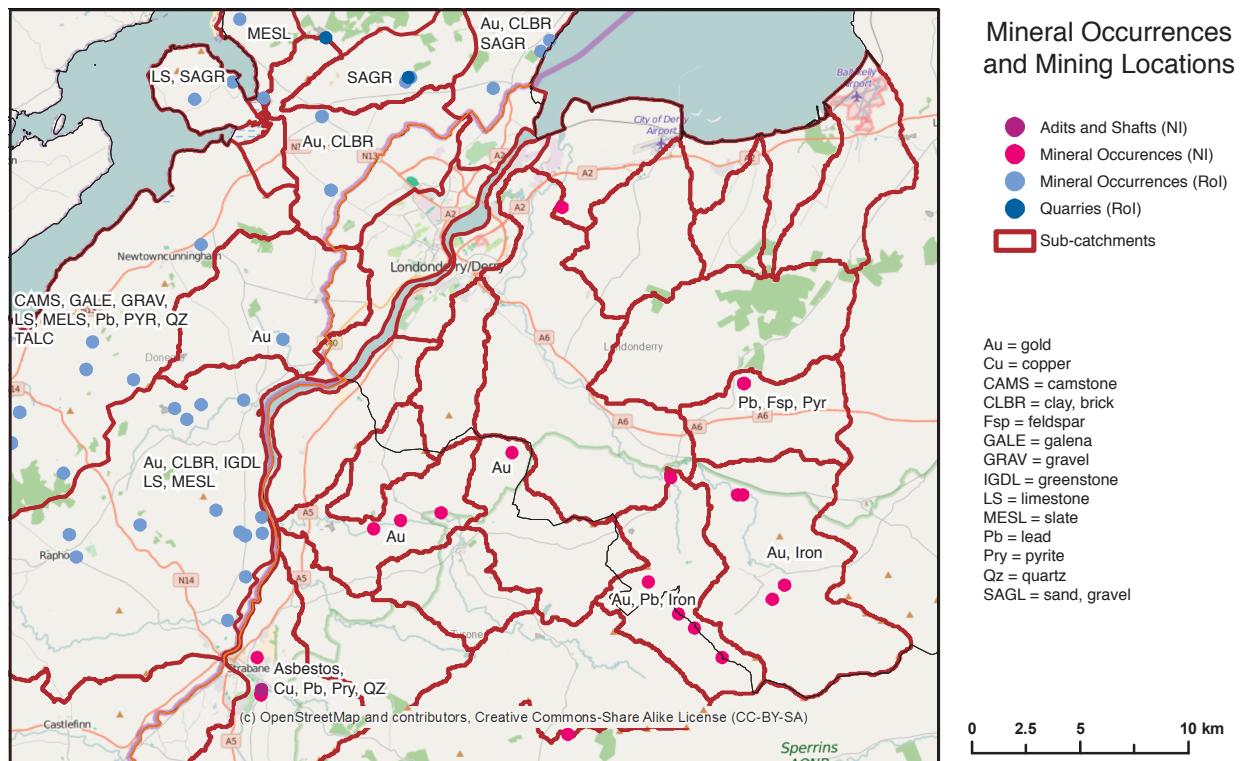
Figure 24.3. Overview of the bedrock geology (1:250,000) in the study area. Geological lithologies that have an area smaller than 10 km² are not included in the legend (Fm = Formation).

to late Neoproterozoic rocks of the Dalradian Supergroup. These predominantly clastic marine sediments are divided into the Argyll Group and the Southern Highland Group.

The oldest Dalradian rocks (Newtownstewart Formation) in the study area occur in the Sperrin Mountains and consist of grey, thickly bedded psammite with thin pelite interbeds. As the highest formation of the Argyll Group, the Dungiven Limestone Formation occurs in the southern part of the study area and consists of limestone with metabasite intrusions, pillow lavas and volcanoclastic sediments.

The Southern Highland Group consists mainly of turbidites. The Dart Formation in the southern Sperrin Mountains comprises amphibolite, overlain by volcanoclastic semipelite. The lithostratigraphy of the Southern Highland Group in the north Sperrin Mountains and north County Londonderry is divided into the Claudy Formation, the Ballykelly Formation and the Londonderry Formation. The oldest, the Claudy Formation, consists of psammite units with semipelite and two limestone units as markers. The succeeding Ballykelly Formation consists mainly of meta-arenites with a Limestone Member at the base of the formation. East Derry–Londonderry is underlain by the succeeding Londonderry Formation, consisting of meta-arenite and pelite.

The Dalradian rocks in County Donegal in the western part of the study area are classified as the Aghyaran Formation, which is equivalent to the Dungiven Limestone Formation in the Sperrin Mountains, consisting of interbedded meta-limestone and meta-dolomite



with quartzite and associated psammite. The Mullyfa Formation, consisting mainly of bedded psammites, occurs at the base of the Southern Highland Group. The upper Dalradian of County Donegal is undivided and consists of psammite and pelite.

Carboniferous-age rocks occur in the study area at the coast east of Derry–Londonderry. The Barony Glen Formation, the upper section of the Roe Valley Group, consists of mudstone, limestone, siltstone and sandstone (Mitchell, 2004).

Soil types

As described by Cruickshank (1997), the soil type in the rural areas west and east of Derry–Londonderry is gleyed soils, developed on mica-schist and mica-schist till with brown earth on the slopes of the uplands. Freely draining and steep-sided gravel formations fill the Sperrin valleys, ranging from brown earths to peat podzols. Blanket peat covers the gently sloping summits and plateau surfaces of the North Sperrin Mountains. Reclaimed marine alluvium occurs at the coast, north-east of Derry–Londonderry.

Catchments and water courses

River and stream catchment boundaries have been established by the Northern Ireland Environment Agency (NIEA) and the EPA (Fig. 24.1). For the purpose of this study, some sub-catchments have been merged and simplified. The locations of water courses were

Figure 24.4. Mineral occurrences and mining locations according to GSNI and GSI records (Legg *et al.*, 1985).

provided by Land and Property Services (Northern Ireland) and the EPA (Republic of Ireland).

Mining locations and mineral occurrences

Figure 24.4 shows the occurrences of mineral locations, as recorded by the Geological Survey of Northern Ireland (GSNI) and the Geological Survey of Ireland (GSI) (Legg *et al.*, 1985).

