Environmental RTDI Programme 2000–2006

Towards A National Soil Database

(2001-CD/S2-M2)

Synthesis Report

Prepared for the Environmental Protection Agency

by

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DISCLAIMER

SOILS

The Soils Section of the Environmental RTDI Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in this area. The reports in this series are intended as contributions to the necessary debate on soils and the environment.

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1 Main Message

The *National Soil Database* has produced, for the first time, a national baseline database of soil geochemistry including data point maps and spatial distribution maps of major nutrients, major elements, essential trace elements, trace elements of special interest and minor elements. In addition, this study has generated a *National Soil Archive*, comprising both dried soil samples and a nucleic acids (DNA) archive as well as sampling and location information for each sampling point. The terms of reference for this physical archive are currently being drawn up by the Environmental Protection Agency (EPA), Teagasc and the National University of Ireland Galway (NUIG). This *National Soil Archive* represents a considerable research resource. The report and archive will provide Ireland with a sound, well-structured baseline of soil geochemical properties relevant to environmental, agronomic and health-related pressures and against a background of increasing soil protection policies.

The *National Soil Database* generated baseline soil geochemical maps (point and spatial distribution) of Ireland, and has begun an interpretation of these in a pedological context. This study also applied large-scale microbiological analysis of soils for the first time in Ireland and in doing so also investigated microbial community structure in a range of soil types.

A number of key outcomes relating to the *National Soil Database* are worth mentioning:

- Geographical coherence of the geochemical results and a strong relationship with the underlying geology

- Evidence of land-use, anthropogenic and climatic effects

- A strong relationship between parent material and microbial data.

These outcomes are discussed in detail in Chapter 2 of this report.

The database has relevance with respect to environmental, agronomic and health-related issues. Further benefits of the *National Soil Database* will arise from disseminating the findings to a wider audience including policy makers and stakeholders. As such, it will contribute to improved decision making and policy development in relation to the sustainable management of Irish soils and also for other environmental media, including water and air. The potential implications of the *National Soil Database* for policy are discussed in Chapter 3 of this report.

2 Synthesis

2.1 Introduction

The publication of the *National Soil Database*[1] in 2007 is timely, against the background of the adoption, in September 2006, of the *Thematic Strategy on Soil Protection* by the European Commission (EC). This Strategy requires Member States to acquire a more comprehensive knowledge of their soils and soil quality and lays the groundwork for a Soil Framework Directive.

The objectives of the research summarised below were fourfold:

1. The first was to generate a national database of soil geochemistry to complete the work that commenced with a survey of the south-east of Ireland carried out in 1995 and 1996 by Teagasc (McGrath and McCormack, 1999).

2. Secondly, to produce point and interpolated spatial distribution maps of major, minor and trace elements and to interpret these with respect to underlying parent material, glacial geology, land use and possible anthropogenic effects.

3. A third objective was to investigate the microbial community structure in a range of soil types to determine the relationship between soil microbiology and chemistry.

4. The final objective was to establish a *National Soil Archive.*

Between 2003 and 2005, 1,015 soil samples were collected in all areas of the country except the south-eastern region, which had already been sampled in 1995–1996. Soil samples were collected from predetermined defined positions on the national grid (two samples per 100 km^2). The grid of sampling locations (including the south-east sampling locations) is shown in Figure 2.1.

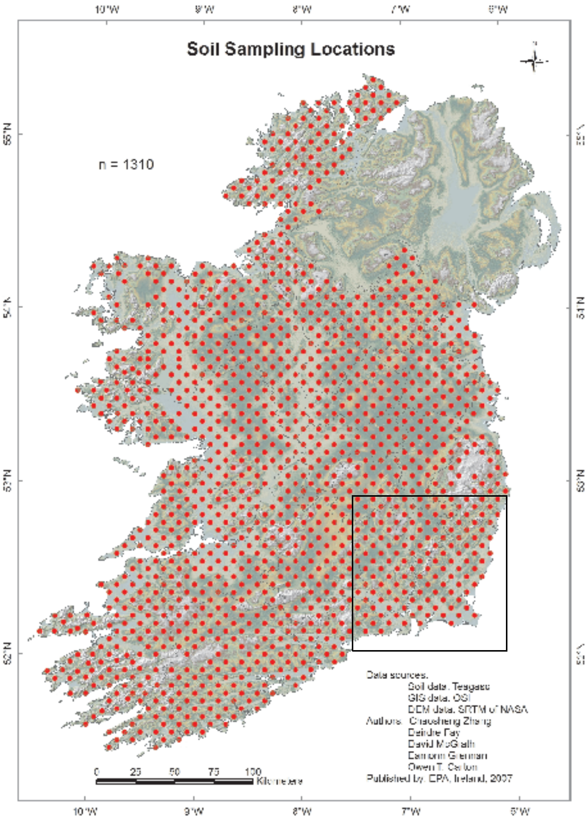

Figure 2.1. Map showing the grid of all the *National Soil Database* sampling locations. The extent of the original south-east study is shown in the square.

At the 1,015 sampling locations, soil cores were taken, using a Dutch auger, to a depth of 10 cm at 5-m intervals on a grid measuring 20 m × 20 m. Soil cores were combined to form a composite sample. These samples were added to the 295 archived soil samples taken during 1995–1996 in the south-east of the country using a similar sampling strategy. The results of this earlier sampling campaign are summarised in McGrath and McCormack (1999). All 1,310 samples were subsampled and these were analysed for a number of chemical parameters, a list of which can be found in Appendix 1. The results were used to generate a national soil geochemical database.

For the microbial analysis, subsamples were taken from the composite soil samples in the field and transferred *in situ* to a vial containing a stabilisation buffer that preserved the samples for microbiological analyses. This was done for all the subsamples collected during the 2003–2005 sampling campaign. A DNA archive was

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[1] http://www.epa.ie/downloads/pubs/research/land/ – Fay *et al.* (2007): *Towards a National Soil Database* (2001-CD/S2-M2).

subsequently generated from these preserved samples by purification of soil microbial DNA and storage of the materials at –80°C in labelled microtitre plates.

Statistical analyses including summary statistics, probability analysis, outlier detection, data transformation, multivariate analyses of relationships identified from correlation analysis, cluster analysis, and comparisons between sample groups were applied in this study. A table including the summary statistics for all of the soil samples taken is included in Appendix 2. Geostatistical analyses and GIS mapping were carried out based on the results of the statistical analyses.

An output of the project was a pair of maps for each element showing concentration ranges for the element at each sampling location as point data and a spatial distribution map of concentration levels generated using the best available statistical and mapping techniques. The term ‘level’ has been used in this report when referring to the spatial distribution maps as this is interpolated data generated from the actual concentrations measured. It is important to note the need for caution when using and interpreting the spatial distribution maps because of spatial variation and modelling uncertainty.

An example for each kind of map is shown for cadmium (Cd) in Figs 2.2 and 2.3. The elevated levels of Cd in the centre of the country are attributed to underlying pure and impure limestone geology in these areas and not to anthropogenic effects. Further maps for the elements Co, Cr, Cu, Hg, Mo, Ni, Pb, Se and Zn are included in Appendix 3 of this report.

A full description of the chemical and microbial analyses as well as the statistical methods and map generation can be found in the main report (Fay *et al.*, 2007).

Both the physical soil samples and the nucleic acids archive have been used to create a *National Soil Archive*. The Archive also includes a paper and electronic catalogue of standard operating procedures for the chemical and microbiological analyses undertaken. The terms of reference to access the archive are currently being developed by the EPA, Teagasc and NUI Galway. Access to the *National Soil Database* will be facilitated via the National Environmental Research Centre of Excellence website of the EPA (http://coe.epa.ie/safer/).

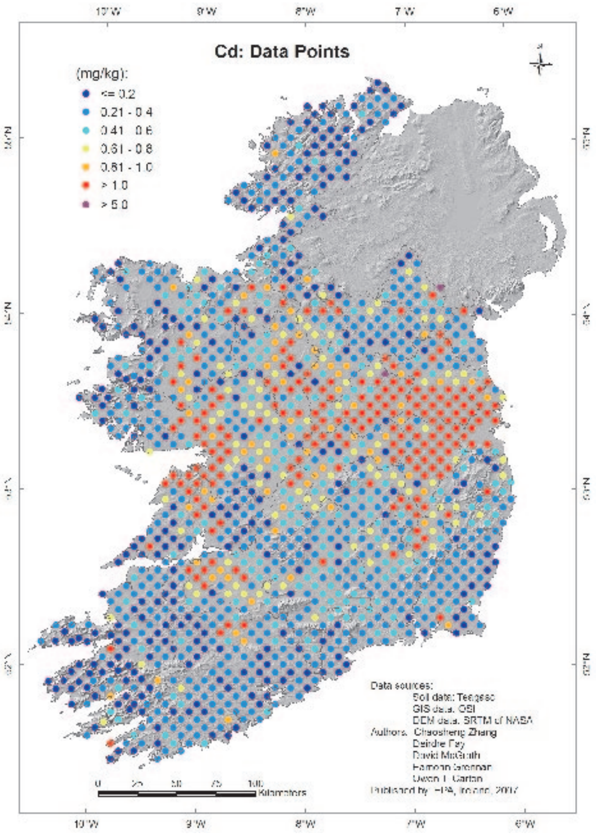

Figure 2.2. Cadmium concentration ranges measured for the data points in mg/kg soil.

Apart from the *National Soil Database* and its two archives, a full report has been published (Fay *et al.*, 2007) with an initial interpretation of the data which is available from the EPA website. The highlights of this interpretation have been summarised in the rest of this chapter.

