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Inorganic soil geochemical baseline data for the urban area of the Belfast Metropolitan Area, Northern Ireland.

Geological Survey of Northern Ireland.

Open Report OR/08/021

BRITISH GEOLOGICAL SURVEY

CHEMICAL AND BIOLOGICAL HAZARDS PROGRAMME

OPEN REPORT OR/08/021

Inorganic soil geochemical baseline data for the urban area of the Belfast Metropolitan Area, Northern Ireland.

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Foreword

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¹ **Tellus** is a Latin word meaning "earth". In mythology, it has been used as an alternative name for [Terra](#), the Roman Earth Mother goddess, and is therefore the equivalent of the Greek goddess Gaia(Wikipedia).

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Summary

This report presents the results of an urban soil geochemical survey of the Belfast Metropolitan Area (BMAP) carried out by the Geological Survey of Northern Ireland (GSNI) and British Geological Survey (BGS) during the summer of 2006, as part of the Tellus project.

The Tellus urban data provide an overview of the urban geochemical signature and, because they are collected alongside a Tellus national rural baseline dataset, can be readily compared with soils in the both rural hinterland and regionally to assess the extent of urban geochemical characteristics.

The concentrations and distribution of potentially harmful elements (PHE) are of interest under current environmental legislation and for urban planning purposes. Such elements are influenced by urbanisation and industrial land uses.

The urban surveying was based upon the collection of samples on a systematic 500 m grid. Soils were sampled from 960 sites, at a density of four per km² across the built-up area (as is the protocol for G-BASE/G-SUE urban surveys. Samples were collected from open ground as close as possible to the centre of each 500 m grid cell (Johnson, 2005; Smyth, 2008)). At each site, two five-hole composite samples are collected: a surface ‘A’ soil (0.05 – 0.2 m) and subsurface ‘S’ soil (0.35 – 0.5 m).

This report summarises some of the geochemical results and gives interpretations within the geological and urban context. It highlights those sites where stated soil guideline values (SGVs) are exceeded.

Table 1 **Summary of the BMAP inorganic geochemical survey area**

Date Sampled:	Summer 2006
	240 km ²
Area Sampled:	BNG Easting min / max: 322580 / 353722
	BNG Northing min / max: 362170 / 390806
Sample Density:	1 per 0.25 km ²
Number of Samples:	960 surface 'A' (0.05 – 0.20 m) & 960 profile 'S' (0.35 – 0.50 m) soils
Elements determined by XRFS	Al ₂ O ₃ , CaO, Fe ₂ O ₃ , K ₂ O, MgO, MnO, Na ₂ O, P ₂ O ₅ , SiO ₂ , SO ₃ , TiO ₂ , Ag, As, Ba, Bi, Br, Cd, Ce, Cl, Co, Cr, Cs, Cu, Ga, Ge, Hf, I, In, La, Mo, Nb, Nd, Ni, Pb, Rb, S, Sb, Sc, Se, Sm, Sn, Sr, Ta, Te, Th, Tl, U, V, W, Y, Yb, Zn, Zr

XRFS = X-Ray Fluorescence Spectrometry

.

Introduction

This report summarises the sampling methodology and results of an inorganic soil geochemical survey of Belfast Metropolitan urban area, as defined by NISRA² (2004), with the exception of the small detached areas of Groomsport, Crawfordsburn, Seahill and Helen's Bay. The city of Belfast is situated on Northern Ireland's eastern coast and is located at the western end of Belfast Lough and at the mouth of the River Lagan (Figure 1).

The survey was undertaken by the Geological Survey of Northern Ireland (GSNI) during 2006 as part of the Tellus project. As a sub-project of Tellus, a total of 960 sites were sampled within the urban area, covering a total area of 240 sq. km, comprising Belfast, Carrickfergus, Carryduff and Bangor.

The Tellus project undertook a systematic regional geochemical survey of soils, stream sediments and stream waters of Northern Ireland at a sample density in rural areas of 1 per 1.5 – 2 km². The data provide information on the surface chemical environment, which can be used to define environmental baselines and the extent of surface contamination. The distribution of chemical elements in the environment is of concern because although many are essential to life, several including As, Cd, Cr, Ni and Pb are potentially harmful to plants and animals in high doses. Concentrations at any location are often controlled by factors such as geology, vegetation, soil forming processes and climate. In addition to natural sources of these elements, environmental concentrations can be enhanced by anthropogenic activities such as mining, industrialisation, urbanisation and waste disposal. The Tellus geochemical data have a wide range of applications, including the assessment of risks to human health, with respect to potentially harmful elements (PHE) through environmental exposure.

The concentrations of many PHE are enhanced in urban environments as a result of atmospheric and terrestrial contamination and the nature of urban ground, which is often disturbed and in-filled and perhaps bears little relation to the soils, bedrock and superficial cover of the surrounding rural hinterland.

The distributions of 49 major and trace elements including several PHE in the surface environment of Belfast are presented with a selection of elements being described in this report in relation to the underlying geology, and are compared to the typical rural background concentrations obtained from the Tellus regional soil data sets. Results are discussed and related to local, present and historical land uses and other site conditions.

² Northern Ireland Statistics and Research Agency. <http://www.nisra.gov.uk/>

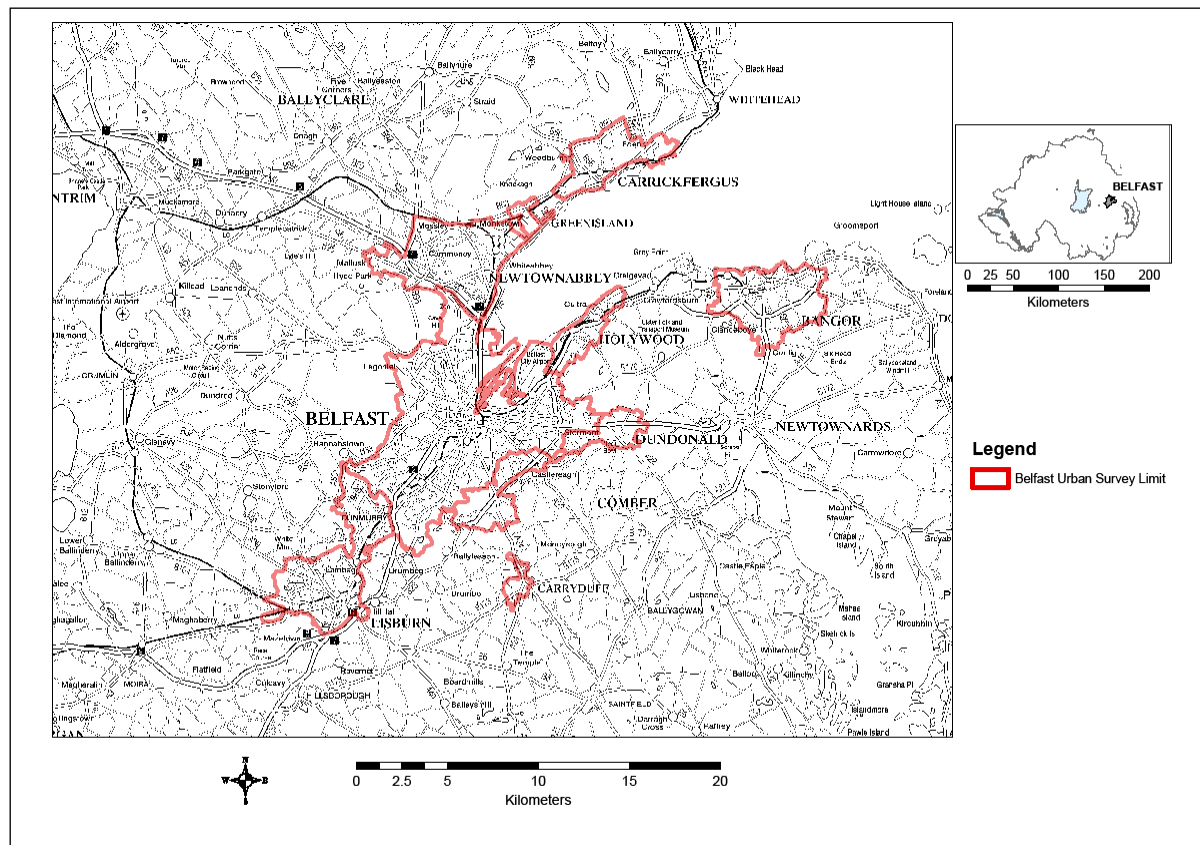


Figure 1. Location map of Belfast (BMAP) and surrounding towns in Northern Ireland

Study area: Belfast

1.1 AREA SAMPLED

An area of approximately 240 km² was surveyed during the summer of 2006, in which a total of 960 surface soils (5 - 20 cm depth) and 960 profile soils (35 - 50 cm depth) were sampled. This extends from British National Grid (BNG) references 322580m east to 353722m east and from 362170m north to 390806m north (Table 1). The survey area is shown in **Figure 2**.

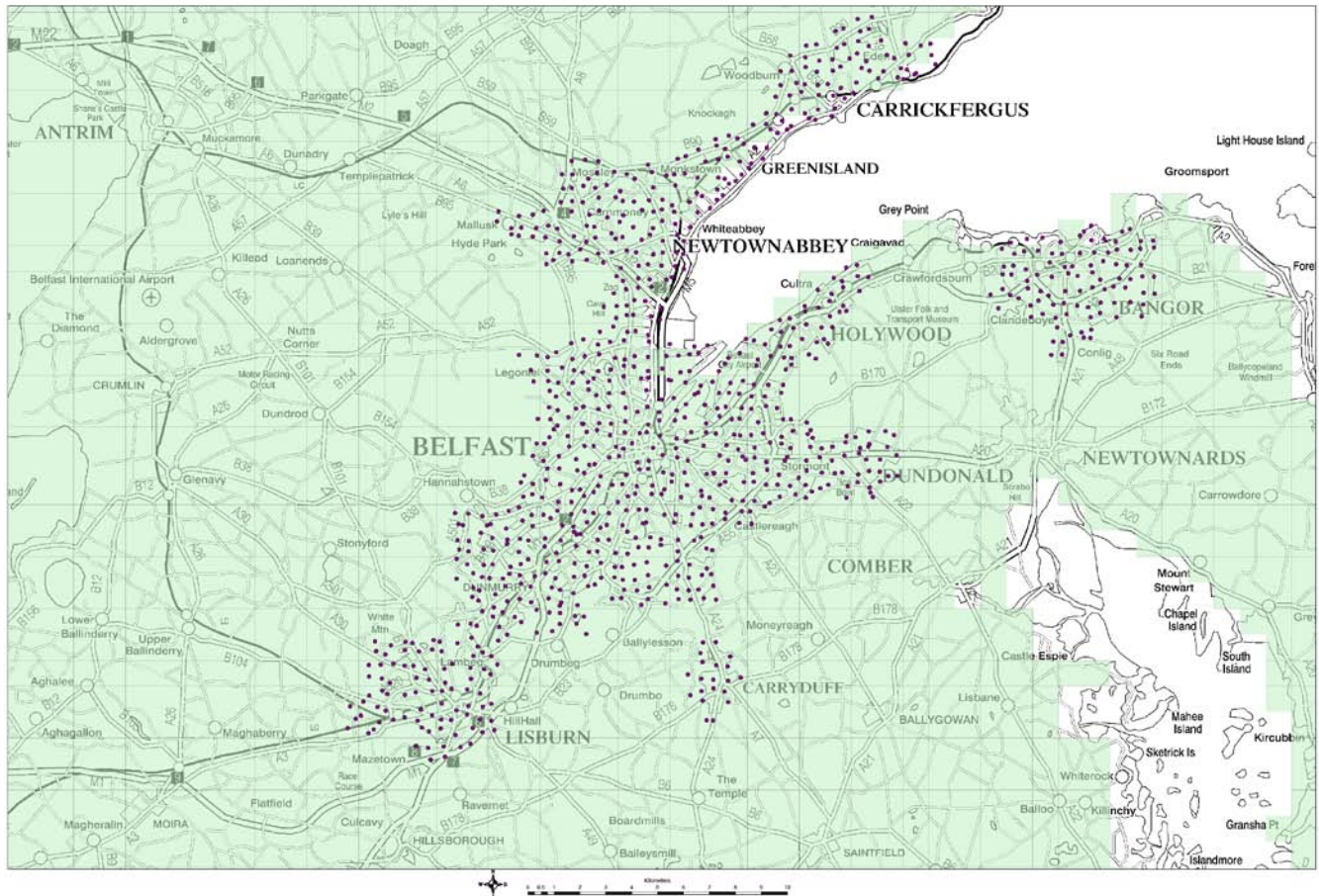


Figure 2. Map of the BMAP urban area and sample locations (denoted by purple dots)

1.2 HISTORY AND INDUSTRY

Belfast (from the Irish ‘Béal Firste’, meaning “the sandy ford at the river mouth”) is the capital City of Northern Ireland. It is situated on the eastern coast and is flanked to the north and south by a series of hills. It is located at the western end of Belfast Lough and at the mouth of the River Lagan, making it an ideal location for the shipbuilding industry for which it was so famous (Wikipedia, 2008). Belfast is the largest city within Northern Ireland, the population of the Belfast Metropolitan area being just under 580,000 and is under the jurisdiction of Belfast City Council.

During the 18th and 19th centuries Belfast became an important commercial and industrial centre. Industries based here included rope-making, tobacco, linen, heavy engineering and shipbuilding. Towards the end of the 19th century the Harland and Wolff shipyards became one of the largest shipbuilders in the world, which at times employed up to 35,000 workers (BBC, 2002), and is most famous for building the ill-fated RMS ‘Titanic’ in 1912. The gantry cranes of Harland and Wolff, shown in Figure 3, have become one of the city’s best known landmarks.



Figure 3. The famous Harland and Wolff gantry cranes, Belfast

Belfast has been the capital of Northern Ireland since the partition of Ireland in 1920 (Wikipedia, 2008), and has been the scene of much sectarian conflict between the mainly Roman Catholic nationalist and mainly pro-Unionist Protestant populations. This was exacerbated as migrants came to Belfast from Ireland, Scotland and England, but particularly from rural Ulster where sectarian tensions ran deep. The “Troubles” ran from c. 1969 to the late 1990s and bombings and street violence in Belfast were all too commonplace. Coincident with this period was a major decline in the city’s industrial base, with the closure of many factories and mills, a sharp reduction in shipbuilding and rising unemployment.