Data mapping

The soil geochemical and field observational data were entered into a GIS, ESRI®ArcGIS v.10. Maps showing the concentration and distribution of metals were generated using the ArcGIS Inverse Distance Weighting (IDW) interpolation function with a grid cell size of 250 m, a fixed radius of 1500 m and a power value of 2. Grids were produced using the Spatial Analyst tool, while the parameters of gridding were based on the methods of the UK G-BASE geochemical survey programme (Johnson *et al.*, 2005). The geochemical data were classified according to the percentiles (5th, 10th, 25th, 50th, 75th, 90th, 95th and 99th) of the data distribution using a gradational colour scheme.

MAPPING THE NATURAL BACKGROUND AND ANTHROPOGENIC COMPONENT

Geological background

Concentrations of metals with anthropogenic origins must be distinguished from those of geogenic origin. Using the methods of Ridgway *et al.* (2003) and Lass-Evans (2013), we modelled the geological background soil geochemical signature for each sub-catchment by considering the different geological lithologies of the study area in the GIS. These modelled geological background signatures were then compared to the observed sub-catchment signatures in order to distinguish whether elevated soil metal concentrations were of anthropogenic or of natural origin.

The observed geochemical signatures for each sub-catchment were calculated by taking the average concentrations from all soil samples within each of the 31 sub-catchment boundaries. The geological background signature was modelled in ArcGIS® as follows:

- the areal extents (in %) of the different geological lithologies in each sub-catchment were computed;
- soil samples within urban areas (e.g. samples that lie within defined urban areas on the current topographic map of Northern Ireland and the Republic of Ireland (1:250,000)) or that might contain known sources of contamination were excluded from the model;
- the average element concentrations of the remaining soil samples were calculated over each lithology, and then combined on a weighted basis, according to the percentage that each lithology occupied in each sub-catchment.

To compare the observed geochemical signature with the modelled geological background signature, the data were interpreted with the help of spidergrams. Element values (reported in wt%) were converted into mg kg⁻¹ (ppm) values; and elements were normalised to the upper continental crust (UCC) (Wedepohl, 1995). These multi-element plots have the advantage that elements with widely different concentrations can be viewed on a single diagram and that the pattern of variations can be compared, even if absolute concentrations are different.

Enrichment factors

To quantify the anthropogenic contribution to metal concentrations in the Derry–Londonderry soil samples, enrichment factors (EFs) for each sub-catchment were calculated by using the following equation (Kuusisto-Hjort and Hjort, 2013):

$$\text{EF} = [(\text{Metal})]_{\text{sample}} / [(\text{Metal})]_{\text{baseline}}$$

where [Metal]_{sample} is the average soil metal concentration in the sub-catchments (observed geochemical signature) and [Metal]_{baseline} is the average soil metal concentration of the modelled geological background.

Heavy metal enrichments were classified as no enrichment ($\text{EF} \leq 1$), minor enrichment ($1 < \text{EF} \leq 3$), moderate enrichment ($3 < \text{EF} \leq 5$), moderately severe enrichment ($5 < \text{EF} \leq 10$), severe enrichment ($10 < \text{EF} \leq 25$), very severe enrichment ($25 < \text{EF} \leq 50$) and extremely severe enrichment ($\text{EF} > 50$) (Birch and Davies, 2003).

DISTRIBUTION OF METALS IN SOILS

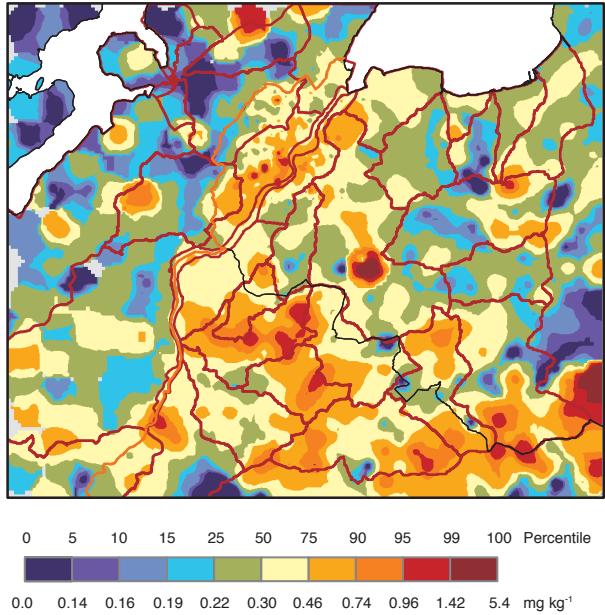
Distribution maps showing the concentrations of metals in soils are given in Fig. 24.5 for the metals that are most likely associated with anthropogenic activities: arsenic (As), chromium (Cr), molybdenum (Mo), antimony (Sb), copper (Cu), nickel (Ni), cadmium (Cd), lead (Pb), tin (Sn), cobalt (Co), mercury (Hg), zinc (Zn).

A brief overview is given below, but it was beyond the scope of this study to analyse the element distribution patterns in great detail; it is recommended that further investigations be carried out to relate heavy metal concentrations to parent material or soil formation processes. In general, the soils underlain by the Southern Highland Group in the Republic of Ireland west of Derry–Londonderry have higher Co, Cr, Cu and Ni concentrations than the Dart and Claudy Formations of the Southern Highland Group in Northern Ireland. The maps of these elements show similar patterns, so it is likely that their concentrations in the study area are mainly controlled by their parent material.

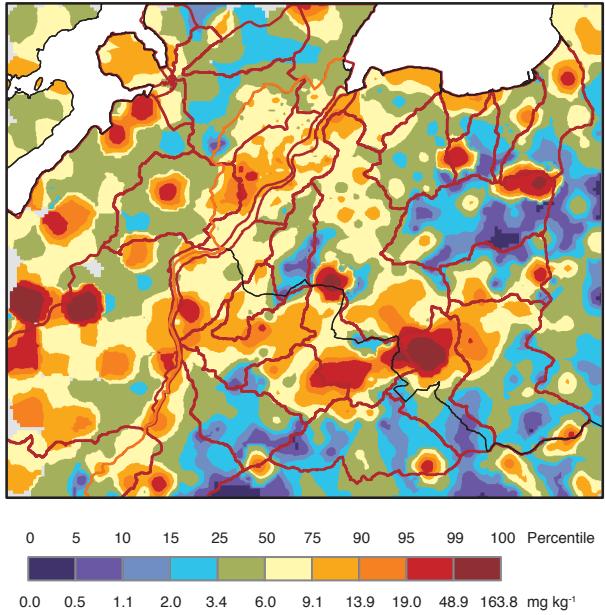
The soils underlain by the Southern Highland Group in the Republic of Ireland have low Hg, Pb, Sb and Sn concentrations, probably also associated with their parental material. In contrast, in Northern Ireland, Hg, Pb, Sb and Sn concentrations are elevated over the Dart Formation of the Southern Highland Group. This area corresponds to the upland

Figure 24.5. (a) Antimony, (b) arsenic, (c) cadmium, (d) chromium, (e) cobalt, (f) copper, (g) lead, (h) mercury, (i) molybdenum, (j) nickel, (k) tin and (l) zinc distribution in topsoil samples within the study area.