2.2 The Coherence of Soil Geochemistry with Soil Type and Underlying Geology

Soils are derived from parent material. This can be solid rock which has weathered, superficial deposits such as glacial drifts or alluvium or organic matter accumulated *in situ*. Parent material is composed of any one or a combination of these, and is strongly related to geology. The soil sampling strategy used in the *National Soil Database* study has shown the baseline soil geochemistry in a clear and unequivocal manner and allowed a more informed interpretation of the relationships between the geographical distribution of the measured geochemical data, soil types and the underlying geology. For example, the coherence between the elements As, Fe, Mg and Mn, visible in Fig. 2.4, can predominantly be explained by the underlying parent material. The high levels coincide to a

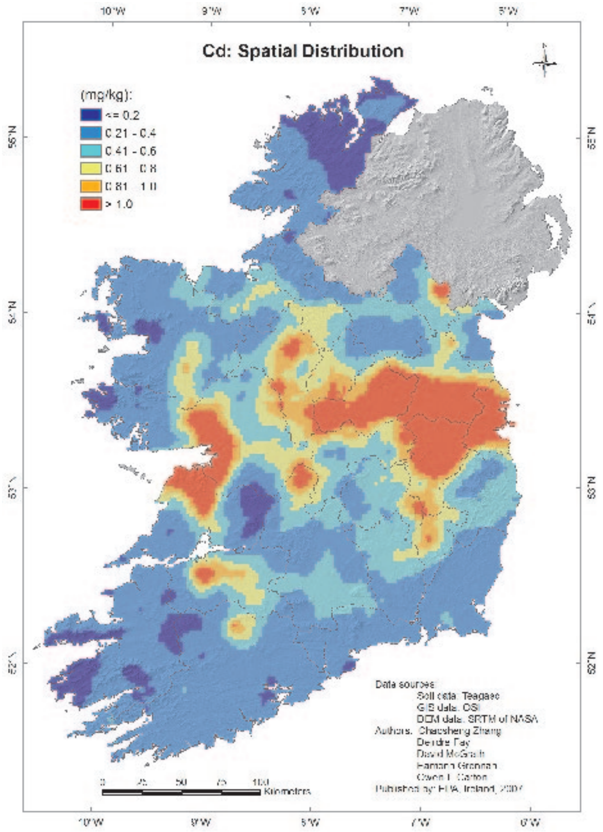

Figure 2.3. Spatial distribution of cadmium levels in mg/kg soil.

large extent with the sandstones and shales in the country, whilst the low levels are associated with underlying limestone. This observed geographical coherence of the results is also evident for Co, Cr, and Cu (see Appendix 3) and is noteworthy given the extensive sampling strategy used.

An attempt was made to summarise this extensive geochemical data set using expert opinion to divide the country into five major geographical regions based on observations of the measured elements from the spatial distribution maps and the simplified soil and rock type maps. The general area covered in these regions is projected on the soil and rock type maps in Figs 2.5 and 2.6 and can be described as: the Central North East (A), the South East (B), Cork, North Kerry and Clare (C), Western Seaboard (D) and the Midlands (E). In Table 2.1, elements have been highlighted for each region on the basis of relatively high (h) or low (l) observed levels of the element compared to the other regions. The denotation (o) means that localised high or low levels were observed. This table is an observational summary of the extensive information in the maps and can be used as a guide to identify links between geomorphologic regions and the relative concentrations of the measured chemical elements in the maps. Some of the geographical coherences identified in Table 2.1 are discussed below.

The soils of the central north-eastern area of the Republic of Ireland (A) consist mainly of Gleys, which have been derived from Lower Palaeozoic greywackes and shales and which have a significant volcanic mineral content. High levels of total P, total K, total Mg, Fe, Na, Al, Ti, Cu, Co, Cr and Ni were present in this region.

The soils of the south-eastern region (B) consist mainly of Acid Brown Earths with subsidiary podzolics and marine-derived glacial muds, underlain by a volcano–sedimentary sequence. The latter has been metamorphosed to varying degrees by the intrusion of the Leinster Granite. High levels in all or parts of this region were noted for total P, total K, Fe, Na, Al, Ti, Co and Cr. High levels of total Mg in parts of this region were attributed to either the marine-derived glacial muds or to the dolomitised limestones in counties Kilkenny and Kildare. Elevated levels of Na in this region are coincident with the Leinster Granite.

The Cork, North Kerry and Clare (C) region has a few different characteristic properties. The relatively narrow geographical area of southern Cork is underlain by sandstones, siltstones and black shales. The geochemical imprint continues northwards across the Old Red Sandstones to join with the younger siltstones and grits of northern Kerry and Clare. Elevated total K in southern Cork was attributed to the underlying shales and siltstones. Elevated levels of Fe in the central and western Cork area are associated with Carboniferous shales. In western Cork and Clare, elevated levels of Al are associated with the underlying sandstone and shales. It was noted that Al and Fe show similar distribution patterns. Elevated levels of total P and Cd in northern Clare are associated with phosphate-rich rocks. In Ireland, seleniferous soils are typically low lying and poorly drained. These soils have been influenced to a large degree by percolating waters from Se-rich rocks where black shales are the predominant facies, and are found in northern Kerry, western Limerick and southern Clare.

The overriding effect of the ‘blanket peat’ is visible all along the Western Seaboard (D). A soil organic carbon

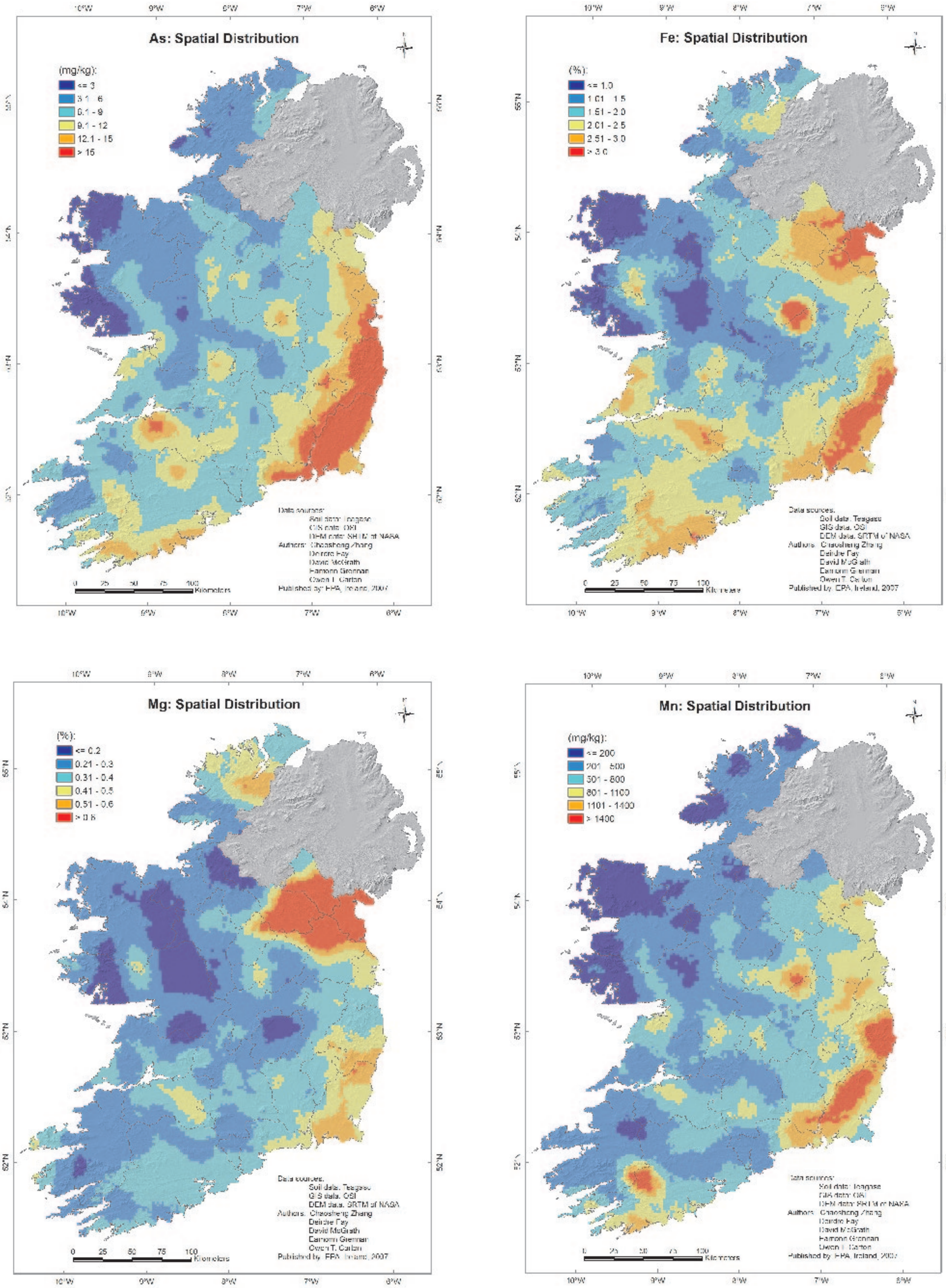

Figure 2.4. Spatial distribution maps for the elements arsenic, iron, manganese and magnesium (clockwise from top left) showing the coherence in distribution for these elements.