In recent years, as the political situation has stabilised, the city in general has seen significant redevelopment and investment. The formation of the Laganside agreement in 1989 heralded the start of the regeneration of the River Lagan and its surrounding areas. Other areas that have been regenerated are the Titanic Quarter, Cathedral Quarter and Victoria Square.

1.3 SOLID AND SUPERFICIAL GEOLOGY - A BRIEF OUTLINE

This account of the solid and superficial geology of the Belfast area is taken from the 1:250k GSNI Solid (GSNI, 1997) and Drift (GSNI, 1991) editions of the Geological Map of Northern Ireland, and a much more detailed description may be found in Mitchell (2004). Below are solid and superficial deposit maps for the Belfast area (Figure 4 and Figure 5 respectively).

The central part of Belfast is underlain by Triassic sedimentary rocks of the Sherwood Sandstone and Mercia Mudstone Groups. The outcrop of these units extends to the southwest of Belfast underlying Lisburn and to the northeast of the city beneath the coastal towns of Whiteabbey, Greenisland and Carrickfergus. The Sherwood Sandstone Group comprises mainly of pink to reddish brown sandstones and silty sandstones, while the Mercia Mudstone Group is formed predominantly of calcareous red-brown mudstone and thin siltstones. Sandstones of the Sherwood Sandstone Group are important aquifers and water is abstracted from them for public supply in the Lagan Valley and around Newtownards.

Triassic rocks are separated from the basaltic hills to the northwest of the city by a thin NE-SW trending outcrop of latest-Triassic to early Jurassic mudstones of the Penarth Group and Waterloo Mudstone Formation and Cretaceous rocks comprising the Hibernian Greensands and Ulster White Limestone formations (the latter being the equivalent of the Chalk in England). The sharp change in topography marked by the hills to the northwest of Belfast city centre indicates the outcrop of olivine tholeiite lavas of Palaeogene age of the Lower Basalt Formation of the Antrim Lava Group, and marks the edge of the Antrim Plateau, a large area of basaltic rocks underlying much of counties of Antrim and Londonderry.

The Castlereagh Hills and much of the suburban area of south-east Belfast extending into North Down is underlain by older, Lower Palaeozoic turbiditic sedimentary rocks of the Leadhills Supergroup and Gala Group. The former, which outcrops beneath Holywood and Bangor, is lithologically diverse including spilitic lavas, black mudstones and sandstones. The Conlig-Whitespots mine, located between Newtownards and Bangor, and hosted by greywackes of the Gala Group was one of major lead mines in the UK in the 19th Century; the main ore minerals were galena, sphalerite and chalcopryrite. On the southeastern edge of Belfast and Lisburn, Permian sandstones overlie the Lower Palaeozoic turbidites, and a narrow outcrop of early Carboniferous rocks underlies part of the Holywood district.

The solid bedrock is overlain by till deposits over much of the area, the principal type being a diamicton with both local Irish and more distant Scottish components. Fluvio-glacial sands and gravels and more recently deposited river alluvium are locally present, particularly in the Lagan Valley. Glacial features such as drumlins and eskers are widespread over the whole of Northern Ireland. Within the Belfast area, raised Holocene estuarine shelly grey clay deposits known locally as 'sleechee' also occur, and raised beach deposits (sands and gravels) are present between Newtownabbey and Carrickfergus on the north side of Belfast Lough.

Anthropogenic 'Made ground' and landfill wastes are the most recent deposits.

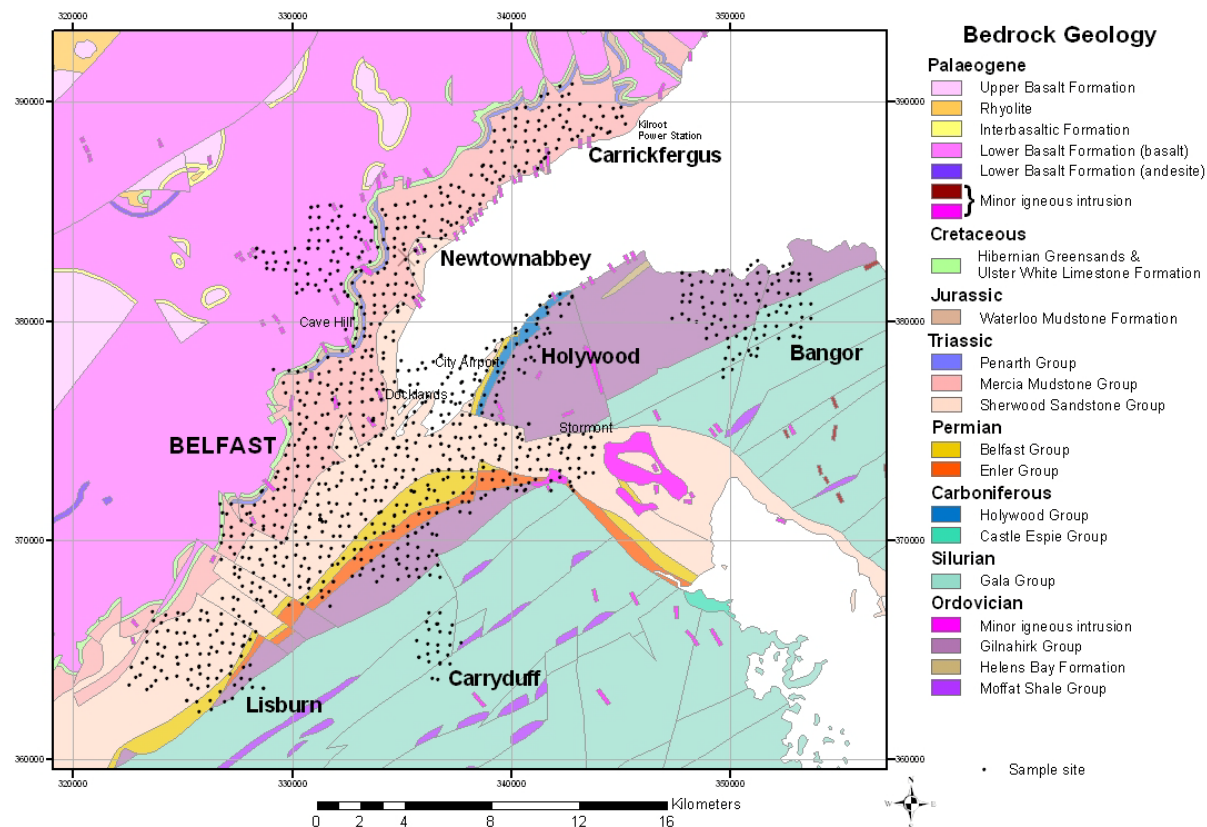


Figure 4. Bedrock geology map of BMAP

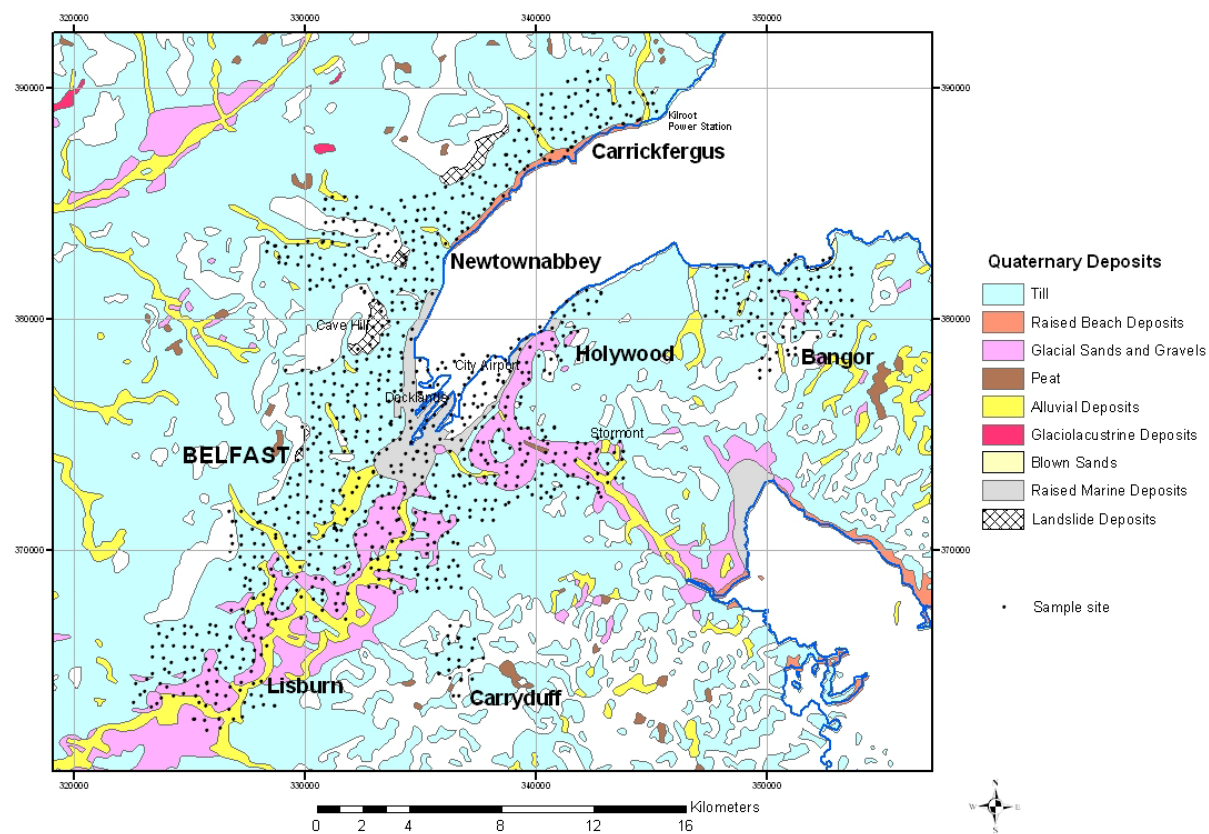


Figure 5. Superficial deposits map of BMAP

1.4 SOIL TYPE

The Department of Agriculture for Northern Ireland (DANI) undertook a soil survey of Northern Ireland between 1987 and 1995 (Cruickshank, 1997); however, urban and industrial areas were not surveyed for soil type. Therefore, no information exists on soil type for the main urban area of Belfast although limited data are available for the outskirts. The predominantly soil types for the north of Belfast are surface water gleys, with smaller area of shallow/ferric brown earths and ground water gleys. To the south of Belfast the main soil types are surface water gleys, with shallow brown earths and brown rankers. To the south west of Lisburn, ground water gleys occur.

Information on soil characteristics including soil texture, colour, clast lithologies, moisture and organic content, are routinely recorded in the field. The soil texture information is presented in Figure 6 and

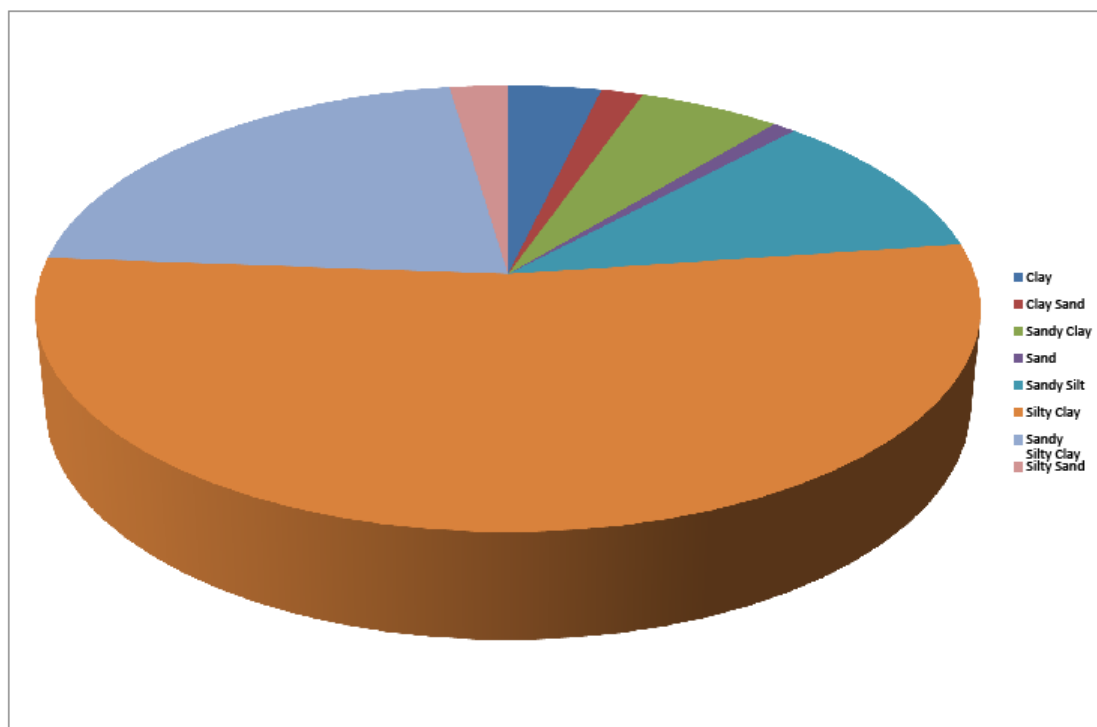


Figure 7. Around the Belfast area the majority of soils are silty-clay or silty in texture. The north of the city has the largest clusters of silty-clay soils, which correlate with the Triassic Mercia Mudstone Group and the Antrim Basalts; and also with the surface gleys recorded by the soil survey. The silty and sandy-silt soils correspond with the Triassic Sherwood Sandstone Group and also with the shallow and ferric brown earths of the soil survey. The soils described as being sandy in texture occur within the city centre, which possibly occur over areas of made ground, although these are not mapped.