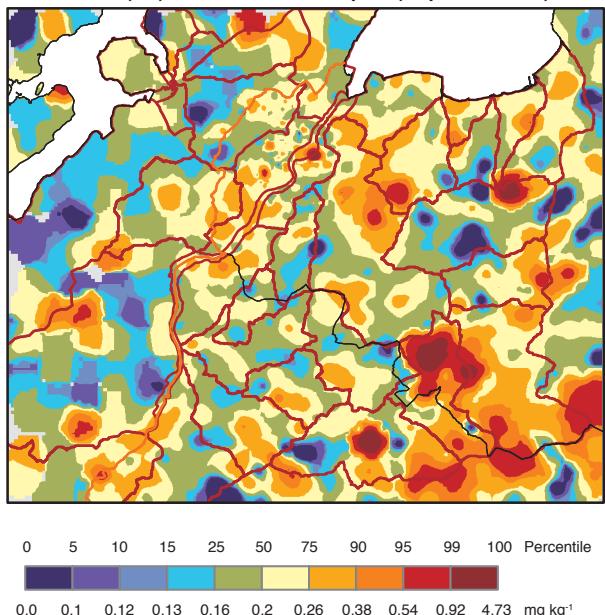
a. Antimony (Sb) in surface soil samples (Depth 5–20 cm)



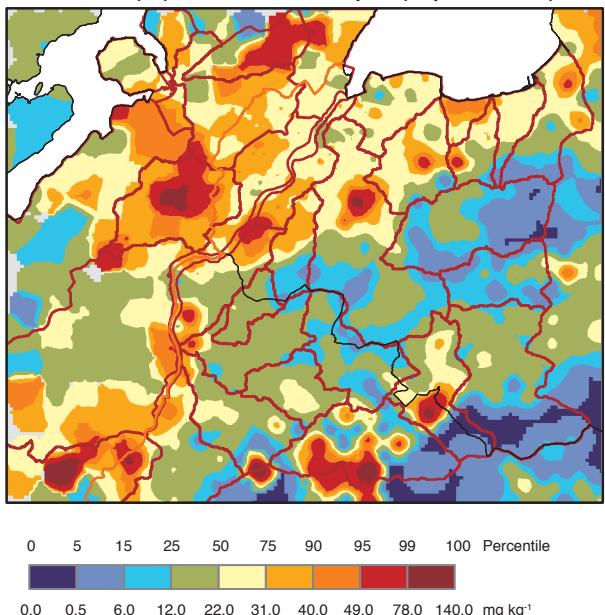
b. Arsenic (As) in surface soil samples (Depth 5–20 cm)

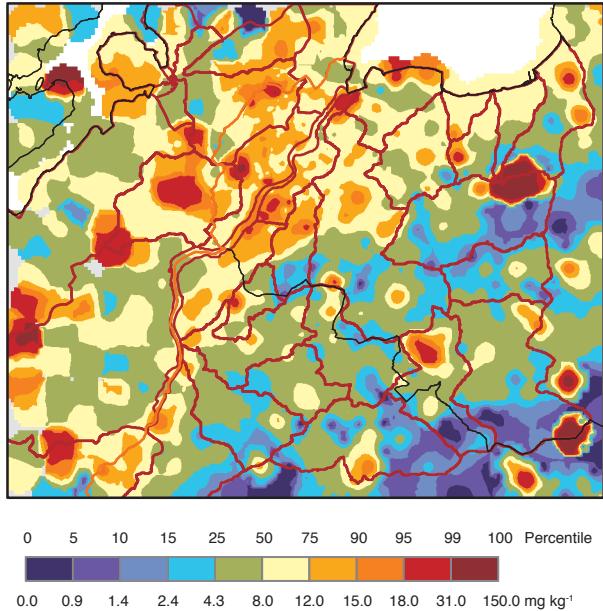
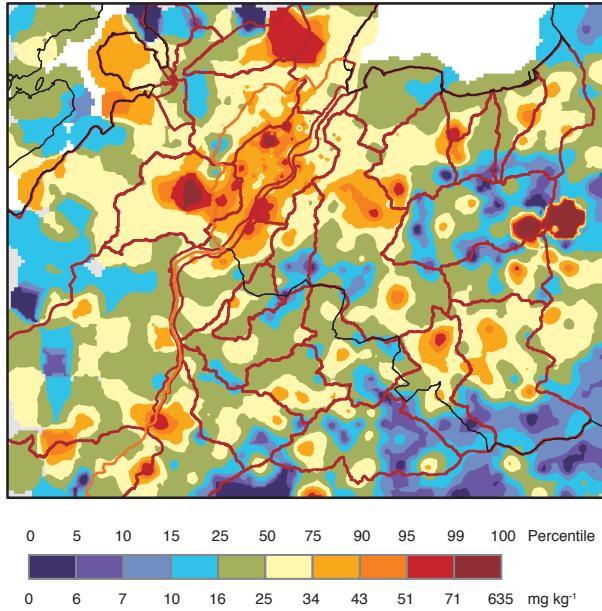
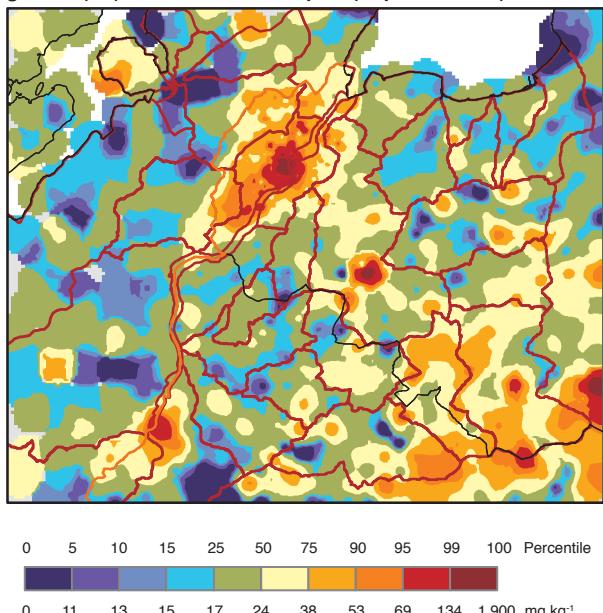
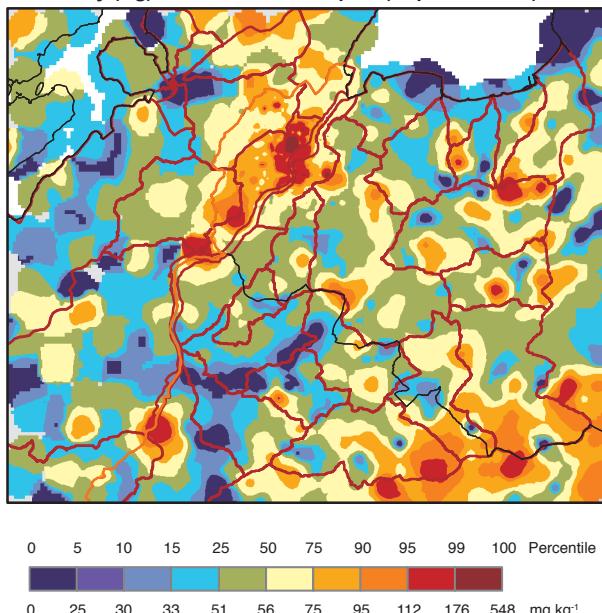