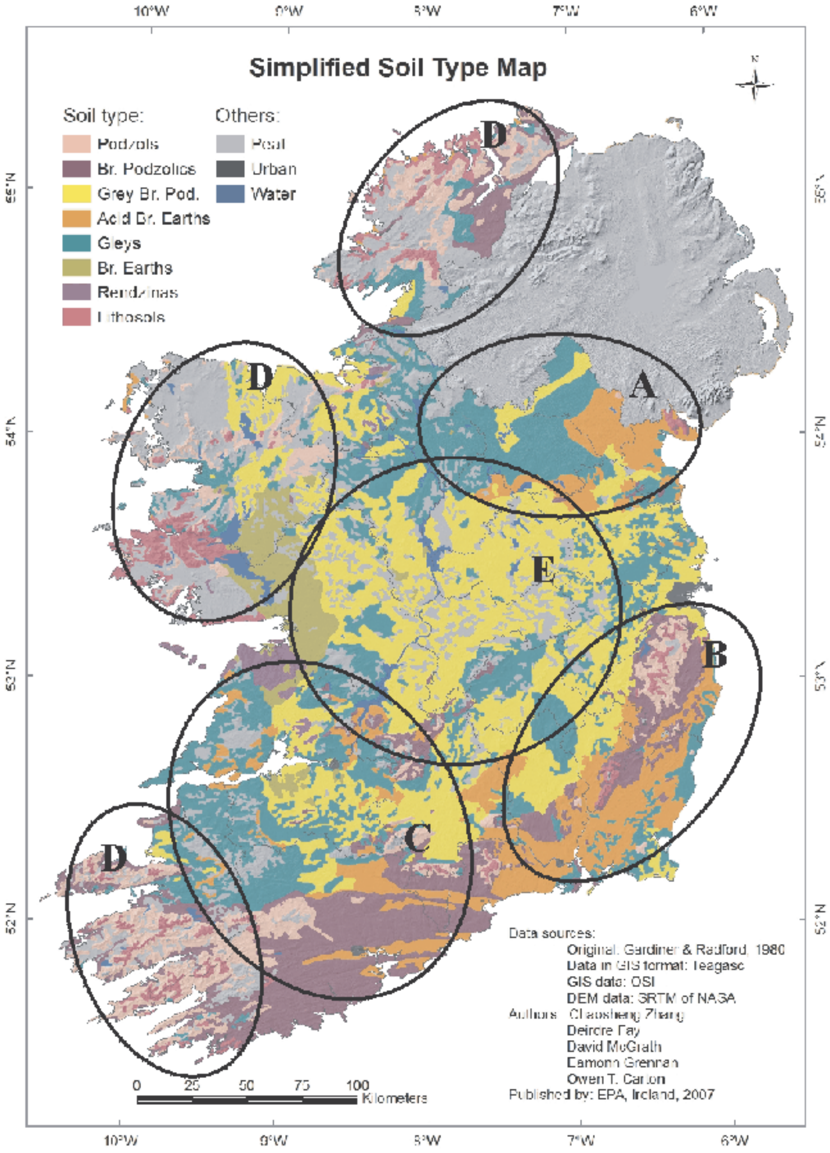

Figure 2.5. Simplified Soil Type map showing the five regions selected to summarise the geochemical data.

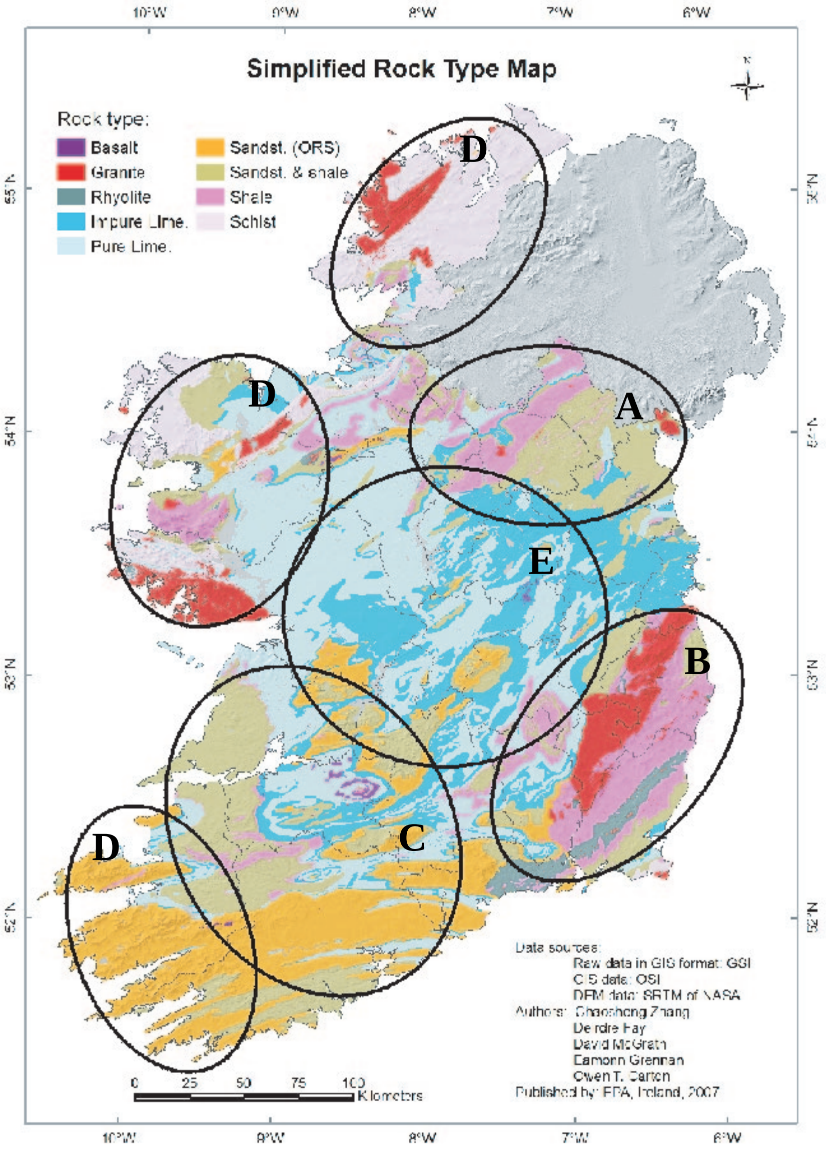

Figure 2.6. Simplified Rock Type map showing the five regions selected to summarise the geochemical data.

Table 2.1. Observed relatively high (h)/low (l) levels of elements for the geographical regions from the spatial distribution maps. Observed localised high/low levels are marked with an (o).

Geographical region	Elements associated with the region
Central North East (A)	**h:** Al, Co, Cr, Cu, Fe, Ga, K, La, Mg, Na, Ni, P, Sc, Sr,V, Zn **l:** S, Se
South East (B)	**h:** Al, As, Ba, Co, Cr, Fe, Ga, Ge, K, La, Li, Mg, Mn, Na, Nb, Pb, Rb, Sb, Sc, Sn, Ta, Ti, V, W **l:** Ca, Cd, S, Se
Cork/North Kerry/Clare (C)	**h:** Al, As, Cd(o), Ce(o), Cu(o), Fe, Ga, Ge, K, La, Nb, Ni(o), P(o), Sc, Ta, Th, Ti(o), Se(o) **l:** Ca, Li, Mg
Western Seaboard (D)	**h:** S, Se, Sr(o), SOC **l:** pH, most measured elements
Midlands (E)	**h:** Ca, Cd(o), Mo(o), S(o), Se(o), SOC(o), Y(o), Zn(o) **l:** Al, Ce, Cr, Ga, Ge, La, Li, Mg(o), Na(o), Nb, Ta, Th, Ti, V, W

content of 15% was defined in this study as the delineation between mineral and peat soils.

While elevated levels of S in the west, north-west and midlands were attributed to an organic matter effect, low levels of Na, As, Cr, Cu and Co were observed in organic-rich soils around the country. It was noted in this study that Cu and Co were negatively correlated with organic C.

The largest area of all, the Midlands (E), is dominated by Grey Brown Podzolic soils, with smaller areas of ‘raised peat’. The former have been derived from either pure limestones or impure limestones, each of which has left its own geochemical fingerprint. Low levels of Fe are found in Roscommon and parts of Mayo, Galway and Clare which are underlain by pure limestone. Low levels of Na and Cr are associated with limestone areas generally. Elevated levels of Zn mirror the occurrence of underlying impure limestones in Dublin, Meath, Westmeath and Kildare (or karstified limestones as in the Allenwood area of Kildare). Seleniferous soils are found in areas with underlying impure limestone geology, such as Dublin, Meath, Westmeath, west Offaly, east Galway and north Tipperary. Elevated levels of Cd in Dublin, Kildare, Meath, Westmeath, north Tipperary and Roscommon are attributed to underlying pure and impure limestone geology in these areas rather than anthropogenic effects.

2.3 Anthropogenic and Climatic Influences on Soil Geochemistry in Ireland

The link between soil geochemistry, soil type and underlying geology was highlighted in the previous section. Soil geochemistry, in turn, has a strong influence on land use. Conversely, human activities such as mining, industry, agricultural land use, with its associated farm management practice, and management of sewage sludge by land spreading can alter the chemical composition of soils.

The impact of land use and farm management practice on soil geochemical properties was particularly evident in terms of available P and available K, as well as pH. Available K concentrations closely paralleled the high available P concentrations and were coincidental with areas of intensive animal and crop production. Strong correlations were found between the soil available P and K concentrations identified in this study and those published by Teagasc based on their national database which contains in excess of 1 million results. Similarly, a good correlation was found between soil acidity (pH) in this study and published Teagasc maps for lime requirement.

Essential trace elements such as Co, Mo and Se were also considered in terms of agricultural land use and farm management practice. Low levels of soil Co, which could result in deficiencies for livestock, were apparent in the traditional sheep grazing areas of Donegal, Mayo, Galway and Kerry. The low Co levels in these soils are a result of inherently low Co in the parent material in these regions and the natural leaching of Co out of these soils. Low levels of Se were coincident with intensively managed agricultural land in the south and east of the country (e.g. Carlow, Wexford, Cork, Tipperary and Waterford), with tillage in Louth and with coastal areas in Wexford that encompass marine-derived glacial soils.

Trace elements such as Cu, Zn, Pb and Hg, which can be toxic to livestock and plants, were considered in terms of possible anthropogenic effects. In most cases where high levels of these elements were observed, their background levels were inherently high due to the local geology.

Mining and industrial activity will, however, have released more of the element into the immediate area, often elevating the concentrations further. Elevated levels of Cu were observed over broad areas of east Wicklow, along the Waterford coastline and particularly in south-west Cork. These were attributed to both high natural background concentrations and the associated historic mining activities. Areas with high naturally occurring Zn concentrations in the soil are or were associated with current and past history of Zn mines and deposits. Spot high concentration levels of Pb were coincident with the point sources of Silvermines in Tipperary and areas bordering Keady in Northern Ireland. High levels of Pb in Dublin and Wicklow are attributed to a combination of urbanisation and historical mining activity. Elevated levels of Hg in Dublin/Wicklow were attributed to an anthropogenic effect (urban and historic mining), and to the old smelter at Ballycorus, Dublin, which is close to the Wicklow border. This activity has undoubtedly contaminated an area around it with a variety of heavy metals, e.g. Hg and Pb.