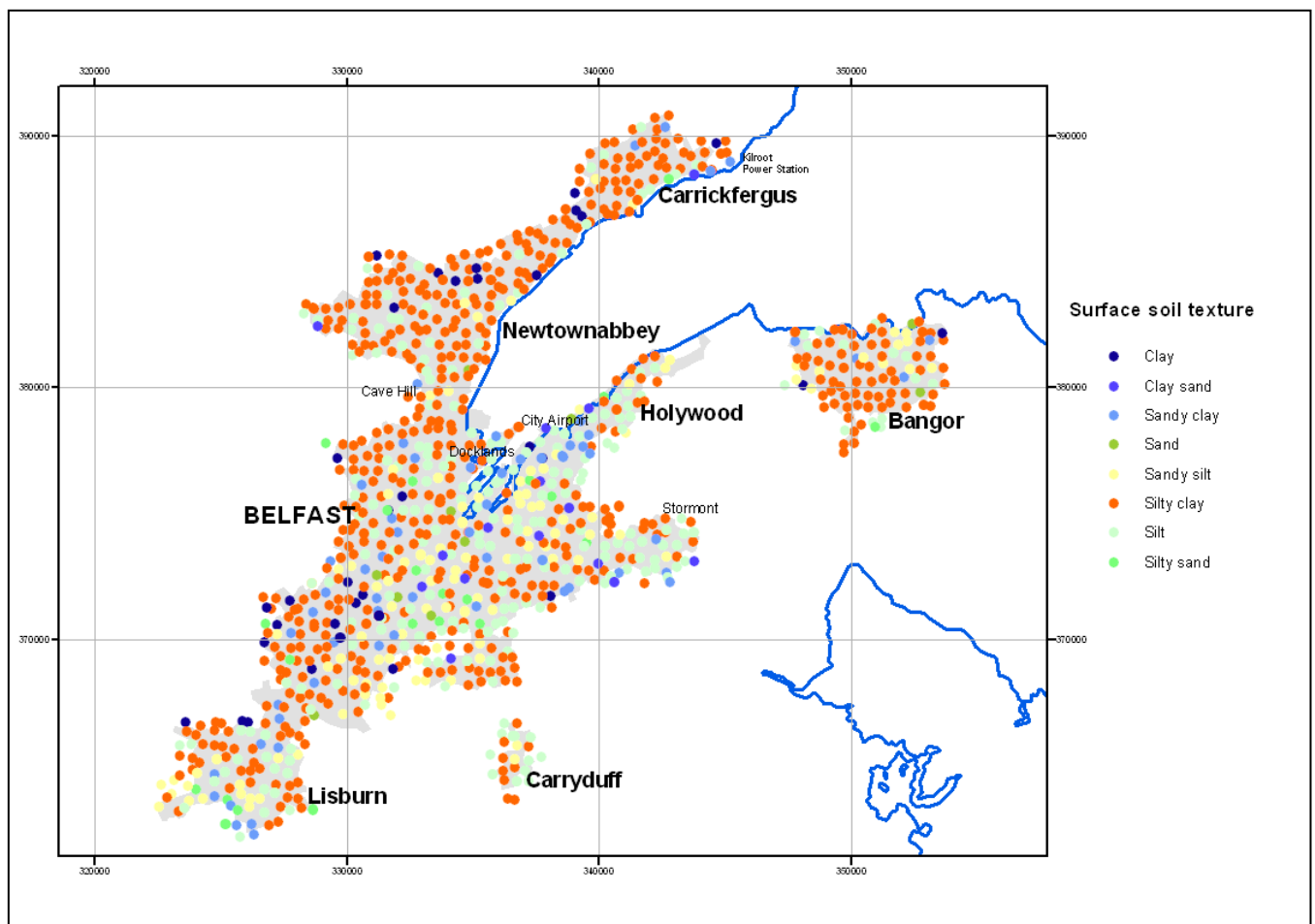


Figure 6. Soil texture classifications, observed in the field

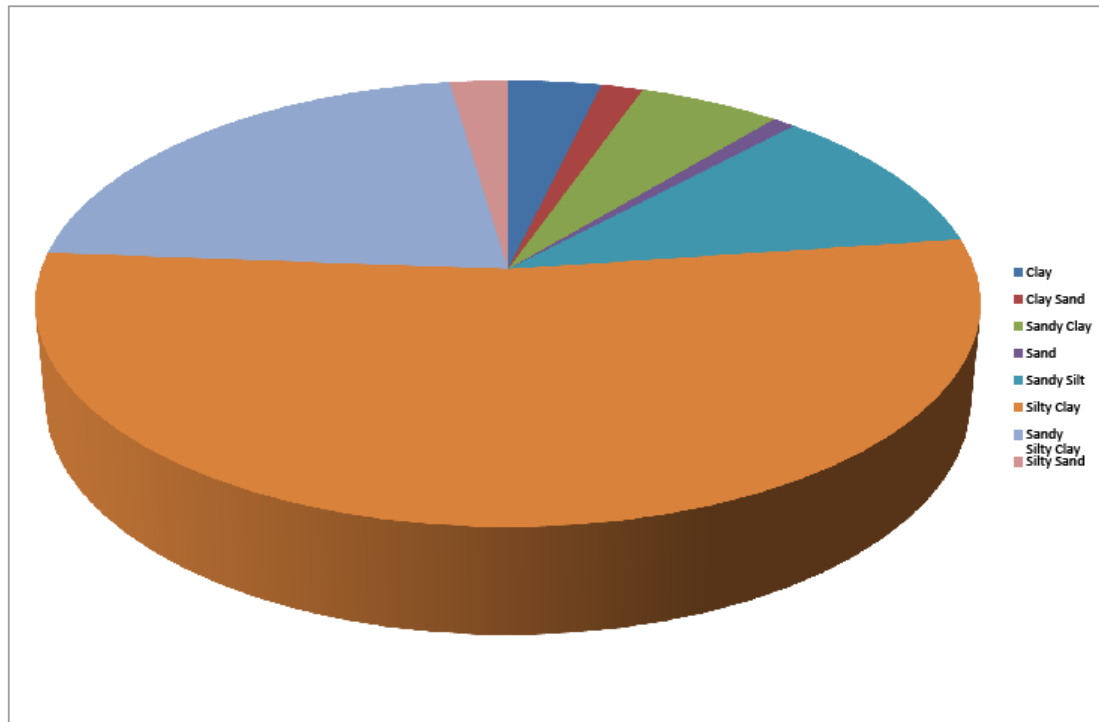


Figure 7. Percentage of soil texture over BMAP

Methodology

1.5 SOIL SAMPLING

Sample sites were arranged on a systematic grid pattern at a density of 4 samples per km² across the built-up area. Each British National Grid (BNG) kilometre grid square, as defined from the 1:25 000 and 1:10 000 scale OSNI[®] topographic maps, was split into four 500 m x 500 m sub-cells. Samples were collected from open ground as close as possible to the centre of each 500 m sub-cell. Sample spacing was kept as regular as possible, namely 500 m apart, but was constrained by the actual conditions that were encountered on the ground (such as buildings and other restrictions). Typical locations for sampling included residential gardens, public parks, sports fields, road verges, allotments, open spaces, schoolyards and waste ground. Whilst attempts were made to select the least disturbed area of open ground as close as possible to the centre of the 500 m sub-cell, sites were also chosen to be representative of the dominant land use for that sub-cell.

Soil samples were collected using a stainless steel Dutch-style hand auger with a 15 cm long flight. Two samples were collected from different depths at each site. Surface samples were labelled 'A' and were collected from a depth of 0.05 – 0.20 m. Deeper 'profile' samples were labelled 'S' and were collected from the same auger holes as the A samples, from a typical depth of 0.35 – 0.50 m (Johnson, 2005). Both A and S samples were made up of a five-hole composite, collected from the centre and corners of a 20 m by 20 m square. Duplicate sampling is described under 1.7.2 in this report.

Soil samples for organic analysis were collected at 1 sample per km². Different collection methods were used and are explained in Young, M.E (2007) and Knights, K.V (2006).

Observations on soil depth, colour, textures and clast lithologies are recorded at the point of sampling alongside information about the site location, land use, contamination and observed geology (Figure 8). This information is entered into the BGS geochemistry database.

G-BASE SOIL

CARD 1		CODE		SAMPLE NUMBER		PROTOCOL		TYPE		EASTING		NORTHING		OS MAP		SCL		COLLECTORS	
A		S70199				AS		328883		382666		1		133		SJW		TB	
B		DUPLICATE SAMPLE		DATE		MONTH		YEAR		WEA		LAND USE		DRIFT		SLP			
		3738		100506		7		DAC0						C1E1				2	

CARD 2		SITE LOCALITY DETAILS																	
		ACROSS ROAD FR		1 HYDE PARK MAWORA															
		15 HYDE PARK RD		E 0 TRENCH LANE, MALLISK															

CARD 3		OB		MIN		MIN		MIN		MAJOR		MINOR		CONTAMINATION					
		0		15															

CARD 4		SOIL DATA																	
		DEPTH		COLOUR		TEXTURE		H2O		ORG									
		0.20		0B S I L		7 I 2													
		DEPTH		COLOUR		TEXTURE		H2O		ORG									
		0.50		LB S I C L		12													

CARD 5		FIELD DATA COMMENTS																	
		150 ROAD SIDE VERGE NEAR RESERVOIR																	
		413 WHITE SANDY PATCHES 498 WHITE																	

G-BASE SOIL CARD FOR 2005 Version 2005.1

Figure 8. An example of field information recorded at site

1.6 SAMPLE PREPARATION

The samples (both A and S) were first air dried and then oven dried at less than 30 °C. They were then sieved to < 2 mm. Initially only the A soils were analysed, the S samples were prepared and the < 2 mm fraction stored at the National Geoscience Records Centre (NGRC) at BGS for future work. The sieved material is coned and quartered and a sample split is milled using an agate mill until 95 % of material is < 53 µm. Subsequently 12 g of this milled sample material is pressed with 3 g of wax binder into pellets for X-Ray Fluorescence Spectrometry (XRFS) analysis. The excess milled material is also stored at the NGDC.

1.7 ERROR CONTROL PROCEDURES

The accuracy and precision of the data are afforded careful procedures adopted in the field and for sample preparation and analyses; these are outlined below. (Johnson, 2005).

1.7.1 Numbering of Samples

Samples were allocated numbers according to a random numbering system (Plant, 1973), but were analysed in sequential numerical order. This allows any systematic error in either sampling or analytical methodologies to be identified and attributed to the appropriate process.

1.7.2 Duplicate and Replicates

Within each batch of one hundred samples, two pairs of sample numbers were assigned as a duplicate pair (denoted Duplicate A and B, and C and D); resulting in a field duplicate pair for both the A and S samples. Duplicate samples were collected using identical sampling methodology, taken from a 20 m by 20 m square adjacent to the first. At the sample preparation stage each of the field duplicate samples were split to obtain an analytical replicate sub-sample. Each sub-sample was assigned a different number and treated as a separate sample for analytical purposes. Thus a total of four analytical samples are analysed for each duplicate site.

The collection of field duplicate samples enables the sampling error, or sampling variation, to be estimated, thus providing a measure of the between-sample variance. Analytical replicate sub-sampling allows the analytical error or variance to be estimated as differences in results between the original and the sub-sample may indicate the influence of the sample preparation and analytical process.

The components of variance were estimated using analysis of variance (ANOVA). This statistical technique is used to determine the residual (or within-sample) variance (introduced by sub-sampling, sample preparation and chemical analysis); the between-sample variance (attributed to within-site variation and variability introduced during sample collection); and between-site variance (representing the environmental distribution of element concentrations across the survey area). All of the analyses form part of a single randomised dataset and a random nested model of ANOVA was therefore used (Snedecor and Cochran, 1989; Johnson, 2002).

Due to the relatively low number of duplicate samples collected in a single urban area, the ANOVA calculations were performed including replicate soils data collected from Derry, which were collected by identical methods. In total 19 replicate sets were used.

The results of the ANOVA indicate that for the majority of elements the between-site variability is greater than 80 % of the total variance (Table 2). This suggests that geochemical variation is the principal control over element concentrations in urban areas. The between-site variance of elements such as Ag, Cd, In, Cs and Cu in surface soils is lower than the other elements, with nearly half the variation in the soils attributed to residual factors. This is an indication of analytical error, most likely resulting from low overall concentrations with respect to the detection limit.

Table 2. ANOVA - Belfast and Derry Surface Soils

Element	Between Site %	Between Sample %	Within Sample %	Total %
Ag	13.80	3.61	82.59	100
Cd	-3.38	19.53	83.85	100
In	2.62	18.62	78.76	100
Sn	47.25	42.42	10.33	100
Sb	13.71	64.27	22.02	100
Te	12.36	-40.66	128.29	100
I	90.80	8.09	1.11	100
Cs	36.67	-9.50	72.83	100
Ba	52.79	9.32	37.88	100
La	81.80	-5.12	23.32	100
Ce	90.01	-1.00	10.99	100
K ₂ O	98.04	1.53	0.43	100
CaO	93.11	3.47	3.41	100
TiO ₂	89.05	10.80	0.15	100
MnO	95.59	4.05	0.36	100
Fe ₂ O ₃	90.69	9.06	0.25	100
S	80.22	2.87	16.90	100
Cl	69.53	24.68	5.79	100
Sc	91.76	5.23	3.01	100
V	91.75	8.01	0.24	100
Cr	92.69	7.13	0.18	100
Co	93.77	5.17	1.06	100
Ni	93.73	5.78	0.49	100
Cu	49.09	49.43	1.48	100
Zn	77.18	22.52	0.31	100
Ga	79.56	13.98	6.46	100
Ge	30.47	48.57	20.96	100
As	29.36	60.55	10.09	100
Se	58.39	23.92	17.69	100
Br	72.75	26.93	0.31	100
Rb	97.37	1.81	0.82	100
Sr	76.20	22.64	1.16	100
Y	91.40	7.34	1.26	100
Zr	90.44	8.20	1.35	100
Nb	68.92	-19.85	50.94	100
Mo	71.31	23.84	4.86	100
Nd	82.27	1.45	16.28	100
Sm	85.68	-4.76	19.08	100
Yb	41.21	-2.29	61.08	100
Hf	49.90	16.97	33.14	100
Ta	38.22	-34.05	95.83	100
W	56.50	-11.46	54.96	100
Tl	14.74	-13.88	99.14	100
Pb	28.25	71.13	0.62	100
Bi	87.96	0.68	11.36	100
Th	82.78	9.89	7.33	100
U	83.70	-1.16	17.46	100
Na ₂ O	84.67	4.18	11.15	100
MgO	80.66	-4.18	23.52	100
Al ₂ O ₃	83.14	9.08	7.78	100
SiO ₂	85.04	10.79	4.17	100
P ₂ O ₅	63.62	29.73	6.65	100
SO ₃	18.09	25.79	56.11	100
CaO	81.30	-5.54	24.24	100
TiO ₂	80.58	14.74	4.68	100
Fe ₂ O ₃	82.55	11.76	5.68	100

1.7.3 Internal Standards

In-house secondary reference materials were analysed within each batch of field samples, in order to monitor analytical instrument performance, and to provide continuity of data between different analytical campaigns and between regional and urban data. The In-house standards used were bulk soil samples ANTBAS, DAL, LWRPALA and S13B. Each were assigned unique sample IDs and inserted in duplicate or triplicate into each batch of field samples. Where values for the standards differed significantly, the data were normalised using simple X-Y plots and regression calculations to correct for calibration variance between sample batches (Lister and Johnson, 2005). By making use of these secondary reference materials, the urban data is more readily comparable with the peri-urban and rural regional soil dataset from the whole of Northern Ireland. The mean element concentrations for standards analysed alongside the urban and regional samples are included in Table 3.