c. Cadmium (Cd) in surface soil samples (Depth 5–20 cm)

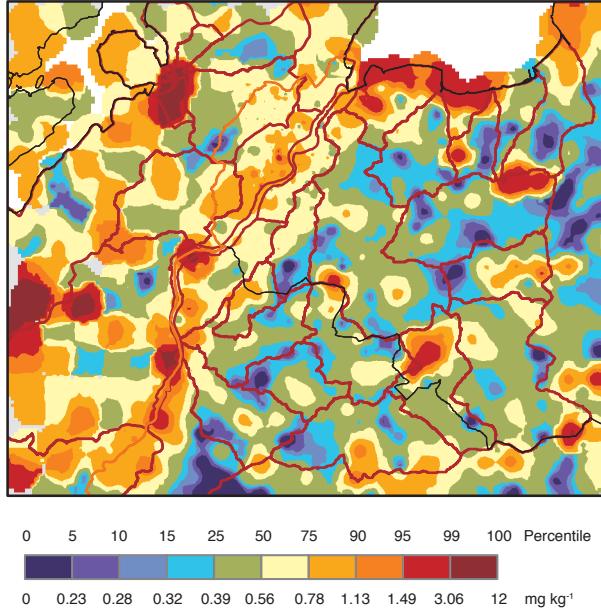


d. Chromium (Cr) in surface soil samples (Depth 5–20 cm)

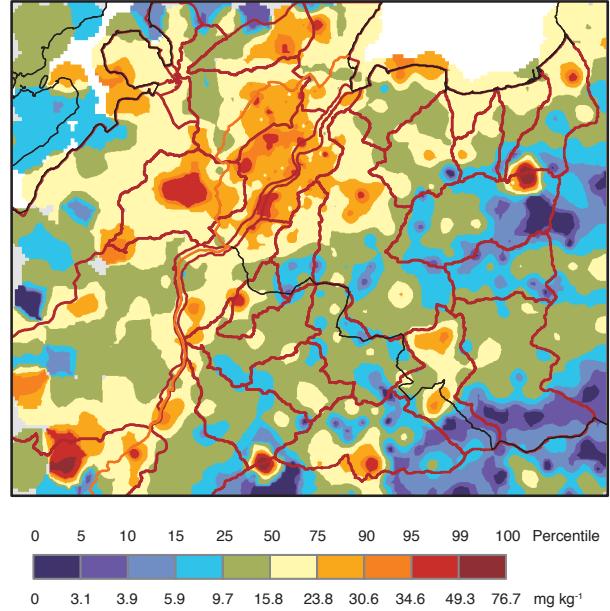


e. Cobalt (Co) in surface soil samples (Depth 5–20 cm)**f. Copper (Cu) in surface soil samples (Depth 5–20 cm)****g. Lead (Pb) in surface soil samples (Depth 5–20 cm)****h. Mercury (Hg) in surface soil samples (Depth 5–20 cm)**

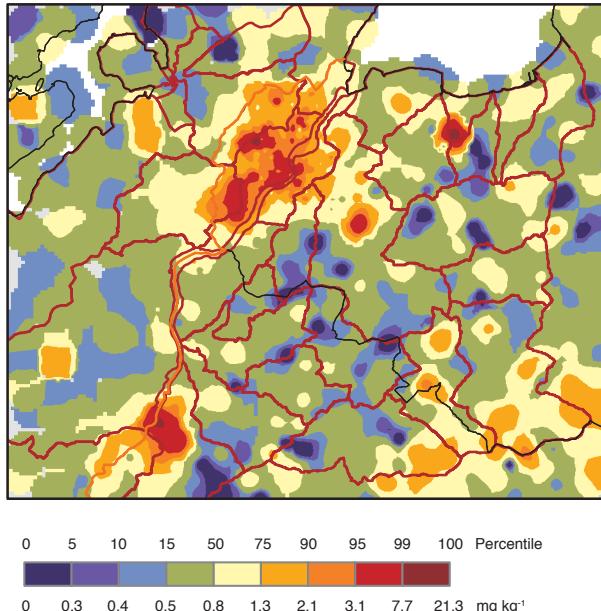
i. Molybdenum (Mo) in surface soil samples (Depth 5–20 cm)