The climatic effects on soil geochemistry observed in the data set are due mainly to proximity to the Atlantic seaboard and, to a lesser extent, being to the west of the industrial heartland of Europe. The influence of the Atlantic Ocean has manifested itself in the elevated levels of available Mg in soils on the western seaboard. This is due to the prevailing westerly winds blowing the Mg-enriched seawater overland either as rain or in the wind. There also appears to be an effect of oceanic deposition in relation to elevated levels of S and a narrow strip of elevated Na in parts of the west.

The mild temperate oceanic Irish climate, which has dominated since the end of the last glaciation, combined with the deforestation of the country, especially since the middle of the second millennium, has facilitated significant leaching of major nutrients and elements from soils leading to the development of podzols. However, in the Midlands, this leaching was significantly retarded by the high Ca content of the boulder clay, which is derived from limestone parent material and which has led to the development of Grey Brown Podzolics.

The natural growth of our peats, which is intimately related to climate and biology, is well documented. High soil organic carbon concentrations (>15%) in this study reflected the peat distribution in Hammond's (1978) *Peatland Map of Ireland* well, even though the samples in this study were only taken to a depth of 10 cm.

2.4 Comparative Values

A comparison was made of the Irish soil geochemical data set with similar data sets for Northern Ireland, Scotland and England and Wales. The elements compared were Cd, Cr, Cu, Ni, Pb and Zn (Table 2.2).

The median Irish Cd and Pb values were similar to those for Northern Ireland and lower than those for England and Wales where there are major anthropogenic effects. The median Irish Cr value is comparable to those of Northern Ireland (Jordan *et al*., 2002), Scotland (Paterson *et al*., 2002), and England and Wales (McGrath and Loveland, 1992). The median Cu and Ni values are similar to those of England and Wales, but are lower than those reported for Northern Ireland where the background levels are enhanced by the presence of the basalts. For Zn, the median value is similar to that of Northern Ireland, and England and Wales.

It is worth noting that the observations concur with previous studies that suggest that elevated concentrations of heavy metals are generally naturally occurring regional highs, which are a consequence of the underlying soil parent material.

Table 2.2. Median concentrations (mg/kg) for Cd, Cr, Cu, Ni, Pb and Zn soil for Ireland (all soils and mineral soils), Northern Ireland, England and Wales and Scotland.

Element	Irish median value for all soils	Irish median value for mineral soils	Median value for Northern Ireland	Median value for Scotland	Median value for England and Wales
Cd	0.33	0.36	0.33	0.15	0.70
Cr	42.6	48.9	46.5	41.4	39.3
Cu	16.2	18.6	27.1	7.4	18.1
Ni	17.5	20.6	29.2	17.5	22.6
Pb	24.8	24.8	17.9	23.2	40.0
Zn	62.6	72.7	65.4	48.0	82.0

2.5 Microbiological Analyses

The two main achievements of the microbial analysis section of the *National Soil Database* can be summarised as follows:

1. The development of a robust method for the preservation and extraction of DNA in soil which was undertaken on 1,005 soil subsamples collected between 2003 and 2005 (i.e. excluding the south-east survey, see Fig. 2.1)
2. An investigation of the bacterial community structure using denaturing gradient gel electrophoresis (DGGE) analysis. This has resulted in the genetic fingerprinting of 102 soil samples, extracted from the database using soil type and land use as selection criteria.

The use of composite soil samples, with associated stabilisation in buffer, was found to be a suitable method for microbial analysis and for generating highly reproducible and robust DGGE-based bacterial community structure profiles. This high throughput microbiological analytical approach facilitated for the first time in Ireland an investigation of the soil microbial community structure and its relationship with other soil properties.

While it is widely accepted that significant micro-scale variations in the distribution of microbial communities in soils occur, due, for example, to local crop-induced nutrient availability effects, local pH, oxygen and nutrient gradients, etc. (Torsvik *et al.*, 1996; McDougald *et al.*, 1998), these do not have a significant impact on the ability to generate reproducible, albeit low-resolution, bacterial community fingerprints from a variety of soils. The analysis of archived *National Soil Database* samples supported this view, as the reproducibility of DGGE profiles was excellent with all soils tested. While it is clear that the approach adopted here, which relied on universal primer sets, is not suitable for investigation of micro-scale variations, such as rhizosphere effects in soils, it was interesting to note that variation in microbial community structure was not an impediment to relating such wide area data together, and that bacterial community structure profiles have the potential, with further research, and a more extensive database, to be treated in a similar manner to geochemical data.

Land-use management has been shown by several studies to have an effect on both the chemical composition of the soil and the structure of the microbial community (McCaig *et al.*, 1999; Boddington and Dodd, 2000). This study also suggested an influence of crop type on bacterial community fingerprints from bulk soil. However, due to the limited number of samples analysed, and their geographical spread, this relationship could not be definitively established.

Based on the DGGE analysis, soil type and parent material appear to be the main factors determining the bacterial community composition. A relationship was evident between combinations of soil parent material and soil type and bacterial community structure in all of the soils analysed. These results are in line with recent research (e.g. Gelsomino *et al.*, 1999; Girvan *et al.*, 2003).

A feature of the microbial analysis for this data set was the occurrence of many common bands in the DGGE profiles, representing organisms from a limited number of dominant bacterial divisions (the Proteobacteria in particular) across all soils studied. These results indicate that the total bacterial community compositions are determined primarily by the underlying chemistry and physical structure of the soil rather than by the different management practices or cropping regimes. This suggests that future analysis could focus on the functional significance of these groups and could employ more specific primer sets.

3 Relevance to Policy

3.1 Thematic Strategy on Soil Protection

The *National Soil Database* provides Ireland with a robust and structured baseline of soil geochemical properties from which to assess future environmental issues and that can be used to compare future trends in the measured parameters. The *National Soil Database* will underpin Ireland's response to the recent adoption of the EC's *Thematic Strategy on Soil Protection*, which forms the basis for the proposed Soil Framework Directive.

The *Thematic Strategy on Soil Protection* requires securing and maintaining a comprehensive knowledge of soil quality and quantifies this by identifying eight threats to soil. Of these eight, five threats (soil erosion, organic matter decline, salinisation, compaction and landslides) will require risk assessment methodologies to identify areas at risk for each threat. The *National Soil Database* and Archive will provide baseline data for the risk assessments for some of these threats both in terms of potential locations for monitoring sites and the chemical and biological parameters to be considered. In addition, the Soil Framework Directive may require Ireland to set risk reduction targets for the areas at risk, establish programmes of measures to achieve them and monitor their progress. There is a further requirement to identify contaminated sites and establish a national remediation strategy aimed at reducing soil contamination and the potential associated risks. In the context of agricultural systems, limited national information exists on the effects of soil contamination with heavy metals or veterinary residues (such as antibiotics and hormones) on soil quality. The *National Soil Database* and Archive will provide a reference point in the identification of sites or areas contaminated with heavy metals.

3.2 Other European Directives and Policy

The *National Soil Database* will provide baseline soil geochemical and microbial data for current and future European environmental directives and policy. The Water Framework Directive (WFD) addresses eutrophication of waters and sets out a framework for the implementation of a comprehensive system for the management of water resources with the objective of maintaining a 'high status' of water quality where it exists, preventing any deterioration in the existing status of waters and achieving a 'good status' in all waters by 2015. It is interesting to note that a similarity exists between the *Thematic Strategy on Soil Protection* and the WFD in that both require risk assessment, programmes of measures and reduction targets with respect to the protection and long-term sustainability of soil and water resources. The Nitrates Regulations, which came into force in 2006 (S.I. 378 of 2006), established a series of nutrient management measures for agriculture to address eutrophication. Land-use change and CAP Reform that affect farming practices may also have an impact on soil processes and soil quality, and some of the specific requirements such as those relating to the Good Environmental and Agricultural Conditions (GAEC) of soils are directly relevant to soil protection and the threats to soil quality. The *National Soil Database* and Archive will provide an important baseline data set which will contribute to the establishment and evaluation of the national monitoring environmental programmes that will be used to assess the effectiveness of the measures.

3.3 Sewage Sludge Directive

The provisions of the Sewage Sludge Directive (86/278/EEC), which is transposed into national legislation by the Waste Management (Use of Sewage Sludge in Agriculture) Regulations 1998–2001, set threshold values for the concentration of heavy metals in soils receiving sewage sludge. The maximum Irish soil concentrations are as follows: Cd (1 mg/kg soil), Cu (50 mg/kg soil), Hg (1 mg/kg soil), Ni (30 mg/kg soil), Pb (50 mg/kg soil) and Zn (150 mg/kg soil). It is evident from this study that thresholds in some soils are exceeded for one or more of these elements. In the case of Hg, Cu, Pb and Zn, elevated levels were attributed to a varying combination of natural levels and anthropogenic effects including mining, industrial, land-use and urban activities. The situation with respect to Ni and Cd is more problematic. This study found that at a national level, 15% of soils exceeded the threshold value for Cd, while 23% of soils exceeded the threshold value for Ni. These elevated soil heavy metal concentrations are attributed to the composition of the soil parent material rather than to anthropogenic effects, except on a very local scale. For example, there appears to be a relationship between the Grey Brown Podzolic soils (and limestone parent material) and elevated Cd levels in Westmeath, north Tipperary, Roscommon and east Galway. The high percentage of soils exceeding the threshold level for Cd (1 mg/kg) in Dublin and neighbouring counties (see Figs 2.2 and 2.3) can therefore be explained by the dominating soil type and parent material.

The data and maps pertaining to these regulated metals will provide valuable insight for Irish policy makers involved in any future European discussions concerning proposed amendments to the soil metal limits already established in the Sewage Sludge Directive. In addition, they will provide Irish policy makers and managers with important data required when defining concentration limits for the spreading of organic waste.

3.4 Application to Soil Policy

The *National Soil Database* can provide added value in terms of policy. For example, it can provide policy guidance in relation to elements not covered by existing Statutory Instruments for the application of sewage sludge to agricultural land (see Section 3.3). Currently, no European or international agreement exists, on the basis of toxicological evaluation or even expert opinion, in relation to acceptable additions of unregulated elements that may be present in organic wastes. However, it is suggested that tentative limits may be proposed on the basis of the existing ranges reported for Irish soils in the database.