Table 3. Mean Element Concentrations for Secondary Reference Materials analysed for urban and regional datasets

Element	Unit	ANTBAS	ANTBAS Regional	DAL	DAL Regional	LWRPALA	LWRPALA Regional	S13B	S13B Regional
Ag	mg kg ⁻¹	0.3	0.4	0.3	0.3	0.2	0.4	0.5	0.5
Cd	mg kg ⁻¹	0.2	0.5	0.2	0.3	0.2	0.3	0.3	0.4
In	mg kg ⁻¹	0.3	0.3	0.3	0.2	0.3	0.2	0.3	0.2
Sn	mg kg ⁻¹	2.2	2.4	1.8	2.1	2.3	2.5	2.1	2.4
Sb	mg kg ⁻¹	0.2	0.7	0.7	0.7	1.1	1.3	0.6	0.9
Te	mg kg ⁻¹	0.2	N/A	0.2	N/A	0.3	N/A	0.3	N/A
I	mg kg ⁻¹	10.3	10.6	1.1	1.1	4.0	4.2	2.8	2.8
Cs	mg kg ⁻¹	0.5	1.4	1.1	2.2	3.5	4.3	13.6	14.6
Ba	mg kg ⁻¹	173.0	258.4	519.6	540.3	538.1	560.8	838.9	815.7
La	mg kg ⁻¹	5.8	11.3	28.6	30.8	33.7	35.3	44.5	44.4
Ce	mg kg ⁻¹	15.3	23.4	51.5	54.3	66.0	67.5	83.4	82.5
Na ₂ O	wt%	0.3	0.3	1.3	1.9	0.9	1.1	0.2	0.3
MgO	wt%	4.3	3.1	2.0	1.6	3.5	2.5	1.6	1.4
Al ₂ O ₃	wt%	21.7	18.4	15.2	13.8	18.4	16.0	20.3	17.5
SiO ₂	wt%	40.0	45.5	64.3	70.6	65.9	62.7	62.9	60.7
P ₂ O ₅	wt%	0.2	0.1	0.1	0.1	0.2	0.1	0.2	0.1
SO ₃	wt%	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.3
CaO Ins3	wt%	1.6	1.5	0.5	0.4	0.2	0.0	0.6	0.5
TiO ₂ Ins3	wt%	1.8	1.6	0.8	0.8	0.9	0.8	0.9	0.8
Fe ₂ O ₃ Ins3	wt%	15.7	12.6	3.4	4.0	7.8	7.0	7.5	6.8
K ₂ O	wt%	0.3	0.4	2.9	2.6	3.2	3.1	2.4	2.3
CaO Ins2	wt%	1.6	1.7	0.5	0.7	0.1	0.4	0.5	0.7
TiO ₂ Ins2	wt%	1.7	1.7	0.8	0.8	0.8	0.8	0.7	0.8
MnO Ins2	wt%	0.22	0.21	0.05	0.04	0.10	0.10	0.10	0.10
Fe ₂ O ₃ Ins2	wt%	13.84	13.63	3.52	3.55	7.00	7.01	6.76	6.78
S	mg kg ⁻¹	536	621	384	108	207	69	1138	1816
Cl	mg kg ⁻¹	61	60	52	21	35	34	68	75
Sc	mg kg ⁻¹	37	35	10	10	16	17	13	13
V	mg kg ⁻¹	284	285	70	71	116	120	89	90
Cr	mg kg ⁻¹	483	483	61	59	143	145	92	95
Co	mg kg ⁻¹	57	56	11	11	28	27	18	18

Element	Unit	ANTBAS	ANTBAS Regional	DAL	DAL Regional	LWRPALA	LWRPALA Regional	S13B	S13B Regional
Ni	mg kg ⁻¹	227	211	24	23	71	67	46	43
Cu	mg kg ⁻¹	114	124	15	15	53	57	17	17
Zn	mg kg ⁻¹	123	123	87	87	90	92	109	110
Ga	mg kg ⁻¹	20	22	15	16	18	21	22	24
Ge	mg kg ⁻¹	0.9	1.3	0.8	1.1	0.9	1.3	1.1	1.3
As	mg kg ⁻¹	0.6	1.5	1.3	2.4	16.8	18.3	13.4	14.7
Se	mg kg ⁻¹	0.6	0.7	0.1	0.2	0.3	0.4	0.5	0.6
Br	mg kg ⁻¹	26.0	26.2	1.1	1.6	5.0	5.5	4.9	5.4
Rb	mg kg ⁻¹	9.8	12.4	83.5	84.9	109.5	111.5	116.7	117.7
Sr	mg kg ⁻¹	106.7	100.4	120.9	115.8	54.6	49.7	129.9	125.6
Y	mg kg ⁻¹	15.7	15.3	20.6	20.3	22.5	22.6	20.7	21.0
Zr	mg kg ⁻¹	127.7	132.0	331.2	336.7	200.7	204.1	173.8	177.7
Nb	mg kg ⁻¹	5.2	8.8	14.5	16.7	12.8	15.3	13.3	15.5
Mo	mg kg ⁻¹	0.7	0.8	0.2	0.5	2.2	2.3	0.9	0.9
Nd	mg kg ⁻¹	9.7	6.3	23.4	25.2	26.7	29.6	34.8	39.1
Sm	mg kg ⁻¹	0.9	4.0	3.9	5.1	4.4	5.1	4.6	5.3
Yb	mg kg ⁻¹	3.1	2.3	2.4	2.3	2.7	2.4	2.8	2.4
Hf	mg kg ⁻¹	3.9	4.0	8.7	8.2	5.3	5.3	5.1	4.8
Ta	mg kg ⁻¹	0.5	0.7	0.6	1.0	0.5	0.9	0.8	0.9
W	mg kg ⁻¹	0.4	0.2	1.8	1.8	1.3	1.8	1.5	1.6
Tl	mg kg ⁻¹	0.7	0.6	0.6	0.7	0.8	0.9	0.6	0.8
Pb	mg kg ⁻¹	6.9	8.8	36.9	36.9	41.7	42.1	64.0	64.1
Bi	mg kg ⁻¹	0.4		0.3		0.6		0.6	
Th	mg kg ⁻¹	1.2	1.5	7.9	8.2	9.5	9.9	11.3	11.2
U	mg kg ⁻¹	0.7	0.4	2.2	2.4	2.8	3.1	3.1	3.2

1.8 ANALYTICAL PROCEDURES

1.8.1 X-Ray Fluorescence Spectrometry

All 'A' soils were prepared and analysed at the BGS laboratories in the summer of 2006 for a range of elements by Wavelength Dispersive X-Ray Fluorescence Spectrometry (WD-XRFS) and by Energy Dispersive X-Ray Fluorescence Spectrometry (ED-XRFS) (Ingham and Vrebos, 1994). All the samples were run on two spectrometers; these and the analytes are summarised in Table 4 with the lower limits of detection in Table 5.

Table 4 Analytical instruments used and elements determined in surface soils from the Belfast survey

Lab. Batch ID	11500; 11501; 11502
Sample Nos.	570001 – 571589 (960 samples)
Instrument	Analytes
Epsilon 5-1	mg kg ⁻¹ Ag, Cd, In, Sn, Sb, Te, I, Cs, Ba, La, Ce
PW2400-1	wt % Na ₂ O, MgO, Al ₂ O ₃ , SiO ₂ , P ₂ O ₅ , SO ₃ , CaO, TiO ₂ , Fe ₂ O ₃ , K ₂ O, MnO mg kg ⁻¹ S, Cl, Sc, V, Cr, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Y, Zr, Nb, Mo, Nd, Sm, Yb, Hf, Ta, W, Tl, Pb, Bi, Th, U

Table 5 Lower Limits of Detection for elements by XRFS

Analyte	unit	LLD	Method	Analyte	unit	LLD	Method
Na ₂ O	%	0.3	WD-XRFS	Y	mg/kg	1.1	WD-XRFS
MgO	%	0.3	WD-XRFS	Zr	mg/kg	1.2	WD-XRFS
Al ₂ O ₃	%	0.2	WD-XRFS	Nb	mg/kg	0.9	WD-XRFS
SiO ₂	%	0.1	WD-XRFS	Mo	mg/kg	0.2	WD-XRFS
P ₂ O ₅	%	0.05	WD-XRFS	Ag	mg/kg	0.5	ED-XRFS
SO ₃	%	0.5	WD-XRFS	Cd	mg/kg	0.5	ED-XRFS
Cl	%	0.05	WD-XRFS	In	mg/kg	0.5	ED-XRFS
K ₂ O	%	0.1	WD-XRFS	Sn	mg/kg	0.5	ED-XRFS
CaO	%	0.3	WD-XRFS	Sb	mg/kg	0.5	ED-XRFS
TiO ₂	%	0.02	WD-XRFS	Te	mg/kg	0.5	ED-XRFS
MnO	%	0.01	WD-XRFS	I	mg/kg	0.5	ED-XRFS
Fe ₂ O ₃	%	0.05	WD-XRFS	Cs	mg/kg	1	ED-XRFS
Sc	mg/kg	2.7	WD-XRFS	Ba	mg/kg	1	ED-XRFS
V	mg/kg	2.9	WD-XRFS	La	mg/kg	1	ED-XRFS
Cr	mg/kg	3	WD-XRFS	Ce	mg/kg	1	ED-XRFS
Co	mg/kg	1.5	WD-XRFS	Nd	mg/kg	3.6	WD-XRFS
Ni	mg/kg	1.4	WD-XRFS	Sm	mg/kg	3	WD-XRFS
Cu	mg/kg	1.3	WD-XRFS	Yb	mg/kg	1.4	WD-XRFS
Zn	mg/kg	1.2	WD-XRFS	Hf	mg/kg	1.1	WD-XRFS
Ga	mg/kg	1	WD-XRFS	Ta	mg/kg	1.1	WD-XRFS
Ge	mg/kg	0.5	WD-XRFS	W	mg/kg	0.6	WD-XRFS
As	mg/kg	0.9	WD-XRFS	Tl	mg/kg	0.5	WD-XRFS
Se	mg/kg	0.2	WD-XRFS	Pb	mg/kg	1.3	WD-XRFS
Br	mg/kg	0.8	WD-XRFS	Bi	mg/kg	0.3	WD-XRFS
Rb	mg/kg	1	WD-XRFS	Th	mg/kg	0.7	WD-XRFS
Sr	mg/kg	1.1	WD-XRFS	U	mg/kg	0.5	WD-XRFS

The quoted LLDs are theoretical values for the concentration equivalent to three standard deviations above the background count rate for the analyte in a pure silica matrix. High instrumental stability results in practical values for these materials approaching the theoretical detection limit.

1.8.2 Other Analyses

The soil pH and loss on ignition (LOI) at 450 °C were determined in all 'A' soil samples including duplicates and replicates. The mass of material lost on ignition is a reasonable indicator of the organic carbon content in the soil (the wt % of organic carbon of soils is assumed to be 0.5 * total wt % LOI). It is useful to determine the proportion of organic carbon as several heavy metals can accumulate in organic compounds and complexes. The soil pH was determined by glass electrode and pH meter using a slurry method with CaCl₂ as the releasing electrolyte. The pH is an important parameter in considering the mobility of elements and the Soil Guideline Value (SGV) (1.9.2).

Geochemical Results and Discussion

1.9 INTRODUCTION

Once full error control and data quality procedures were completed, the BMAP geochemical data were loaded into ArcMap™ v.9.2 GIS software. Coloured and graduated symbol geochemical maps for the surface soils were then generated, categorising the data according to percentile classes (these are presented in the Appendix).

1.9.1 Sample Site Data and Land Use

Information on the dominant land uses of sample sites is valuable when interpreting the chemical variations in the surface soil environment. In total 22 different principal land-use types were sampled and are shown in Figure 9. These are recorded in the field database using a hierarchical code system.