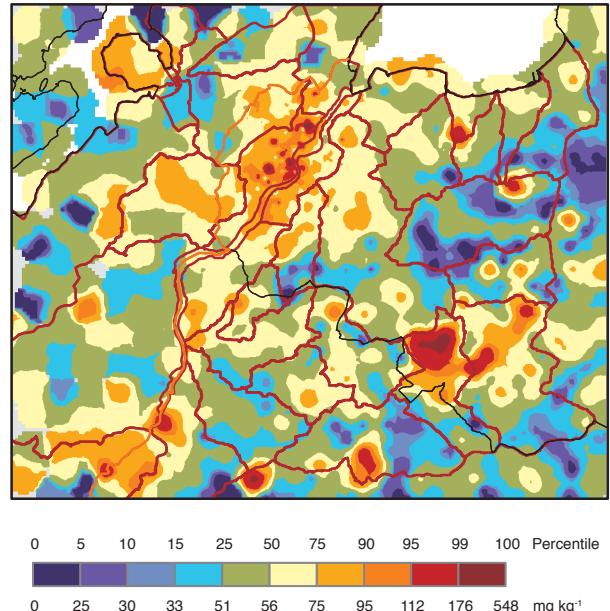
j. Nickel (Ni) in surface soil samples (Depth 5–20 cm)

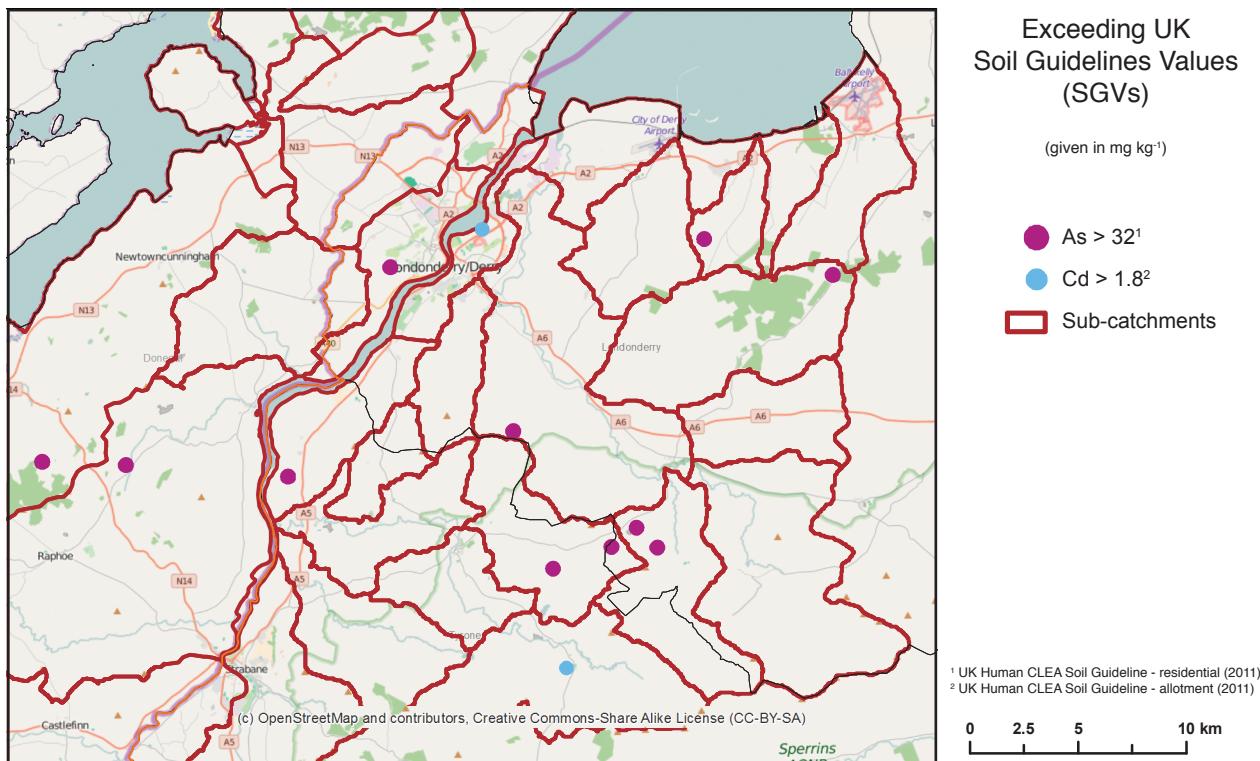


k. Tin (Sn) in surface soil samples (Depth 5–20 cm)



l. Zinc (Zn) in surface soil samples (Depth 5–20 cm)





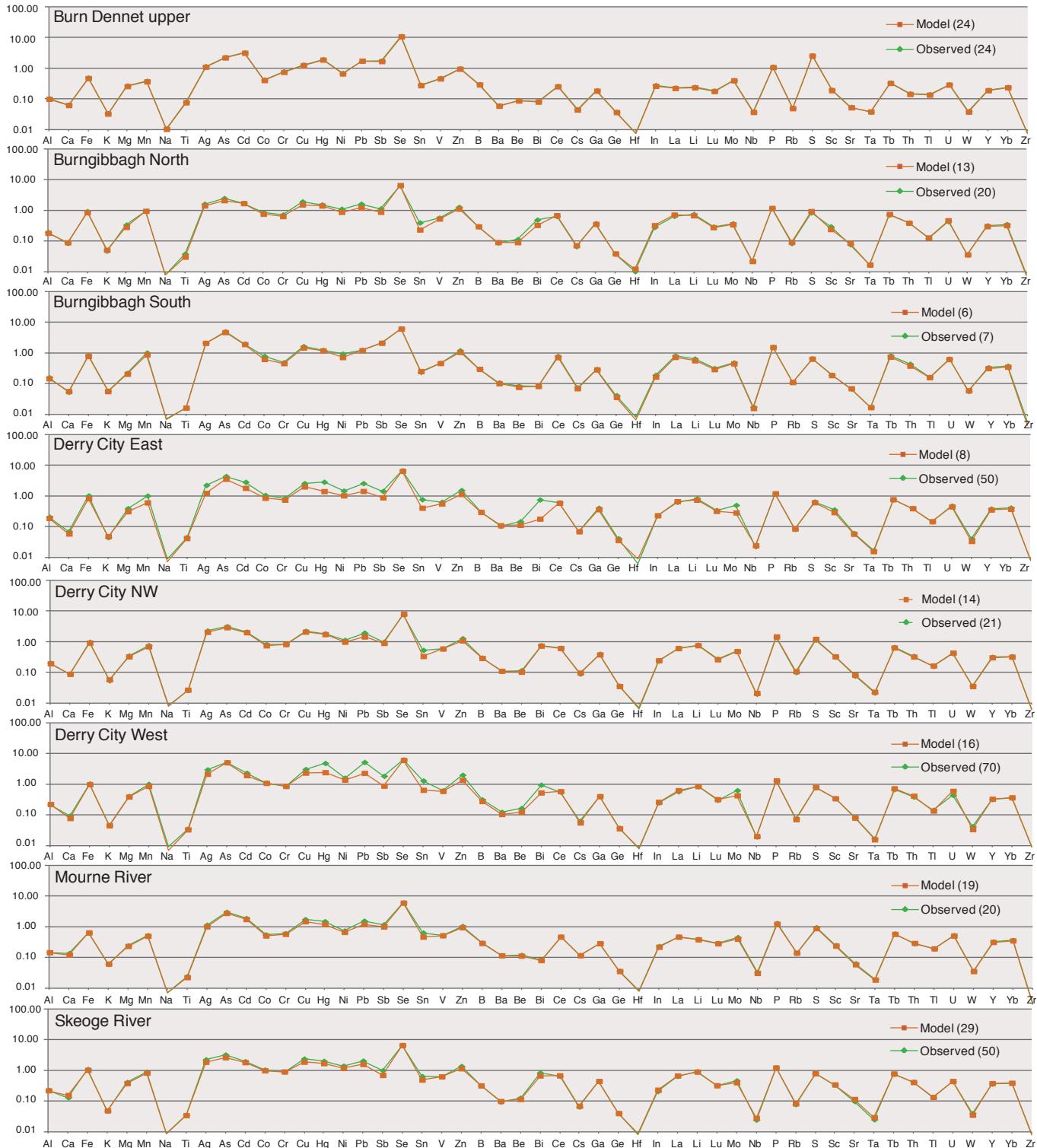
peaty soils of the Sperrin Mountains, so it is possible that these higher concentrations could be the result of atmospheric deposition due to higher rainfall, or to adsorption on peat in a reducing environment, or a combination of the two.