The availability of suitable methods for soil sampling and processing suggest that routine analysis of the microbial community structure of soils can be incorporated into soil protection and monitoring programmes.

3.5 Application to Future Soil Research

The *National Soil Database* and Archive have contributed to national and international soil research initiatives and will continue to do so. To date, two new EPA-funded projects (*Soil C: Measurement and Modelling of Soil Carbon Stocks and Stock Changes in Irish Soils* (2005-S-MS-26) and *Crébeo: A National Project on Soil Biodiversity (*2005-S-LS8-M1)) are directly linked to the *National Soil Database* and its Archive. Furthermore, the *National Soil Database* is linked to an international soils research project – *Environmental Assessment of Soil for Monitoring* (ENVASSO – Contract No. 022713). The main objectives of this European-funded project are to harmonise existing national data sets, to form a central reference point to assess current soil status and to ensure sustainable management in the future. There is considerable potential for further linkages with the large-scale EU-funded Framework Programme 7 (FP7).

The national soils nucleic acids archive has a potentially highly significant role in a wider research context. The cloning of large fragments of soil DNA into expression vectors has already been successfully used to mine the soil metagenome (or gene pool) for novel anti-microbial drugs, for enzymes for industrial applications, for compounds with anti-tumour activity, for antifouling agents and a host of other potentially valuable compounds. These studies are based on the analysis of DNA extracted from soil and the fact that such a diverse and comprehensive soils archive is available is (to our knowledge) unique in an international context, although many other countries are now developing large-scale metagenomic projects (e.g. the NERC marine metagenomic project in the UK). The bio-prospecting of the archive in projects will be expensive using the currently available methods, although potentially extremely rewarding. It is likely, however, that methods to access the soil metagenome will become less expensive and more rapid in the near future, which will encourage more interest in this field. Given the potential socio–economic value of the archive, both European projects and national programmes are likely to seek access to the archive for research purposes in the near future.

The *National Soil Database* and Archive have provided an important contribution to the development of national soils geochemical and biological information. However, this contribution to existing soils information highlights some important information gaps. No soil physical measurements were conducted as part of this project. It would be of considerable scientific value if the soil physical data (bulk density and particle size analyses) were measured at a range of soil depths for a representative number of the sampling sites used in this study. The soil samples collected should be incorporated into both soil archives as appropriate. As well as being analysed for the same suite of chemicals, these samples should also be analysed for a range of ‘available’ and/or biologically active elements (e.g. Cu, Se, Zn, Mo, Mn and Co).

The availability of suitable methods for soil sampling and processing suggest that routine analysis of the microbial community structure of soils should be included in the new research. The effect of the soil type and parent material on the soil's microbial community should be evaluated systematically taking into account other soil-forming factors such as climate, land use, and topography.

Consideration should be given to analysing the samples collected for a range of environmentally important organic chemicals. The potential impact of these contaminants (including those of agricultural and sewage sludge origin) and their long-term effects on soil quality indicators are worthy of a new soils research initiative.

The geostatistical analyses will provide a basis for future soil geochemical risk assessment and risk management. It is recommended, therefore, that the geochemical database generated be subject to interrogation with the objectives of:

(a) modelling of soil geochemical properties and their relationships with other parameters (e.g. road network and DEM)

(b) hotspot identification and further site investigation to determine the relevance to environmental, agronomic and health issues, and

(c) uncertainty analyses of the data for better quantification of the quality of the spatial maps.

In addition, further interrogation of the database will aid the integration with the database for Northern Ireland and will further aid the interpretation of spatial patterns which are truncated at the border and were derived using different formats.

The re-sampling of the south-east region of Ireland, to complete the nucleic acids archive is recommended, as the fundamental value of the archive with respect specifically to soil science is extremely important.

As currently constituted, access to the nucleic acids archive is severely limited due to potentially irreversible loss of material arising from thawing and re-freezing on the quality of the DNA. It is recommended that an additional 10 copies of the archive be created and stored using a more accessible system to provide adequate coverage of future national research needs.

Further research to investigate relationships between the individual chemical parameters and the microbial data would help to understand the driving forces that regulate the bacterial community composition in soil.

It is recommended that a TELLUS-type project such as that in Northern Ireland (http://www.tellus.detini.gov.uk) be undertaken in the Republic. The *TELLUS Programme* is using state-of-the-art airborne geophysical surveying techniques, which are complemented with ground geochemical surveys. On completion, the *TELLUS Programme* and the *Soil Geochemical Atlas of Northern Ireland* will provide an integrated baseline survey of Northern Ireland. These data will have relevance for agro–economics, environmental status (e.g. 'extreme' concentrations), and aggregate resource management.

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Acronyms and Notation

DEM	Digital Elevation Model
DGGE	Denaturing Gradient Gel Electrophoresis
EC	European Commission
EPA	Environmental Protection Agency (of Ireland)
ERTDI	Environmental Research, Technological Development and Innovation
NUI	National University of Ireland
RTDI	Research, Technological Development and Innovation

Appendix 1 List of Parameters Measured with Associated Abbreviations

Al	aluminium	**Nb**	niobium
As	arsenic	**Ni**	nickel
Avail_K	available potassium	**P**	phosphorus
Avail_Mg	available magnesium	**pH**	soil acidity
Avail_P	available phosphorus	**Pb**	lead
Ba	barium	**Rb**	rubidium
Ca	calcium	**S**	sulphur
Cd	cadmium	**Sb**	antimony
Ce	cerium	**Sc**	scandium
Co	cobalt	**Se**	selenium
Cr	chromium	**SOC**	soil organic carbon
Cu	copper	**Sn**	tin
Fe	iron	**Sr**	strontium
Ga	gallium	**Ta**	tantalum
Ge	germanium	**Th**	thorium
Hg	mercury	**Ti**	titanium
K	potassium	**Tl**	thallium
La	lanthanum	**U**	uranium
Li	lithium	**V**	vanadium
Mg	magnesium	**W**	tungsten
Mn	manganese	**Y**	yttrium
Mo	molybdenum	**Zn**	zinc
Na	sodium		

Appendix 2 Summary Statistics for the Measured Parameters in all Samples

Table A2.1. n = 1,310 (all samples, organic and mineral soils); n<DL: number of samples below detection. Units are reported in mg/kg except for available (Avail_) elements (Avail_P, Avail_K, Avail_Mg) in mg/l; soil organic carbon (SOC), Al, Ca, Fe, K, Mg, Na, S, P in %; pH in pH unit.

	n<DL	Min	5%	10%	25%	Median	75%	90%	95%	98%	Max
pH	0	3.2	3.7	3.9	4.6	5.3	6.1	6.6	7.0	7.2	7.7
SOC	0	1.40	2.86	3.56	4.92	7.00	14.26	40.82	48.01	50.81	55.80
Avail_P	0	0.56	2.32	2.98	4.32	7.05	12.47	20.48	30.52	43.75	316.41
Avail_K	0	4.66	45.52	55.94	82.51	124.01	181.95	266.55	312.77	386.79	949.23
Avail_Mg	0	13.49	71.11	89.38	127.51	186.13	276.28	404.65	485.92	559.39	1001.97
Al	0	0.06	0.20	0.56	2.21	3.48	4.89	6.03	6.65	7.38	9.74
As	1	<0.2	1.43	2.09	4.41	7.25	10.66	15.97	21.90	33.38	122.70
Ba	0	6.6	21.3	56.0	141.7	230.2	305.6	387.3	454.5	545.5	1296.9
Ca	0	0.026	0.102	0.149	0.225	0.358	0.613	1.495	2.591	4.900	26.628
Cd	1	<0.02	0.111	0.150	0.212	0.326	0.640	1.253	1.652	2.267	15.148
Ce	0	0.6	1.9	5.7	22.3	34.8	46.6	56.3	62.3	70.2	136.4
Co	0	0.2	0.5	0.9	3.0	6.2	9.7	13.0	15.1	19.0	58.7
Cr	44	<2	2.6	6.1	25.2	42.6	58.6	74.9	86.8	99.6	221.7
Cu	0	1.1	3.5	4.8	9.5	16.2	24.7	35.1	45.9	64.1	272.4
Fe	0	0.05	0.20	0.44	1.14	1.87	2.59	3.31	3.80	4.39	19.43
Ga	10	<0.1	0.60	1.53	5.66	8.46	12.47	15.76	17.76	20.42	25.16
Ge	72	<0.1	<0.1	0.25	0.86	1.26	1.55	1.82	2.00	2.24	2.58
Hg	11	<0.02	0.022	0.035	0.058	0.086	0.134	0.185	0.237	0.295	3.450
K	0	0.02	0.08	0.17	0.59	0.98	1.33	1.68	1.85	2.13	2.64
La	12	<0.5	1.1	3.4	12.7	20.0	25.4	30.2	33.1	36.5	75.2
Li	137	<2	<2	<2	10.7	19.7	29.1	41.2	54.2	72.1	165.7
Mg	0	0.038	0.107	0.137	0.196	0.298	0.429	0.645	0.824	1.062	2.096
Mn	0	7	25	59	190	462	844	1355	1903	3173	21077
Mo	0	0.07	0.32	0.42	0.61	0.91	1.37	2.17	3.29	4.77	21.14
Na	0	0.015	0.053	0.080	0.205	0.338	0.545	0.860	1.091	1.354	2.254
Nb	0	0.06	0.34	1.08	4.42	6.83	8.95	10.64	12.01	14.76	38.88
Ni	0	0.8	1.9	2.8	9.2	17.5	28.6	41.6	50.0	58.6	176.0
P	0	0.007	0.036	0.048	0.075	0.105	0.136	0.174	0.202	0.242	0.493
Pb	0	1.1	11.7	13.6	18.2	24.8	33.5	48.0	61.9	86.2	2634.7
Rb	0	0.6	2.2	5.8	29.8	53.5	75.7	100.5	117.5	136.8	222.0
S	0	0.011	0.035	0.042	0.055	0.073	0.127	0.252	0.319	0.399	0.701
Sb	30	<0.05	0.10	0.18	0.31	0.53	0.85	1.24	1.54	2.02	5.29
Sc	1	<0.1	0.36	0.86	3.34	5.85	8.37	10.95	12.33	13.79	17.11
Se	0	0.08	0.34	0.40	0.51	0.74	1.14	1.94	2.67	5.12	17.44
Sn	10	<0.2	0.54	0.73	1.12	1.68	2.34	3.35	4.72	6.79	17.84
Sr	0	9.2	20.7	24.8	32.5	49.7	70.1	93.5	115.0	162.7	1252.5
Ta	129	<0.05	<0.05	0.05	0.27	0.45	0.61	0.74	0.85	1.07	2.71
Th	6	<0.1	0.25	0.73	2.91	4.65	6.28	7.69	8.50	9.42	11.15
Ti	0	39	125	345	1355	2133	2851	3401	3773	4468	8704
Tl	72	<0.02	<0.02	0.079	0.292	0.430	0.568	0.715	0.818	1.008	2.664
U	20	<0.1	0.20	0.53	1.48	1.96	2.48	3.21	4.74	7.36	64.19
V	14	<2	3.9	9.4	30.8	52.2	74.2	94.8	104.8	123.6	240.3
W	132	<0.1	<0.1	<0.1	0.36	0.59	0.85	1.10	1.31	1.80	7.72
Y	0	0.22	0.73	1.82	6.94	10.33	14.46	20.31	24.04	30.61	111.78
Zn	0	3.6	15.9	21.4	35.6	62.6	90.8	126.1	144.7	178.9	1384.4