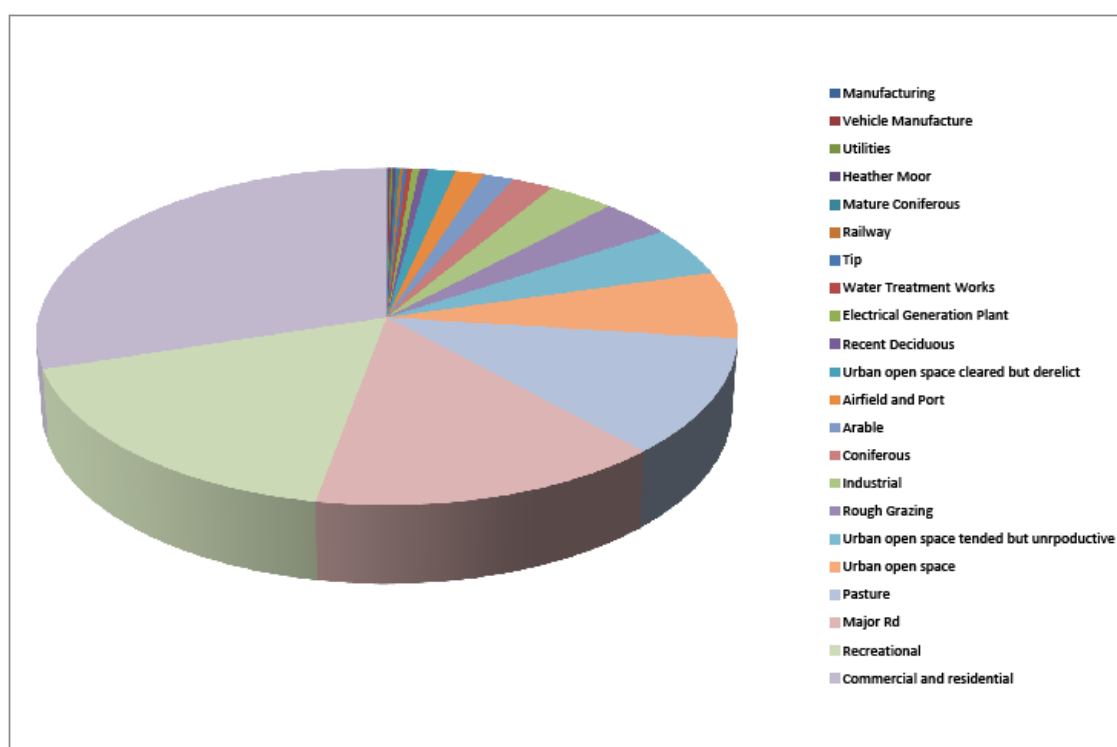


Figure 9. Principal Land Uses at Sample Sites within BMAP

The four major land uses of sampled sites in Belfast were Commercial and Residential (30%), Recreational (17%), Major Roads (15%) and Pasture (11%). This equates to almost half of the sampling sites being from a land use that could be of risk to human health (i.e. residential and recreational) as this would include areas such as allotments, childrens' playgrounds and school playing fields – all of which could be part of the source-pathway-receptor sequence. It would therefore be of use to further investigate the geochemistry at these sites to ensure that elements that are potentially harmful to human health do not exceed the soil guideline values (SGVs), which are described in section 4.1.2.

Samplers recorded any observations of contaminants at site. These are significant because some isolated chemical anomalies can be attributed to specific contaminants. Below (section 4.2) is a generalised description of geochemical trends; site specific descriptions are accounted as appropriate.

1.9.2 Soil Guideline Values (SGVs)

For some elements, Soil Guideline Values have been assessed for different land use types by the Environment Agency (EA) working under the Contaminated Land Exposure Assessment (CLEA) that was developed in 2002 along with the Department of Environment, Food and Rural Affairs (DEFRA). SGVs are scientifically based generic assessment criteria that can be used to simplify the assessment of human health risks arising from long-term and on-site exposure to chemical contamination in soil (EA, 2009a). It is beyond the scope of this report to assess risks posed by the soils at individual sampled sites; however it is useful to compare and highlight cases where data exceed the given values, considering that the topsoil sampled in Belfast, as elsewhere, is the immediate interface between land and human activity.

Soil guideline values (mg kg^{-1} dry weight soil)

	As	Cd	Ni	Se
Land Use				
Residential	32	10	130	350
Allotment	43	1.8	230	120
Commercial	640	230	1800	13000

Table 6 Soil guideline values for specified land uses (EA, 2009b,c,d,e)

The SGVs are quoted with respect to different land use types, to account for the likelihood of uptake by plants and thus contact with humans, including direct contact and through ingestion. The interpretation of the urban geochemistry in Belfast (1.10) considers these SGVs, where available.

Figures 10 and 11 depict where the SGVs are exceeded within Belfast and it is recommended that further investigation is carried out into these sites and also into the bioavailability and mobility of the elements. There are no SGV maps for Se or Cd as none of the data points exceed the SGV for residential land use which is 350 mg kg^{-1} and 10 mg kg^{-1} respectively.

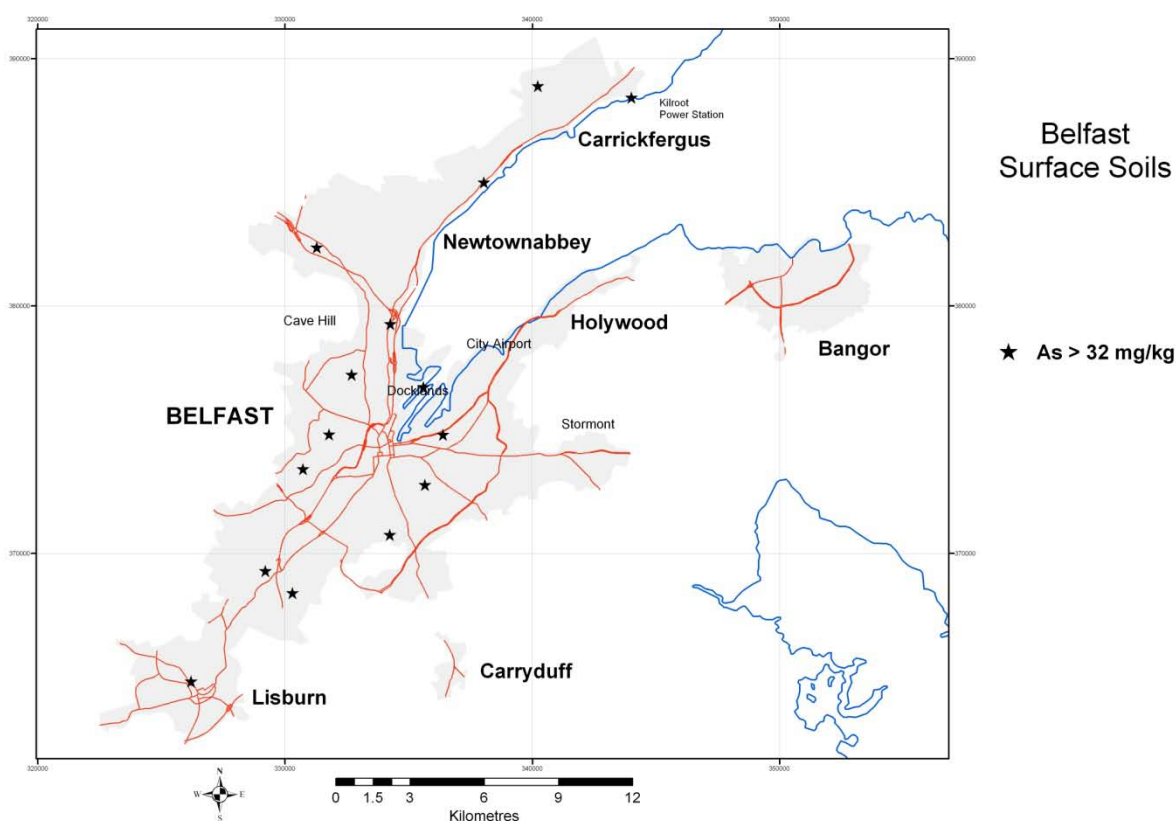


Figure 10. Sample sites where SGV for Arsenic is exceeded within BMAP

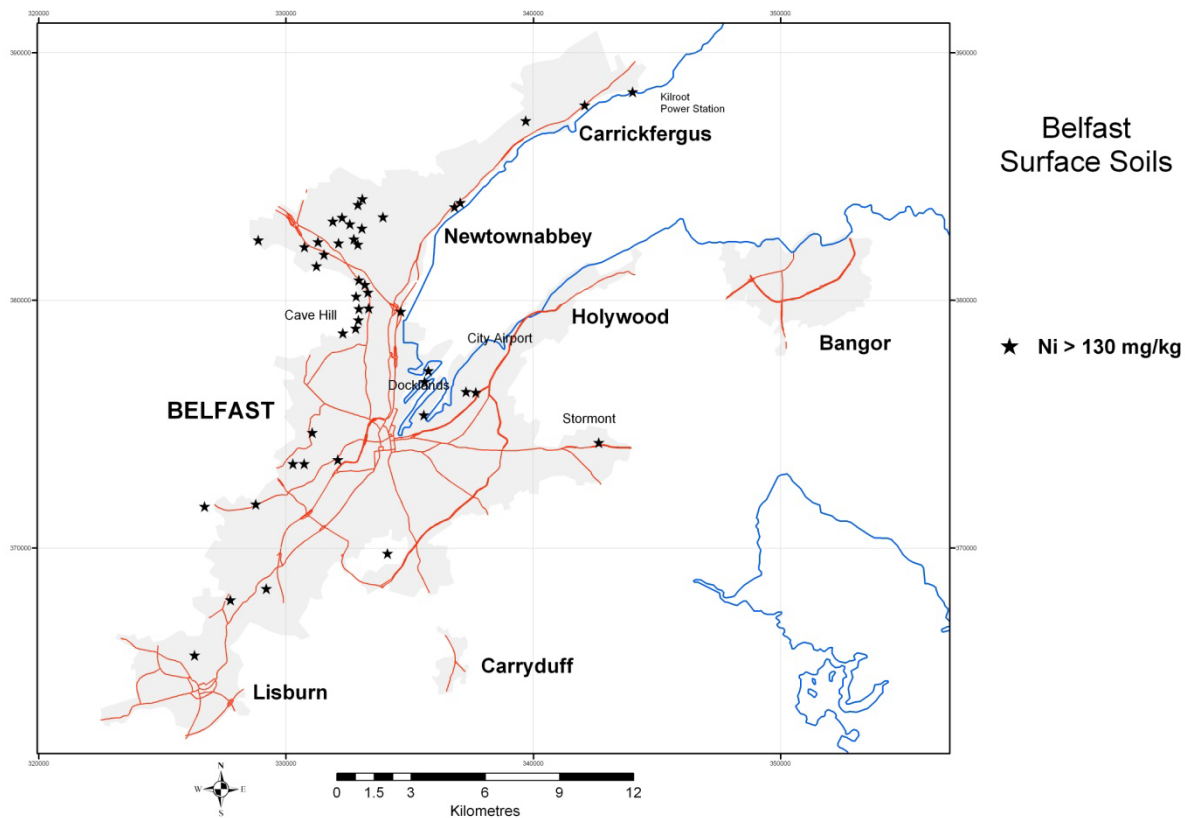


Figure 11. Sample sites where SGV for Nickel is exceeded within BMAP

1.10 REGIONAL GEOCHEMISTRY OF NORTHERN IRELAND

Topsoil ('A' soils) collected as part of the regional TELLUS project was sampled at a density of 1 per 2 km² using identical procedures as in this urban survey. These regional geochemistry soil data are therefore readily comparable with the surface soils collected in Belfast. Table 7 gives summary statistics for the element concentrations determined in 6862 top soils, to aid in comparison with the urban data. Elements for which the median value in the urban survey exceeds that for the regional survey are highlighted.

Table 7. Summary statistics for BMAP data and regional data

Analyte	Unit	URBAN				RURAL			
		Min	Max	Median	Mean	Min	Max	Median	Mean
Na ₂ O	%	0.33	2.06	1.07	1.05	0.2	3.1	0.9	0.9
MgO	%	0.87	7.73	1.96	2.05	0.5	5.8	1.3	1.5
Al ₂ O ₃	%	7.07	20.27	11.45	11.34	3.5	17.2	11.4	10.6
SiO ₂	%	23.60	89.70	57.70	56.91	13.8	87.9	54.1	49.6
P ₂ O ₅	%	0.11	2.62	0.34	0.37	0.1	1.7	0.3	0.3
SO ₃	%	0.10	0.90	0.20	0.19	0.0	18.9	0.6	0.9
S	mg kg ⁻¹	104	4243	880	965	251.3	10217.4	1303.5	1686.5
Cl	mg kg ⁻¹	53	1645	115	124	14.2	2755.4	90.9	160.8
K ₂ O	%	0.36	3.32	1.71	1.66	0.2	5.2	1.5	1.4
CaO	%	0.42	13.84	1.54	1.77	0.3	16.3	0.8	1.2
TiO ₂	%	0.26	1.60	0.73	0.78	0.1	2.1	0.7	0.7
MnO	%	0.02	0.73	0.09	0.10	0.0	15.0	0.1	0.1
Fe ₂ O ₃	%	1.86	15.58	5.32	5.71	0.3	42.2	4.2	4.7
Sc	mg kg ⁻¹	1.4	41.9	13.2	14.3	0.0	37.6	10.6	11.8
V	mg kg ⁻¹	33.2	446.7	112.6	124.0	5.9	401.6	85.0	99.7
Cr	mg kg ⁻¹	51.5	826.9	176.4	198.8	4.1	1228.8	94.1	131.0
Co	mg kg ⁻¹	5.2	120.6	20.3	22.8	0.1	205.1	10.9	15.2
Ni	mg kg ⁻¹	16.1	372.2	65.9	71.7	1.4	333.6	29.1	46.2
Cu	mg kg ⁻¹	7.1	1149.4	52.8	66.4	0.0	1510.1	31.6	39.7
Zn	mg kg ⁻¹	25.0	9030.0	117.6	165.0	2.8	2460.5	71.8	78.3
Ga	mg kg ⁻¹	3.8	60.3	12.8	12.9	0.0	31.1	13.9	12.6
Ge	mg kg ⁻¹	0.1	63.5	1.3	1.6	0.2	3.3	1.1	1.1
As	mg kg ⁻¹	0.0	65.9	10.1	11.1	0.0	271.2	8.7	10.5
Se	mg kg ⁻¹	0.0	4.7	0.5	0.5	0.1	7.8	0.7	0.8
Br	mg kg ⁻¹	1.9	167.3	19.0	21.7	1.4	664.3	26.0	47.6
Rb	mg kg ⁻¹	10.7	111.3	59.5	58.0	2.1	340.1	50.5	51.3
Sr	mg kg ⁻¹	29.8	851.6	98.5	110.7	1.6	929.8	74.0	81.4
Y	mg kg ⁻¹	6.3	87.0	17.5	18.2	1.6	261.1	15.4	15.5
Zr	mg kg ⁻¹	78.7	395.6	192.3	188.8	13.5	666.6	197.7	185.2
Nb	mg kg ⁻¹	6.9	32.5	12.1	12.1	4.5	29.0	11.7	11.5
Mo	mg kg ⁻¹	0.1	29.9	1.3	1.6	0.0	5.4	0.8	0.8
Nd	mg kg ⁻¹	0.6	80.6	10.6	12.4	0.0	165.5	12.7	14.1
Sm	mg kg ⁻¹	3.2	6.8	5.1	4.8	2.4	9.6	4.7	4.7
Yb	mg kg ⁻¹	2.3	2.5	2.3	2.3	1.3	5.4	2.3	2.3
		URBAN	RURAL			URBAN	RURAL		
Hf	mg kg ⁻¹	1.2	9.1	4.7	4.7	1.4	12.7	5.1	4.9