Elevated concentrations of As, Cd, Cu, Pb, Sb and Zn at sporadic locations over the Dalradian Supergroup could also be the result of natural mineralisation. Gold mineralisation with associated Fe, Pb and Zn sulphides and other elements in minor concentrations is common in the Sperrin Mountains. Alluvial gold occurrences are common across north-west County Derry–Londonderry, which may imply as yet undetected mineralisation. Quartz-calcite vein mineralisation containing Pb and Cu, with the potential for associated precious metals, occurs at a number of locations within the Precambrian-age metamorphic rocks in County Derry–Londonderry (Pitfield *et al.*, 2012). However, most of the known mineral occurrences (Fig. 24.4) seem not to have an effect on soil quality in the study area, but some localised mineralisation near sampling points might have caused enhanced metal concentrations. For example, gold mineralisation in the sub-catchment Burn Dennet Lower may contribute to elevated As and Sb concentrations, while Cu and Pb mineralisation might have had caused enhanced As, Cd, Cu, Sb and Pb concentrations in the area around Strabane. However, Co, Hg, Mo, Ni and Sn concentrations are also enhanced around the urban area of Strabane, suggesting that anthropogenic activities might also have had an impact on soil quality locally.

Figure 24.6. Arsenic and cadmium distribution with respect to UK CLEA contaminated land SGVs.

Figure 24.7. Example spidergrams from a sub-catchment where no anthropogenic sources are known (Burn Dennet Upper) and seven urban sub-catchments, where anthropogenic activities have an impact on soil quality.

Metallic contamination of soils in the Lower Foyle catchment



Elevated element concentrations in the urban area of Derry–Londonderry compared to the surrounding rural areas are seen for Cu, Hg, Ni, Pb, Sb and Sn. Highest concentrations of Pb (1900 mg kg^{-1}), Hg (7 mg kg^{-1}), Sn (21 mg kg^{-1}) and Zn (548 mg kg^{-1}) occur in the Derry City West sub-catchment, while the highest concentration of Cd (4.7 mg kg^{-1}) occurs in the Derry City East sub-catchment. Lead and Hg concentrations display zonation patterns with elevated element concentrations in the inner city that gradually decrease towards outer city areas.

Quantifying soil quality

Table 24.1 summarises the only inorganic UK CLEA SGVs published to date. In the study area, 11 samples exceeded the SGV for As ($>32 \text{ mg kg}^{-1}$; residential land use type) and two samples exceeded the SGV for Cd ($>1.8 \text{ mg kg}^{-1}$; allotment land use type) (Fig. 24.6). None of the soil samples in the study area exceeded the three other published SGVs, for Hg, Ni or Se. In the Derry–Londonderry urban area only two samples, both from visibly contaminated sites, exceeded the guideline values. Derry–Londonderry has relatively low metal concentrations compared to other cities, such as Belfast (Nice, 2010) and Glasgow (Fordyce *et al.*, 2012). For example, in Belfast, 15 and 45 samples exceeded the SGV for As and Ni respectively, while in Glasgow 74 samples exceeded the SGV for As and 654 samples exceeded the SGV for Ni. In Glasgow, 78 samples also exceeded the former UK CLEA residential/allotment SGVs of 1 mg kg^{-1} for Cd (Fordyce *et al.*, 2012). The samples exceeding the SGVs for As and Cd in the rural area of Derry–Londonderry do not correlate with known mineralisation occurrences, but not all of these may have been mapped so it is not certain whether these anomalies have geogenic or anthropogenic origins.

Calculating the geological background

To assess anthropogenic impacts on soil quality for each sub-catchment in the study area, the modelled geological background signatures were compared to the observed signatures for each element by plotting these on spiderplots (Reimann *et al.*, 2008). The *y*-axis on these plots is a ratio of the elemental averages determined here divided by the UCC values (Wedepohl, 1995).

In rural sub-catchments, where no anthropogenic impacts are known, the observed signatures and the modelled geological background signatures follow the same patterns in the spiderplots, suggesting that the soil composition is largely determined by the underlying rock types. An example of such a rural catchment is the Burn Dennet Upper (Fig. 24.7a).