Appendix 3 Data Point and Spatial Distribution Maps for Selected Elements

The maps for the trace elements on the following pages have been included in this appendix because of a particular interest in these elements from a farming and policy point of view. The elements Cr, Cu, Hg, Ni, Pb and Zn are interesting from a toxicity point of view and with regard to the sewage sludge directive. Co, Mo and Se are important trace elements for agriculture. Note that although the ranges for all the included elements vary, all the included maps show concentration ranges (for the data point maps) or levels (for the spatial distribution maps) in mg/kg.

When using these maps as a reference, it is important to remember that, in most cases, the concentrations are a result of background concentrations in the parent material or the result of soil-forming processes such as leaching, and only in rare cases the result of anthropogenic activity. It is also important to treat the concentrations on the spatial distribution maps with caution, as these are interpolated values and do not necessarily reflect the exact concentration at a given location. The data point maps do, however, give the concentration range into which the measured sample from that location fell.

Explanations for the distribution of the elements, in as far as this is understood, can be found to a large extent in the main text or in the full *National Soil Database* report (Fay *et al.*, 2007).

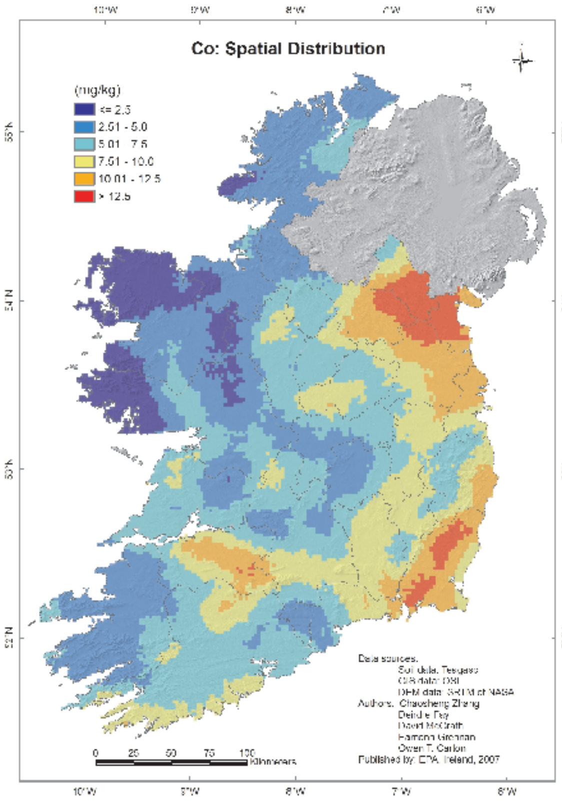

Figure A3.1. Cobalt spatial distribution.

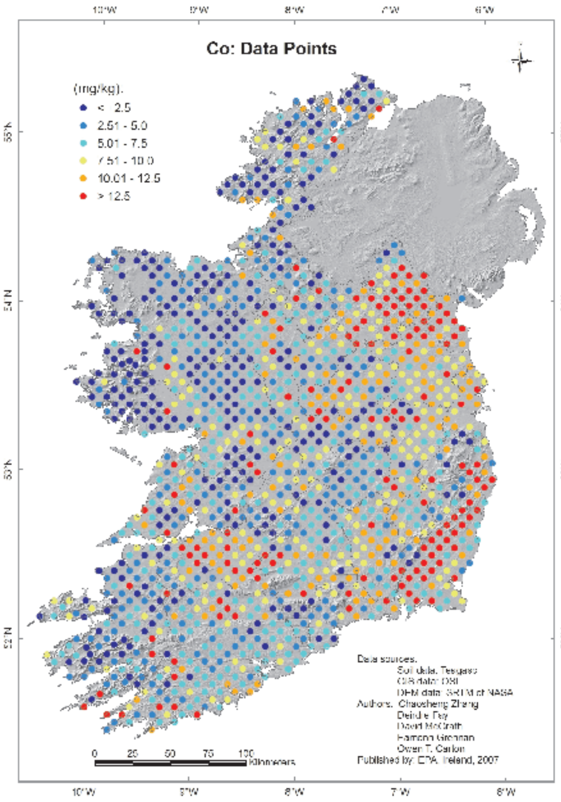

Figure A3.2. Cobalt data points.

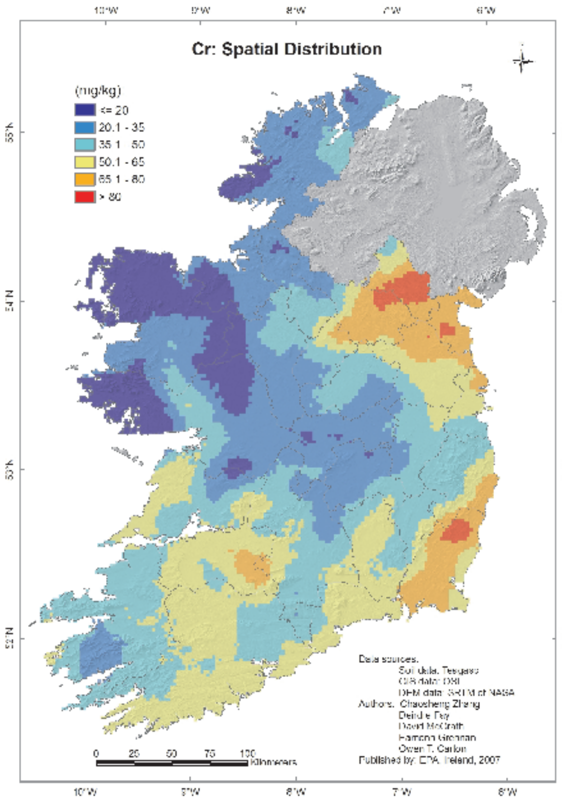

Figure A3.3. Chromium spatial distribution.

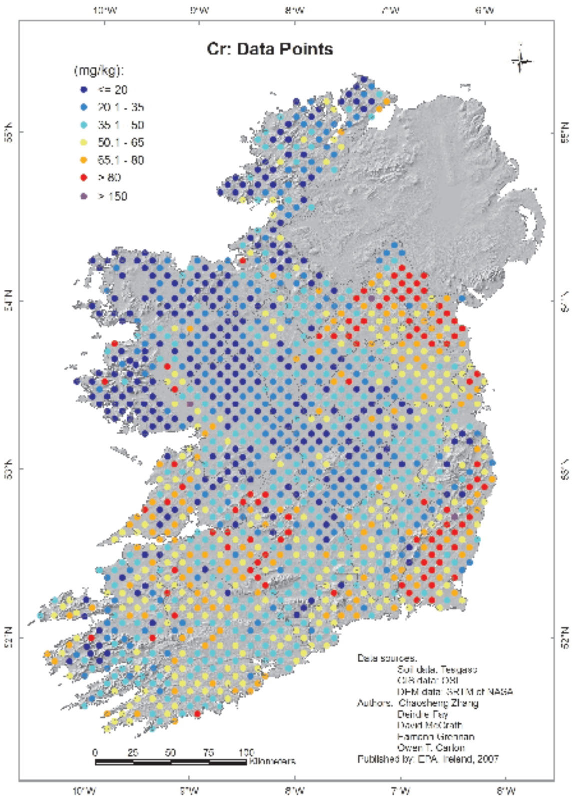

Figure A3.4. Chromium data points.

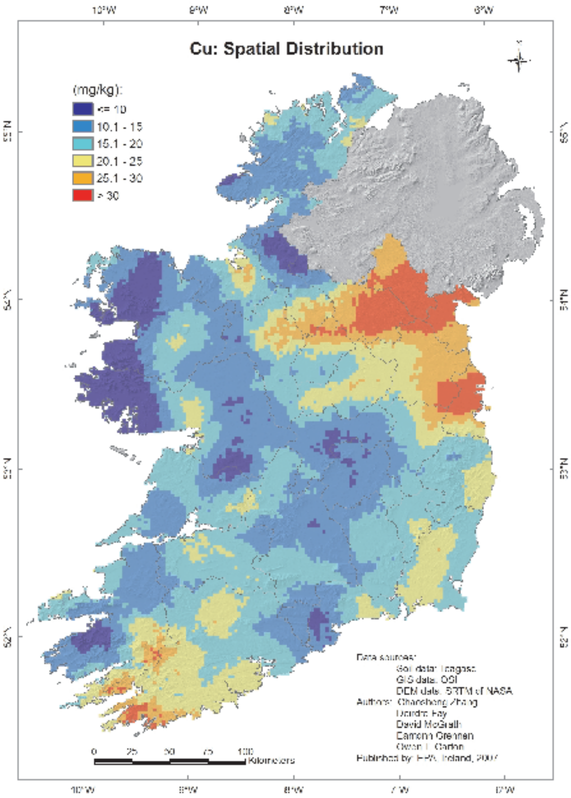

Figure A3.5. Copper spatial distribution.