Ta	mg kg ⁻¹	0.0	14.2	0.5	0.5	0.0	2.8	0.8	0.8
W	mg kg ⁻¹	0.0	364.0	1.2	1.8	0.0	9.3	1.5	1.5
Tl	mg kg ⁻¹	0.0	3.7	0.4	0.4	0.3	8.5	0.7	0.7
Pb	mg kg ⁻¹	9.8	3466.9	67.7	112.3	2.2	18756.8	28.8	41.7
Bi	mg kg ⁻¹	0.0	7.8	0.2	1.1	0.0	24.0	0.5	0.5
Th	mg kg ⁻¹	0.5	19.4	4.7	4.8	0.0	42.9	5.0	5.0
U	mg kg ⁻¹	0.1	9.1	1.5	1.6	0.0	142.9	2.3	2.5
Ag	mg kg ⁻¹	0.1	3.8	0.3	0.3	0.3	5.9	0.3	0.3
Cd	mg kg ⁻¹	0.1	2.8	0.3	0.3	0.2	63.3	0.5	0.5
In	mg kg ⁻¹	0.1	0.8	0.3	0.3	0.2	0.7	0.2	0.3
Sn	mg kg ⁻¹	0.6	400.5	4.8	11.1	1.7	37.5	2.4	2.6
Sb	mg kg ⁻¹	0.2	99.1	1.3	2.1	0.7	156.9	1.0	1.1
Te	mg kg ⁻¹	0.1	0.4	0.3	0.2	0.1	0.5	0.1	0.1
I	mg kg ⁻¹	0.3	261.0	5.8	8.7	0.1	660.0	6.7	10.6
Cs	mg kg ⁻¹	0.5	10.4	2.8	3.0	1.0	11.3	2.6	2.8
Ba	mg kg ⁻¹	179.20	2058.82	420.39	428.41	112.2	2360.7	348.7	342.5
La	mg kg ⁻¹	10.3	115.0	20.9	21.3	6.6	152.0	19.3	19.8
Ce	mg kg ⁻¹	17.6	223.8	38.8	39.5	12.1	349.6	36.5	37.8

The most significant elements where the Urban median is much greater than the rural median are, not surprisingly, the ‘classic’ anthropogenic metals Cu, Zn, Pb, Sn and Co; and to a lesser extent, Mo and Sb. Barium also tends to show some ‘urban anthropogenic’ character as it is present in diesel fuels, paints, paper etc. The high Cl median is driven by the high levels near the docklands district, which may be related to the Holocene estuarine clays of the area. Nickel, Cr and Sr are high compared to the regional median, but these values may be skewed by the presence of the Antrim Basalt Group, and median soil values over the basalts are much higher than the regional median for these elements (Cr >200 mg kg⁻¹, Ni 150 mg kg⁻¹, Sr 150 mg kg⁻¹).

Only two elements have significantly lower mean values within the Belfast urban district compared with the regional data: these are sulphur and bromine. Sulphur, as both total S or as SO₃, is low possibly because of the predominance of the Triassic and Permian sandstones in the local geology, while the regional high values of Br are related to peaty soils which are largely absent from the Belfast area.

1.10.1 pH of Surface Soils

The pH was determined in all of the surface soil samples, by the CaCl₂ slurry method. The pH influences the mobility of trace elements in soil, and is a primary factor for the uptake of these by plants and other organisms. The pH results for Belfast are plotted on Figure 12. Table 8 presents a summary of pH results for Belfast and the regional surface soils for all of Northern Ireland.

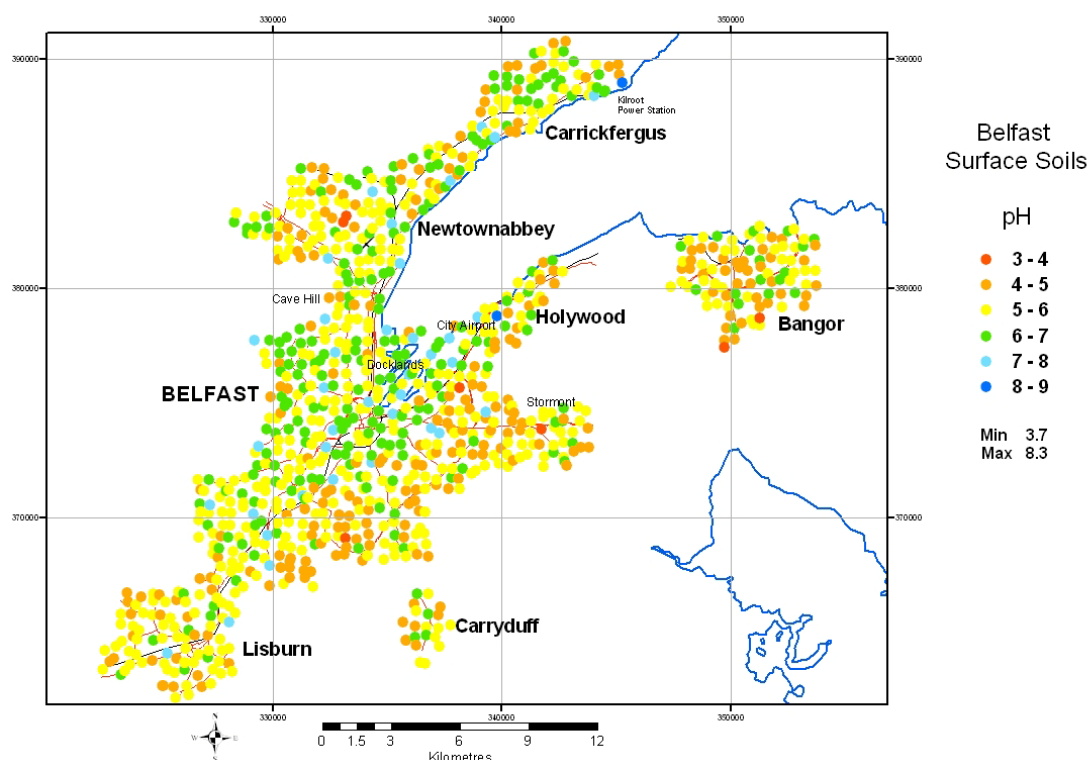


Figure 12. pH of Belfast soils

Table 8 Summary of pH of surface soils in Belfast and Northern Ireland

pH of surface soils	Belfast Urban	Northern Ireland regional
Min.	3.69	2.83
Max.	8.25	7.68
Mean	5.56	4.74
Median	5.45	4.82
No. of samples \leq pH 7.0	918 (96 %)	4088 (99%)
No. of samples \leq pH 5.0	241 (25 %)	2741 (66.8%)

The overall range of pH values for Belfast is slightly higher than those of the regional data; the regional data have lower, more acidic pH conditions. The low pH values (<5.0) in the regional data are associated with peat substrates in both mountainous and lowland terrain where production of humic and fulvic acids and CO_2 in wet and waterlogged reducing conditions from decomposing organic matter contribute to the acidification of pore waters.

1.11 INTERPRETATION OF GEOCHEMICAL DATA OF BELFAST

1.11.1 Potential Sources of Contaminants in Urban Environments

The likely sources of contaminants in urban environments have been well documented in the literature and useful synopses are provided by Bridge et al. (1998a), Appleton (1995), Fordyce et al. (2005), Hooker et al. (2000) and D'Arcy et al. (2001). Possible sources include building, waste disposal, transport, industrial and manufacturing activities and the use of fossil fuels. The types of contaminants commonly associated with these activities are summarised as follows.

Buildings, Households and Waste Disposal

Metal accumulation in the environment is well documented and is often associated with the disposal of fossil fuel residues (ash and soot), household refuse, bonfires and the application of phosphate fertilizers (mainly P_2O_5 but often contain U and Cd as impurities). Soils are also affected by atmospheric contamination from the burning of fossil fuels, vehicle emissions and industrial processes. Although the majority of building materials are relatively inert, the demolition of properties, particularly older buildings may lead to contamination with metals such as Pb from paint and substances such as asbestos. Metal contaminants are often present in variable concentrations in domestic and industrial wastes. Over 90 % of refuse in the UK is now deposited in landfill sites from which there is usually little dispersion of metals into the neighbouring environment. In the past, however, the disposal of waste materials was often uncontrolled and undocumented. In addition to solid refuse, waste-waters from a host of urban activities such as food processing, laundries and breweries often contain high concentrations of metal and metalloid elements; arsenic is present in some household detergents, for example.

Urban Surface Run-off and Transport

Urban surface run-off waters often contain high concentrations of Pb, Zn, Cu and other compounds derived from road traffic and industrial sources. Until recently, traffic fumes have also been a major source of Pb in the surface environment due to the use of leaded fuels and, for example, Kelly et al. (1996), Davies (1995) and Ward (1990) have demonstrated the effects of proximity to roads on urban soil quality. Although there is evidence to suggest that Pb levels in urban environments are falling due to removal of this element from petrol, studies have shown a coincident increase in Pt concentrations as a result of usage in catalytic converters (Farago et al., 1996). Due to the fall in Pb levels, Monaci and Bargagli, (1997) and Monaci et al., (1999) have suggested that Ba is a good indicator of traffic fume contamination as it is added to diesel to reduce soot emissions (for example, (Petkov et al., 1999)). Elements such as Zn (used in tyres) are also enhanced in the urban environment as a result of road vehicle usage. In addition to road transport, areas of railway land often contain scrap metal, oil and debris from rolling stock in the soil.

Metal Smelting and refining

Metal smelting activities can result in the contamination of land via smokestack and fugitive emissions, liquid effluent and the dumping and erosion of slag materials and the transport and spillage of metal concentrates. Historically, atmospheric emissions were large, but today depend on the technology employed in the plant, the composition of the raw materials and the pollution control system. Elevated levels of Ni, Cr, Fe, Cu, Zn, Cd, As, Sb, Ag, Se, Hg and Pb are often recorded in the vicinity of smelters, and other elements such as F, Mo, Tl, Sn, W, Au and Bi may also be enhanced in the local environment depending on the type of smelter.

Extraction and Combustion of Fossil Fuels

Coal mining and the waste products derived from it (ash and slag) can contain elevated concentrations of PHE. Drainage waters from old coal mines and leachates and run-off from coal and waste piles may be extremely acidic due to the oxidation of sulphides i.e. pyrite, FeS_2 . These fluids can contain high levels of Fe, Mn, Cu, Ni and Zn and appreciable amounts of other elements such as As and Pb which can contaminate soils. Sites of disused and demolished power stations often contain soluble salts of elements such as B, residues of coal and pulverised fuel ash (which is highly alkaline with pH 11 – 12). Atmospheric contaminants associated with power stations include Cu, Zn, Ag, Cd, Sb, Se, Ga, Ge, Hg and Pb and environments around coal power stations can be also be enriched in Ti, Fe, Co, Cr, Ni, Cu, Zn, Cd and Hg. Fly ash from power stations, which was often used historically to condition land, contains high concentrations of B, Be, V, Ni, Mn, Cu, Zn, Cd, Mo, As, Se, Sb and Te and may have resulted in contamination if application was not regulated correctly.

Manufacturing Industries

Many industrial processes can give rise to contamination. As a general rule, the older the industry, the more likely it is to have produced substantial contamination of nearby drainage systems. The usual industry policy on waste disposal used to be something like “The most convenient, least expensive way of disposing of waste – up the chimney or down the river – is the best” (quoted in Weiner, 2000) and naturally this approach has left a legacy of pollution and contamination. Chemical works, gas works and oil refineries give rise to a wide range of contaminants in air, soil, sediment and waters. Potential pollutants from chemical works include Cr, Cu, Zn, Cd, Sn, Hg and Pb. Agricultural-chemical and fertiliser industries may be associated with a wide range of contaminants (trace metals, metalloid elements, P_2O_5 and N) whilst explosive works residues may contain Cu, As, Hg and Pb. Oil refineries and the manufacture of oil-based products are potential sources of Cr, Ni, V, Co, Cu, Zn, Cd, Mo, As and Pb whereas petroleum cracking catalysts have been traced as the source of light rare-earth element anomalies. Old gas works may be contaminated with coal and coal residues, spent iron oxides, cyanides, sulphates and a range of potentially hazardous organic compounds such as polynuclear aromatic hydrocarbons and phenols.

Many metals may be present in high concentrations around steelworks, foundries, electroplating and finishing works. Steel alloys, especially engineering and tool steels, use Cr, V, Mn, Ni, Mo and W, while Mo is also present in lubricants. The cleaning and etching of bare metal surfaces in metal finishing and plating processes are major sources of Cr, Ni, Cu, Zn and Cd in drainage systems. Battery manufacture may generate waste rich in Ni, Cd, Zn, Sb, Hg and Pb. The processing of scrap metals results in site contamination with metal and metalloid elements in addition to organic substances. Waste-waters derived from paint and dye-stuff producers often contain elevated levels of Cr, Cu, Cd, Se, Hg and Pb from the pigments and raw materials of these industries. Electrical and electronic industry waste can contain Cd, Zn, Se, Cu and Pb whereas Zn, Sn, Pb and Cd are used in the manufacture of synthetic rubber and plastics as stabilisers and pigments. The leather and textile industries use chromates and dichromates to condition cloth and hides, which can be sources of Cr enhancement in drainage systems. The glass and ceramic industries use Cr, Pb, Co, Se, Cu, Mo, Ti and Fe among other elements as pigments, glazes and conditioning agents. Finally, new technologies such as mobile phones can contain up to 39 mined and processed inorganic elements, including rare elements such as Ta and lanthanides.

1.12 GEOLOGICAL CONTROLS ON THE URBAN ENVIRONMENT IN BELFAST

There are strong geological controls on the geochemistry of the urban environment in Belfast. Many elements are influenced by the basalts to the north of the city and by the Triassic and Permian deposits to the south. Table 9 below demonstrates which elements are influenced by the basalts, Triassic/Permian deposits and also elements that are influenced by anthropogenic or other inputs.