In an urban environment, elements most likely associated with anthropogenic activity (e.g. Cd, Cu, Hg, Ni, Pb, Sb, Sn, Zn) have higher values in the observed signature, compared to the modelled geological background, while the two signatures show close compatibility for elements not necessarily associated with urban activities. Examples of such urban sub-catchments are Burngibbagh North (Fig. 24.7b), Burngibbagh South

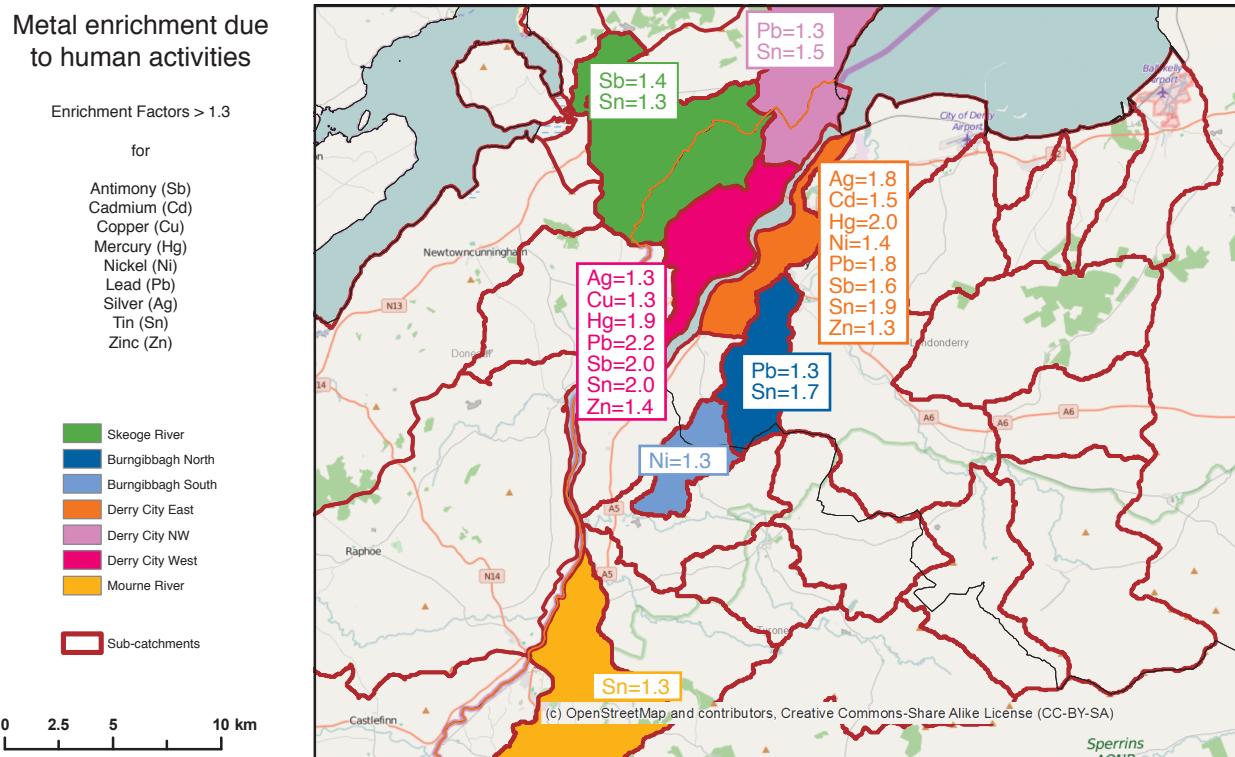


Figure 24.8. Sub-catchments where soil samples are enriched in metals (Ag, Cd, Cu, Hg, Ni, Pb, Sb, Sn, Zn) more than 1.3 times the geological background as a consequence of human activities.

(Fig. 24.7c), Derry City East (Fig. 24.7d), Derry City NW (Fig. 24.7e), Derry City West (Fig. 24.7f), Mourne River (Fig. 24.7g) and Skeoge River (Fig. 24.7h).

Enrichment factors

In central Derry–Londonderry (Derry City East and Derry City West sub-catchments), Ag, Hg, Pb, Sb and Sn are enriched by at least 1.5 times the natural background, while other elements, such as Cd, Cu, Ni and Zn, have EFs between 1.3 and 1.5 in the urban area (Fig. 24.8). The outskirts of Derry–Londonderry show slight enrichments of Pb and Sn in the Derry City NW (EFs: Pb = 1.3; Sn = 1.5) and Burngibagh North (EFs: Pb = 1.3; Sn = 1.7) sub-catchments and of Sb (EF = 1.4) and Sn (EF = 1.3) in the Skeoge River sub-catchment. The Burngibagh South sub-catchment has a slight enrichment of Ni (EF = 1.3), while the Mourne River sub-catchment (which includes the urban area of Strabane) in the southern part of the study area has a slight enrichment of Sn (EF = 1.3). Both the enrichment map (Fig. 24.8) and the distribution maps of Cu (Fig. 24.5f), Hg (Fig. 24.5h), Ni (Fig. 24.5j), Pb (Fig. 24.5g), Sb (Fig. 24.5a) and Sn (Fig. 24.5k) show elevated element concentrations and enrichments compared to the geological background in the urban area of Derry–Londonderry. As the enrichment map only takes account of enhancement of these elements due to human activities, Cu, Hg, Ni, Pb, Sb and Sn present in the urban soils in central Derry–Londonderry are likely of anthropogenic origin.

Possible present-day sources of anthropogenic contamination in the affected sub-catchments are summarised in Table 24.2 on OSI maps. Specific possible sources of contamination in Derry–Londonderry are likely to be industry, a coal depot and sewage works. In addition, many urban activities act as sources of heavy metals to the environment, including buildings, households, waste disposal and surface run-off from road traffic and manufacturing industries. Atmospheric contamination from vehicle emissions and the burning of fossil fuels can also lead to metal accumulation in the urban environment (Fordyce *et al.*, 2005, 2012; Johnson and Ander, 2008; Wong *et al.*, 2006). Historical maps (around 1900) were available for some parts of Northern Ireland. Possible sources of heavy metal contamination in the Derry City East sub-catchment include a factory, a station, a hospital and railways, while brick works, engineering works, factories, gas works, mills, railways, a quarry and station were present in the Derry City West sub-catchment. However, compared to other cities, such as Dublin (Glennon *et al.*, 2014), Belfast (Nice, 2010) or Glasgow (Fordyce *et al.*, 2012), Derry–Londonderry was not heavily industrialised. Median concentrations of As, Cu, Pb, Sb and Zn in Derry–Londonderry are half or less of the concentrations recorded in Dublin, Belfast and Glasgow. Overall, soil sub-catchment EFs in Derry–Londonderry and the surrounding cross-border area are no greater than 2.2, which is classified as minor enrichment (Birch and Davies, 2003).