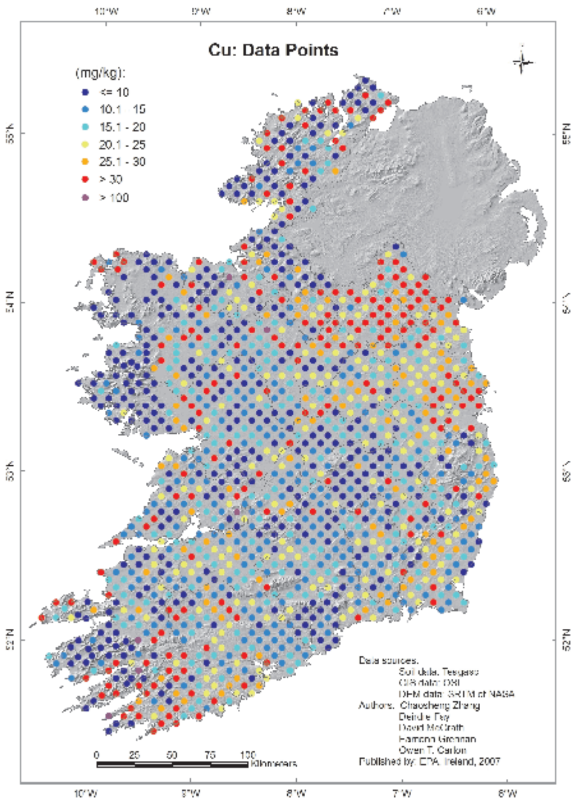

Figure A3.6. Copper data points.

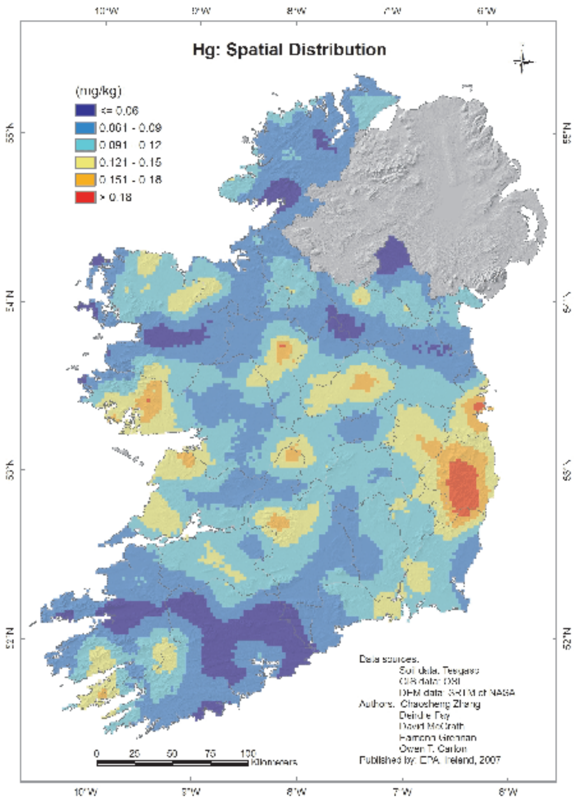

Figure A3.7. Mercury spatial distribution.

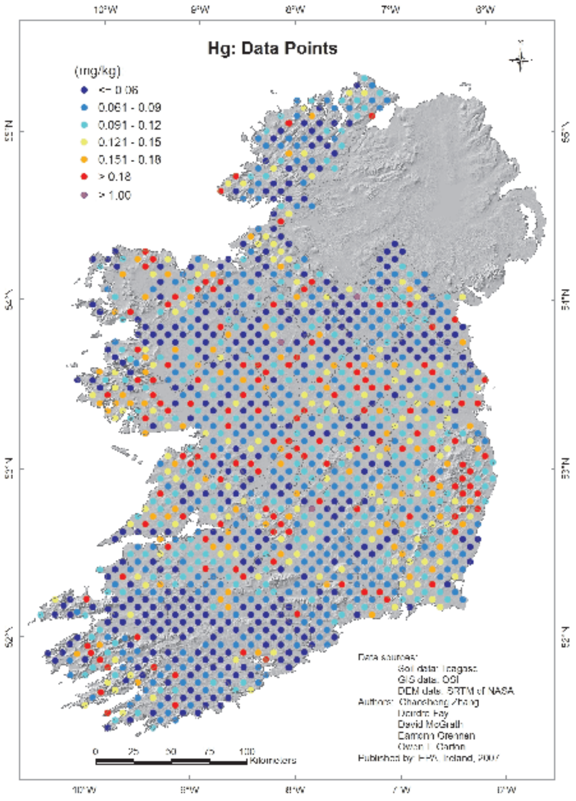

Figure A3.8. Mercury data points.

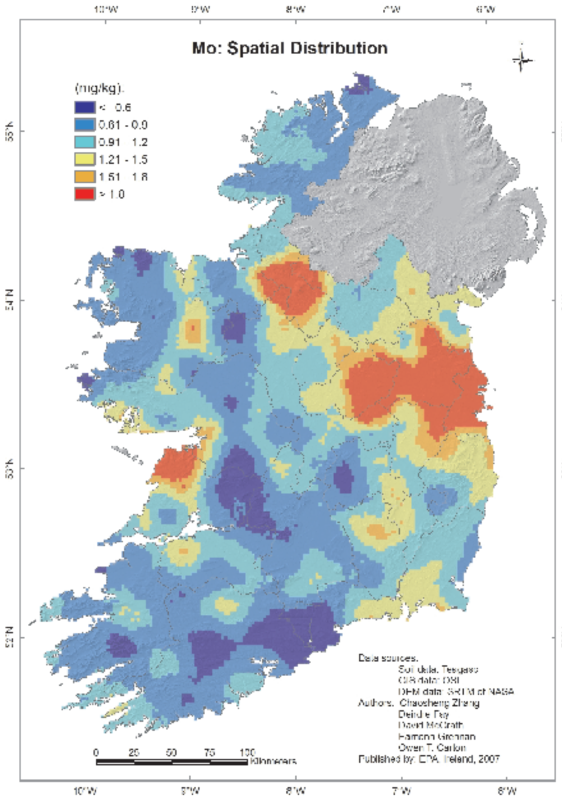

Figure A3.9. Molybdenum spatial distribution.

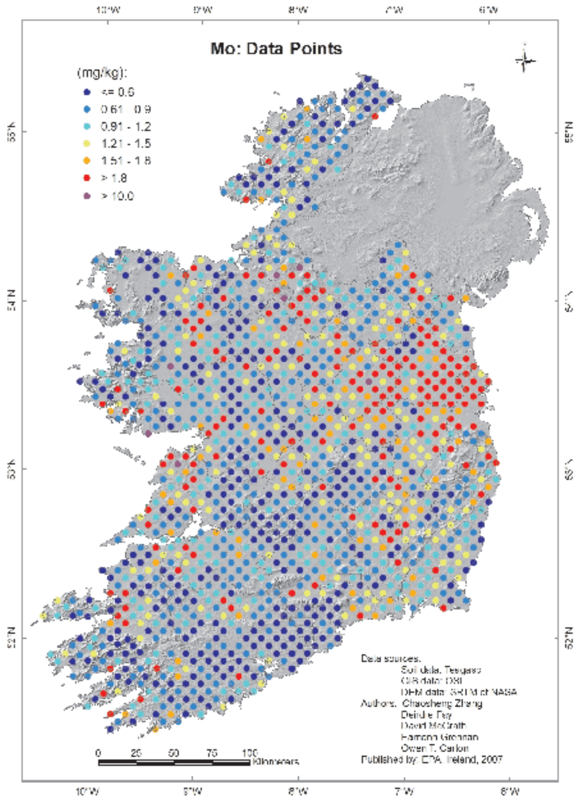

Figure A3.10. Molybdenum data points.

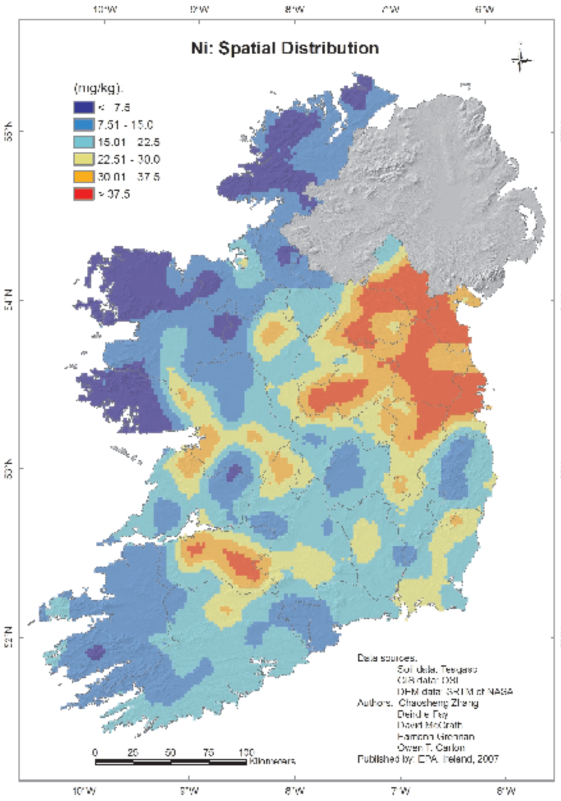

Figure A3.11. Nickel spatial distribution.