Table 9. Major Controls on the Geochemistry of Belfast

Major Control		
Basalts	Permian/Triassic	Anthropogenic/other
Al ₂ O ₃	Ba	Ag
CaO	Bi	As
Ce	K ₂ O	Br
Co	Na ₂ O	Cd
Cr	Nd	Cl
Cu	Pb	Cs
Fe ₂ O ₃	Rb	Ge
Ga	S	Hf
MgO	SiO ₂	I
MnO	Th	La
Nb	Zr	Mo
Ni		P ₂ O ₅
Sc		Sb
Sm		Se
Sr		Sn
TiO ₂		Ta
V		Tl
Y		U
		W
		Zn

An example of geological influence over the geochemistry is demonstrated in Figure 13 which shows Ni values (in mg kg⁻¹) plotted as graduated symbols over a simplified geological map of the BMAP. It shows that the elevated levels of Ni are associated with the Antrim Basalts to the North of the City and the lower levels of Ni are to the south of the city over the Permian and Triassic deposits. There are also “hotspots” of Ni throughout the city centre which will be discussed in due course.

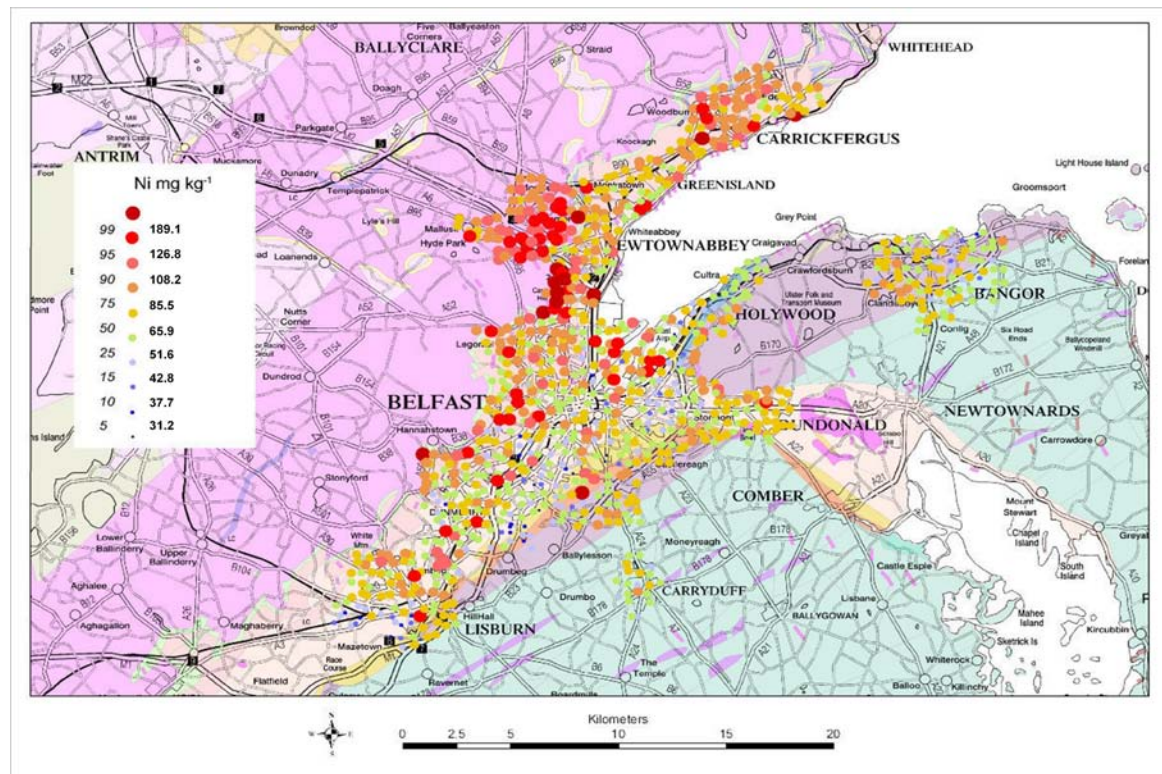


Figure 13. Nickel (mg kg^{-1}) in Belfast top soils with simplified geological underlay

1.13 ENRICHMENT FACTORS

Figure 14 shows enrichment factors of elements analysed in both the rural and urban datasets. The median value was taken for each element from the urban data and the surrounding rural data (using a 10km buffer) and plotted on a log scale. From this we can give a general overview of elements that are anthropogenically influenced, such as Sn, Pb and Mo to the far left of the chart and elements that are influenced by the underlying parent material, such as Ni, Cr and V which lie to the middle and right hand side of the chart. It should be noted that as the parent material is so varied within Belfast that this is an approximation and many other factors such as soil texture should be taken into consideration for a more accurate description of elements that are elevated due to urban contamination.

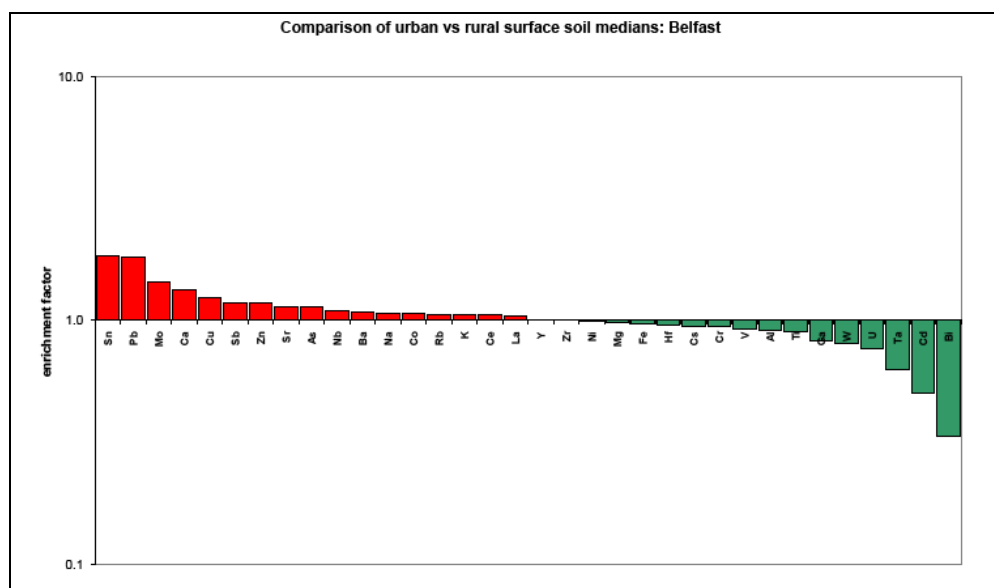


Figure 14. Enrichment Factors for Belfast urban and rural data

1.14 URBAN COMPARISONS

This section of the report outlines a comparison of median values between Belfast and 3 other major industrial cities within the UK; Glasgow (Fordyce, in prep.), Cardiff (Brown, 2004) and Manchester (see Figure 15).

Belfast is relatively low in heavy metal contamination in comparison with other urban areas. In comparison with Glasgow, Cardiff and Manchester, Belfast has much lower concentrations of Cu, Pb and Zn. With their long and extensive industrial history, Manchester and Glasgow have the highest concentrations of these elements.

However, Belfast has the most elevated levels of Cr and Ni. This can be attributed to the underlying Antrim Basalts which have naturally elevated concentrations of these elements; therefore it would be highly unlikely that these levels would be of concern to human health due to its natural mineral form – probably Cr-Ni rich magnetite. The levels of Cr in Belfast are higher still than Glasgow, which has a long history of Cr Ore processing and as such has a legacy of Cr contamination to the south east of the city where the largest Cr ore plant was housed.

None of the cities have elevated levels of As, and no median values fall above the soil guideline of 32 mg kg^{-1} . Again Manchester has the highest concentration of As, which can be explained by the underlying geology and its industrial history. Glasgow has the 2nd lowest median concentration of As which can be explained as it is underlain by As-depleted coal measures and therefore the burning of these coals would not deposit As-rich ash over the city.

Belfast does have areas within the city that seem to be elevated in heavy metals due to anthropogenic contamination, but these are relatively confined to the docklands area and airport.

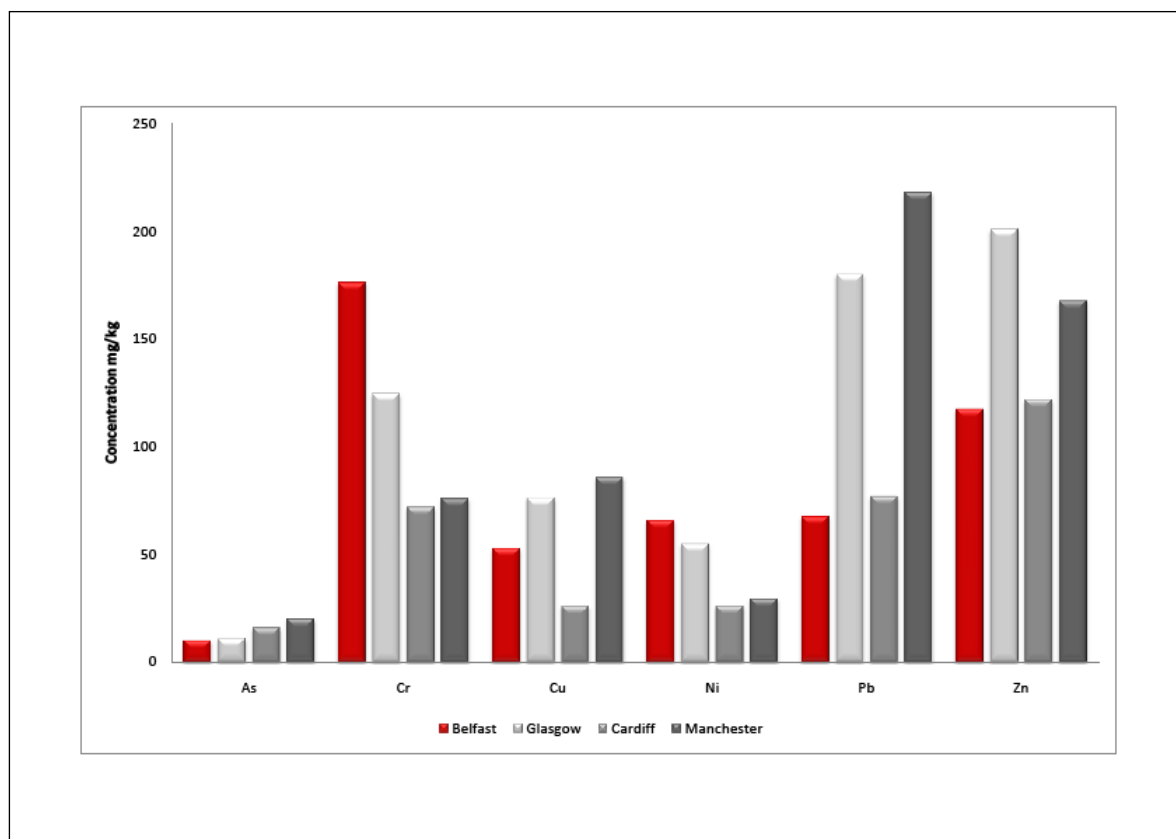


Figure 15. Urban comparisons from Belfast, Glasgow, Cardiff and Manchester

1.15 GEOCHEMICAL ANOMALIES IN THE URBAN AREA OF BELFAST

There are several geochemical “hotspots” within the Belfast area. These can be described as sample sites where three or more elements fall above the 99th percentile of their concentration distributions. The sites fall on various land uses including industrial and also residential/commercial and recreational land uses and are listed in Table 10. It is recommended that further investigation is carried out in order to establish the spatial extent of these hotspots (in three dimensions) and also the bioavailability of the elements in order to establish if these are of risk to human health. It would be useful to have access to historical land use maps and industrial archaeology information to help put the data into context.

Table 10. Belfast ‘hotspots’.

Sample No	Elemental Anomalies	Primary Land use (as noted on field card)	Secondary Land use (as noted on field card)	Other comments (as noted on field card)
570037	As, Ce, Ge, Th, Y	Urban open space, cleared, derelict.	Commercial and residential	Grass verge between shops and houses
570050	As, Ba, La, Nb, Ni, Se, Sr, Y	Electrical generation plant	Tip	Sample taken on ash dump
570185	K ₂ O, Nb, Rb	Commercial and residential		Garden in front of house
570242	V, Zn, Nb, Th	Industrial	Engineering, manufacturing, ship building	Demolition site in docks, much contamination at site
570243	Cr, MnO, Fe ₂ O ₃ , Co, Ni	Rough grazing	Major road	Empty cattle field
570262	K ₂ O, Rb, Nb	Pasture		Housing 10m away
570298	K ₂ O, Rb, Nb	Pasture	Recent coniferous forest	New trees planted
570346	V, MnO, Fe ₂ O ₃ , Sr	Major Road	Commercial and residential	New residential area
570376	Fe ₂ O ₃ , Nb, Pb, Sb, Sn, Ta, W	Industrial	Urban open space, cleared but derelict	Paint Factory
570685	Se, Y, La, Ce	Pasture	Major Road	Field next to busy road
570695	Zn, Sn, Sb, Pb	Recreational		Grassy area around football pitch. Slag in sample. Groundsman informed samplers that ground was landfill site.
571135	Y, La, Ce	Arable	Commercial and residential	Crop field. 30m from residential back gardens. Quartz and dolerite on surface.
571168	Co, Mo, Ce, Th, V, Sr, Y, Ni, Nb, Ga	Industrial	Manufacturing	Old industrial site, possible former spoil heap. Slag in sample.
571322	K ₂ O, Ga, Zr, Nb	Urban Open Space	Commercial and residential	Open space next to newly built houses
571354	Cu, Zn, Sb, Ba	Rough Grazing		Grassy area beside housing. Slag in sample.
571386	As, Ba, Co, Cu, Ge, Ga, Mo, Pb, Sb, Se, Y, Zn	Urban open space	Commercial and residential	Grass mound within sports ground. Formerly an air raid shelter.
571437	V, Y, Th	Port area and airfield		Grass area beside airport runway. Slag and coal in sample
571589	Cr, Fe, Sn, Zn, Pb, Nb, Ta, W	Engineering, manufacturing, shipbuilding	Urban open space, cleared but derelict	Sample taken with stainless steel trowel. Much contamination in sample, inc slag, glass and wire.