CONCLUSIONS

To assess potential anthropogenic impacts on soil quality in Derry–Londonderry and the surrounding cross-border area, this project modelled the soil geochemistry for the geological background of the lower River Foyle catchment. We have been able to distinguish high metal concentrations of natural origin from those affected by human activities.

Soil quality was assessed by determining the samples that exceeded the UK CLEA contaminated land soil guideline values. Eleven samples exceeded the soil guideline value for arsenic and two samples exceeded the soil guideline value for cadmium. Only two of these 13 samples were in urban areas. On the basis of this study, it appears that the higher element concentrations in the rural area are caused by natural metal enhancements rather than anthropogenic contamination.

These results show that soil quality in the rural sub-catchments is good and mainly determined by the underlying geology. The urban area of Derry–Londonderry shows metal enhancements due to anthropogenic activities, and the main sources for this contamination are likely to be buildings, households and waste disposal, surface run-off from road traffic and manufacturing industries, coal disposal and sewage works. In the urban environment, the elements studied are enriched by a magnitude of at least 1.3. However, as their EFs do not exceed 3.0, their enrichment can be classified as minor.

The results of this study should help to inform future land-use management strategies.

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Table of Contents:

Prelim

DOI: <https://doi.org/10.7486/DRI.b851k323d>

Chapter 1

The Tellus geosciences surveys of the north of Ireland: context, delivery and impacts

DOI: <https://doi.org/10.7486/DRI.st74s528d>

Chapter 2

The Tellus airborne geophysical surveys and results

DOI: <https://doi.org/10.7486/DRI.t148tx96z>

Chapter 3

The Tellus geochemical surveys, results and applications

DOI: <https://doi.org/10.7486/DRI.t722wq645>

Chapter 4

Stakeholder engagement for regional geoscientific surveying: the Tellus Border communications campaign

DOI: <https://doi.org/10.7486/DRI.w089fr763>

Chapter 5

Mineral resources and Tellus: the essential balance

DOI: <https://doi.org/10.7486/DRI.wd37kb12s>

Chapter 6

Gold exploration in the north of Ireland: new targets from the Tellus Projects

DOI: <https://doi.org/10.7486/DRI.wh24m696v>

Chapter 7

Using soil geochemistry to investigate gold and base metal distribution and dispersal in the glaciated north of Ireland

DOI: <https://doi.org/10.7486/DRI.wm11n3806>

Chapter 8

Critical metals for hightechnology applications: mineral exploration potential in the north of Ireland

DOI: <https://doi.org/10.7486/DRI.wp98p0649>

Chapter 9

A natural laboratory for critical metals investigations in the Mourne Mountains granites

DOI: <https://doi.org/10.7486/DRI.cc08ww45f>

Chapter 10

Geothermal potential of granitic rocks of the Mourne Mountains

DOI: <https://doi.org/10.7486/DRI.ff36jm09f>

Chapter 11

Shape and intrusion history of the Late Caledonian Newry Igneous Complex, Northern Ireland

DOI: <https://doi.org/10.7486/DRI.2v248822m>

Chapter 12

Using Tellus data to enhance targeting of volcanogenic massive sulphide mineralisation in the Tyrone Igneous Complex

DOI: <https://doi.org/10.7486/DRI.5x226w262>

Chapter 13

The geological significance of electrical conductivity anomalies of the Ordovician- Silurian Moffat Shale Group, Northern Ireland

DOI: <https://doi.org/10.7486/DRI.6m31f4149>

Chapter 14

Faults, intrusions and flood basalts: the Cenozoic structure of the north of Ireland

DOI: <https://doi.org/10.7486/DRI.90205h306>

Chapter 15

Information for agriculture from regional geochemical surveys: the example of soil pH in the Tellus and Tellus Border data

DOI: <https://doi.org/10.7486/DRI.dv14c8060>

Chapter 16

An ecohydrological investigation of wetlands in the border counties of Ireland: a framework for a holistic understanding of wetland systems

DOI: <https://doi.org/10.7486/DRI.hd775d90j>

Chapter 17

Assessing nutrient enrichment risk to groundwater-dependent ecosystems in the border counties of Ireland
DOI: <https://doi.org/10.7486/DRI.k356pk18j>

Chapter 18

Mapping the terrestrial gamma radiation dose
DOI: <https://doi.org/10.7486/DRI.k930rb86z>

Chapter 19

Soils and their radiometric characteristics
DOI: <https://doi.org/10.7486/DRI.mp495t62g>

Chapter 20

Modelling in-house radon potential using Tellus data and geology to supplement inhouse radon measurements
DOI: <https://doi.org/10.7486/DRI.ns06hm86z>

Chapter 21

Determining geochemical threshold values from the Tellus data sets: the examples of zinc and iodine|
DOI: <https://doi.org/10.7486/DRI.r2087418g>

Chapter 22

Identification of the geochemical signatures of diffuse pollution in the Tellus Border soil data set, using source apportionment
DOI: <https://doi.org/10.7486/DRI.wh24m698d>

Chapter 23

Stream sediment background concentrations in mineralised catchments in Northern Ireland: assessment of ‘pressures’ on water bodies in fulfilment of Water Framework Directive objectives
DOI: <https://doi.org/10.7486/DRI.x633tf86g>

Chapter 24

Mapping metallic contamination of soils in the Lower Foyle catchment
DOI: <https://doi.org/10.7486/DRI.9k42bv355>

Chapter 25

Refining the human health risk assessment process in Northern Ireland through the use of oral bioaccessibility data
DOI: <https://doi.org/10.7486/DRI.9p29cr199>

Chapter 26

Combining environmental and medical data sets to explore potential associations between environmental factors and health: policy implications for human health risk assessments
DOI: <https://doi.org/10.7486/DRI.9s16dn03n>

Chapter 27

Mapping a waste disposal site using Tellus airborne geophysical data
DOI: <https://doi.org/10.7486/DRI.9w03fh87q>

Chapter 28

The use of aero-magnetics to enhance a numerical groundwater model of the Lagan Valley aquifer, Northern Ireland
DOI: <https://doi.org/10.7486/DRI.9z90gd711>

Chapter 29

Carbon sequestration in the soils of Northern Ireland: potential based on mineralogical controls
DOI: <https://doi.org/10.7486/DRI.b277h9556>

Chapter 30

Spatial distribution of soil geochemistry in geoforensics
DOI: <https://doi.org/10.7486/DRI.b564j6392>

End matter

DOI: <https://doi.org/10.7486/DRI.bc38m007j>