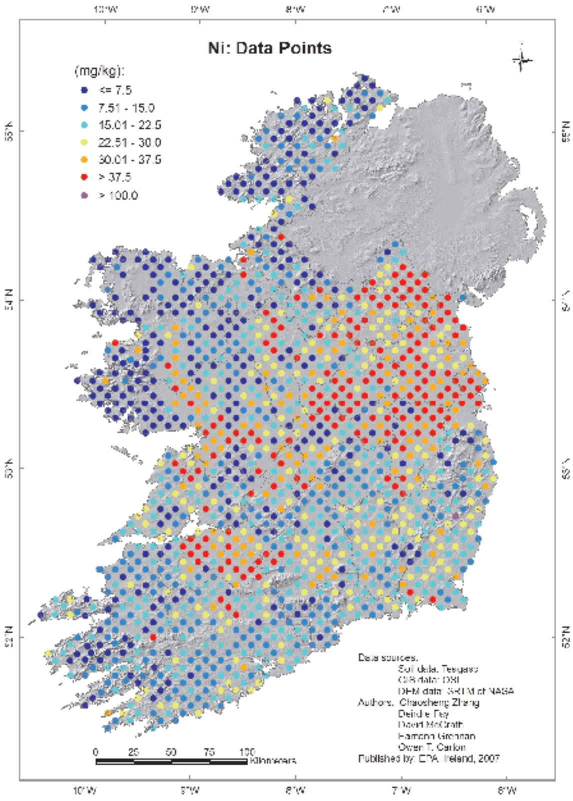

Figure A3.12. Nickel data points.

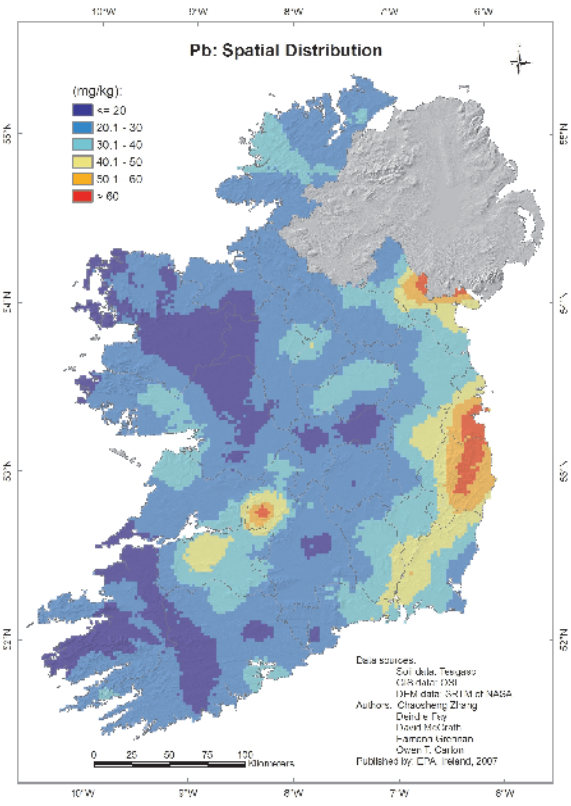

Figure A3.13. Lead spatial distribution.

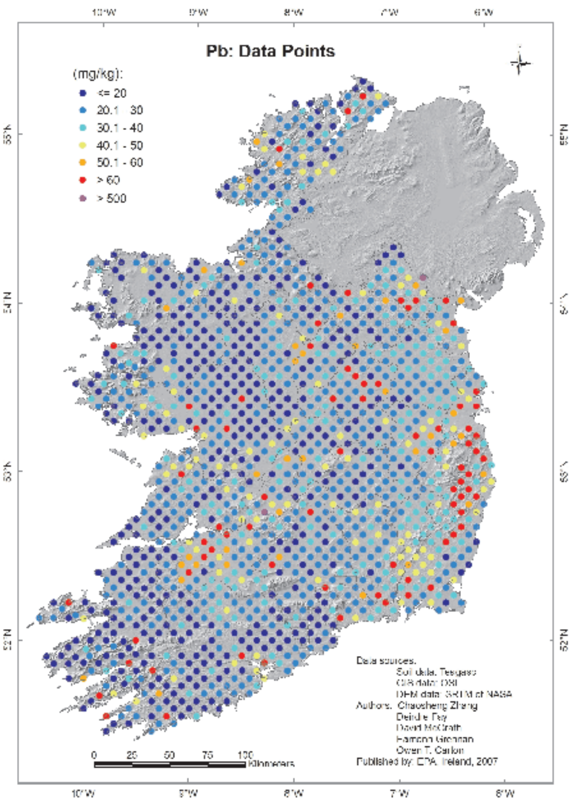

Figure A3.14. Lead data points.

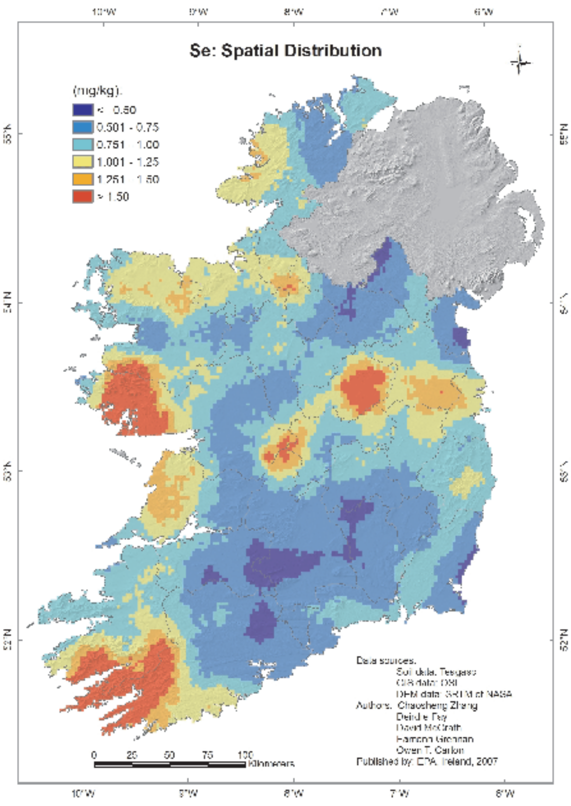

Figure A3.15. Selenium spatial distribution.

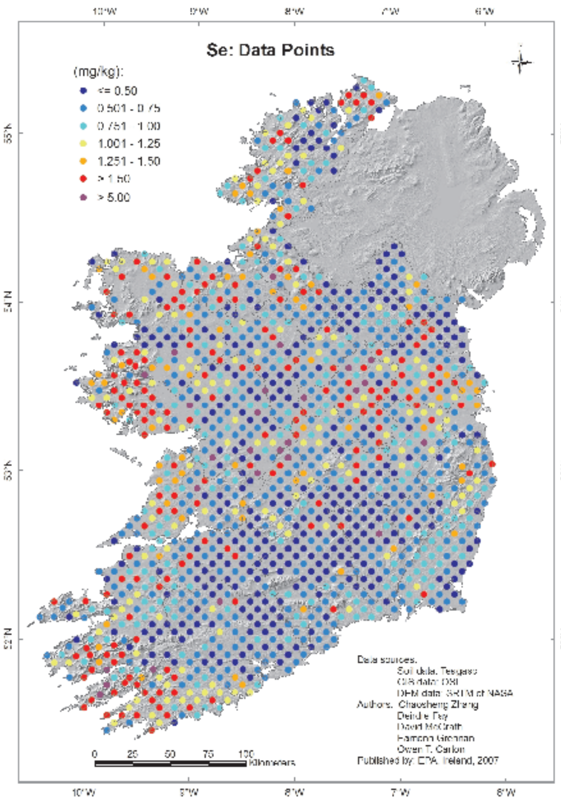

Figure A3.16. Selenium data points.

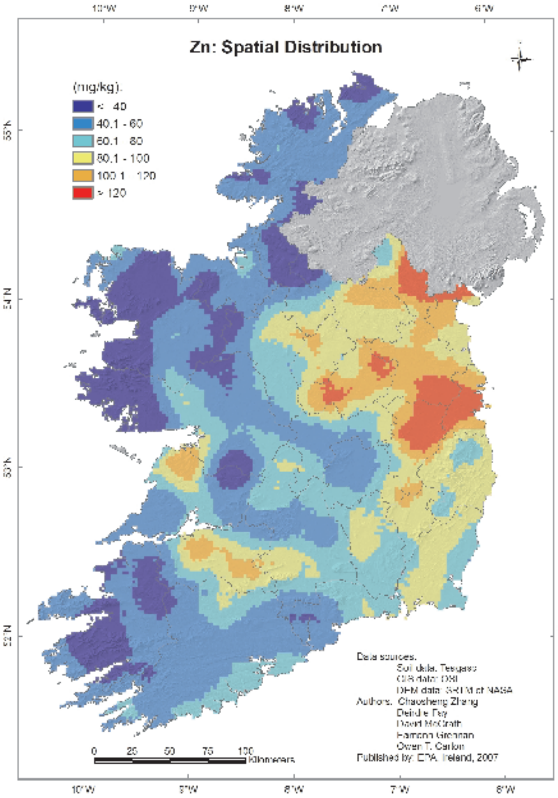

Figure A3.17. Zinc spatial distribution.

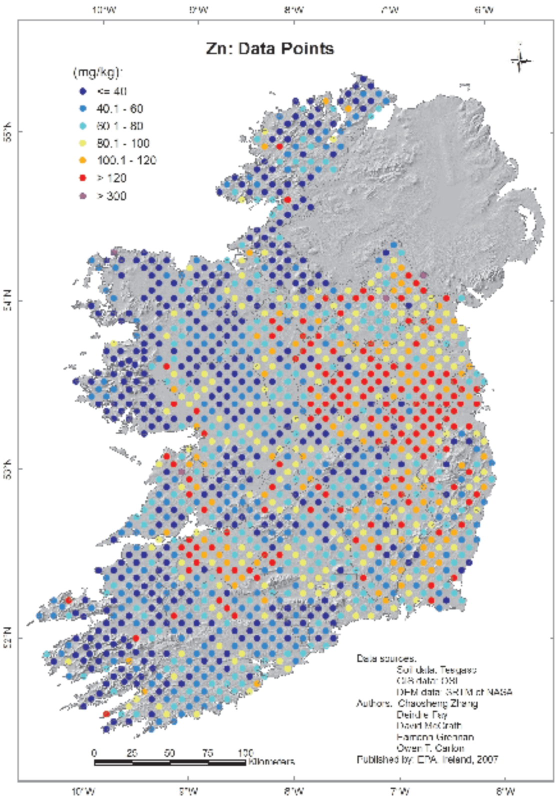

Figure A3.18. Zinc data points.