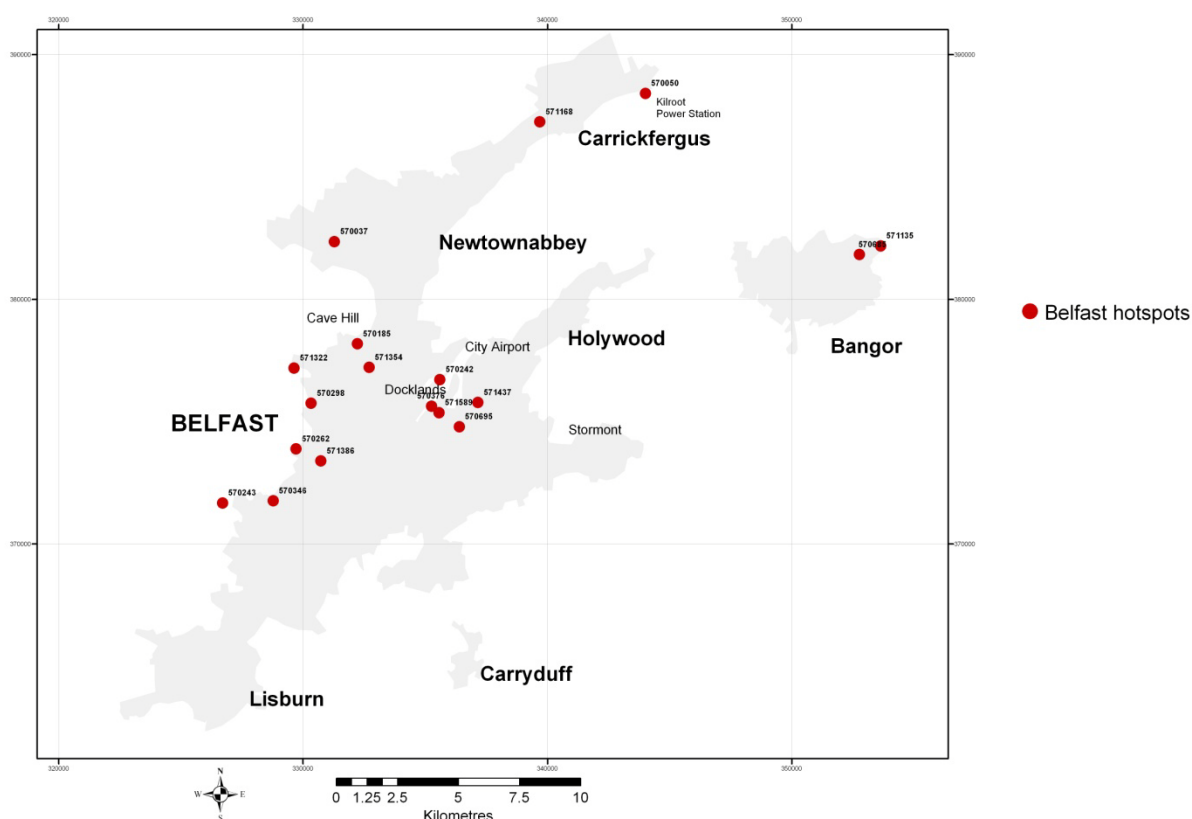


Figure 16. Belfast elemental anomalies within BMAP

The main cluster of anomalies is focussed around the docklands and shipyards area. This can be attributed to its history of shipbuilding and heavy engineering, and the importation and export through the port of raw materials such as metal ores. Elevated levels of elements such as Cr, Zn and Pb can be associated with the materials used for ship building and also are by products of atmospheric deposition from burning fossil fuels. The anomalies here are not of great concern to human health as it is still classed as an industrial area and it is very unlikely that the source-pathway-receptor linkage for human ingestion could occur.

Other interesting findings are to the west of Belfast, one of which is a grassy mound that falls within a sports ground, which apparently was a former air raid shelter and had since been infilled. The field card information collected at site records the presence of contaminants within the soil which includes iron wire and coal, suggesting that the shelter was filled with spoil, which would explain the elevated levels of elements within this sample. Further investigation of this site would be necessary to map the extent of the infill.

There are many areas to the west of Belfast that are being redeveloped and now host new residential areas. It has been identified that land in and around these new estates demonstrate elevated levels of elements such as Zr, Nb and V. Again, further investigation would be suggested for these areas, although these elements are probably hosted by resistate, non-mobile mineral phases. Also they are not thought to be of great risk to human health and as a result there are no action levels for these.

To the east of Belfast in Bangor are two anomalies which are situated to the north east of Bangor and are both high in Y, La and Ce. This is probably geologically related to the presence of monazite, a highly resistate mineral that may have been derived from the underlying Triassic sandstones, though this may be a secondary host rock and their origin may be in the Palaeozoic greywackes to the southeast. These elements are not thought to pose a risk to human health and in their mineral form are highly unlikely to be bioavailable.

Other ‘hotspots’ occur to the north of Belfast around the Carrickfergus area. Both of these samples were collected from ‘made ground’, as noted on the field records, one of which was recorded as an ash dump and one of which was recorded as a possible former spoil heap. These are both likely to be discrete anomalies as they were both taken from ground that has been infilled with other materials. The two samples were recorded as containing slag, which would explain the high levels of elements such as V, Ni and Mo. Both land uses are noted as ‘industrial’ so further investigation would not be recommended for these sites.

Recommendations for further work

Although this survey has shown that the topsoils of Belfast are not highly contaminated with potentially harmful inorganic pollutants, such as heavy metals, relative to other major cities on the UK mainland; and that the most contaminated sites are restricted to the industrially-designated areas rather than residential zones, there are a few ‘hot spot’ sites where additional follow-up work may be desirable.

Higher-density re-sampling on some of the contaminated sites may be beneficial in establishing the spatial extent of the anomalous values, as would more detailed analysis of the stratigraphy of contamination by coring and subsampling at different depths.

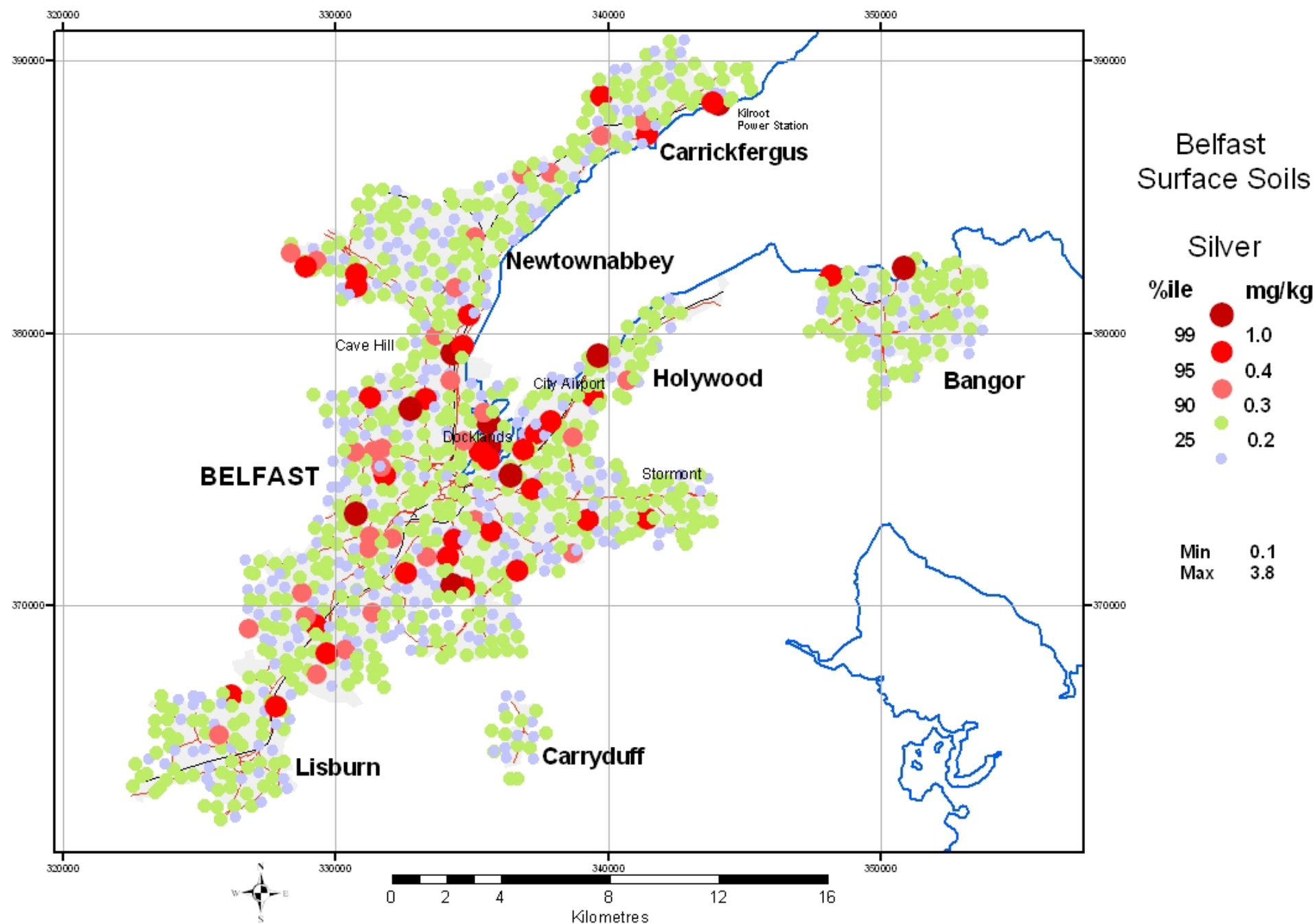
Those sites showing high Cr, Ni, V, La, Ce, Y, Nb or Th values are most likely to be of geogenic origin, and the metals are unlikely to be biologically available even where they are at high levels. However, sites showing high soil levels of anthropogenic heavy metals and metalloids, such as Cu, Pb, Zn, As, Sb and Mo, may be worth testing for bioavailability, to ensure that, if these sites were redeveloped for domestic development then any potential risk could be identified and possible action taken if required (such as topsoil removal and replacement).

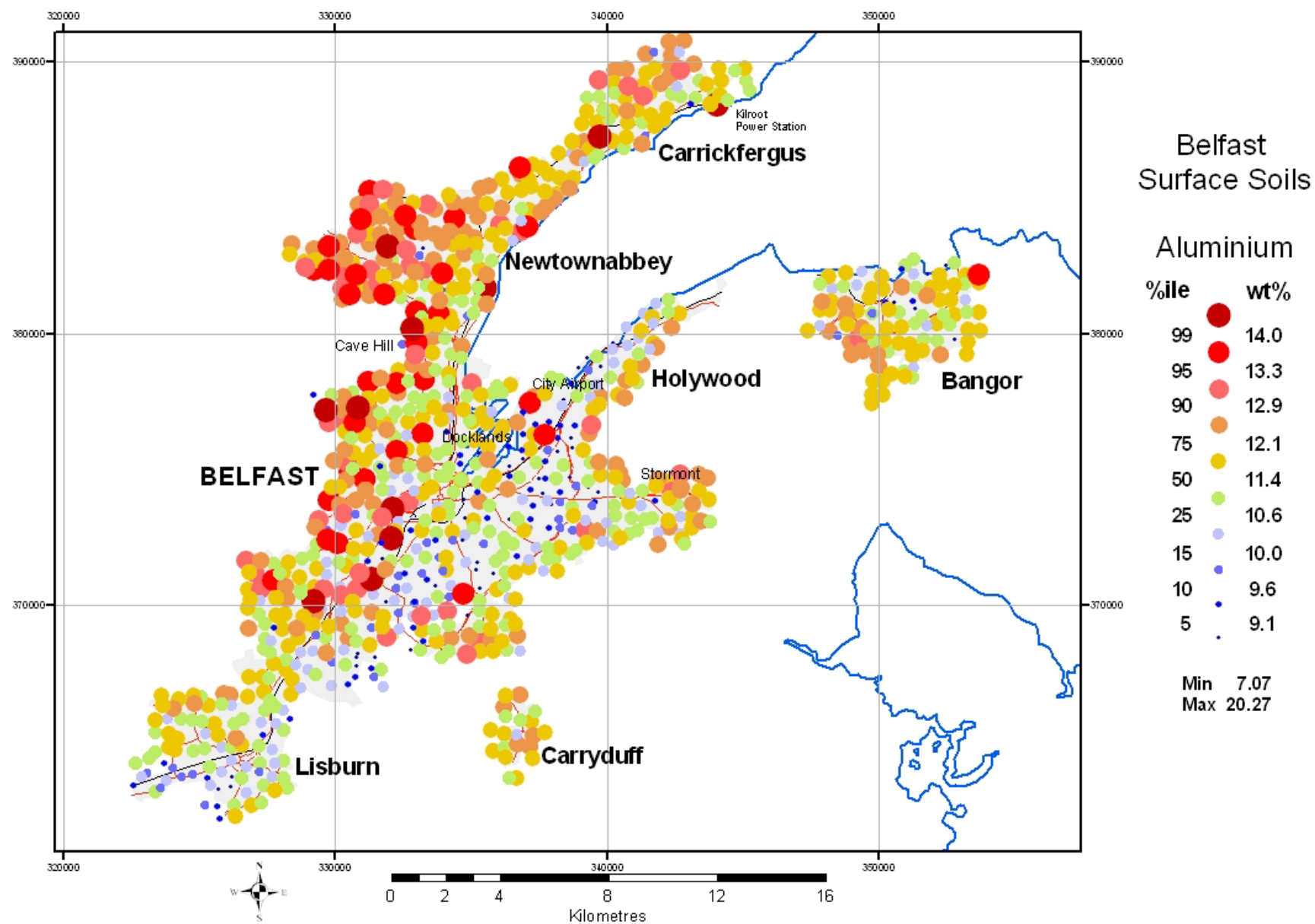
Remaining quantities of the soil samples taken during this survey are archived at BGS for any future examination or analysis to be carried out if required.

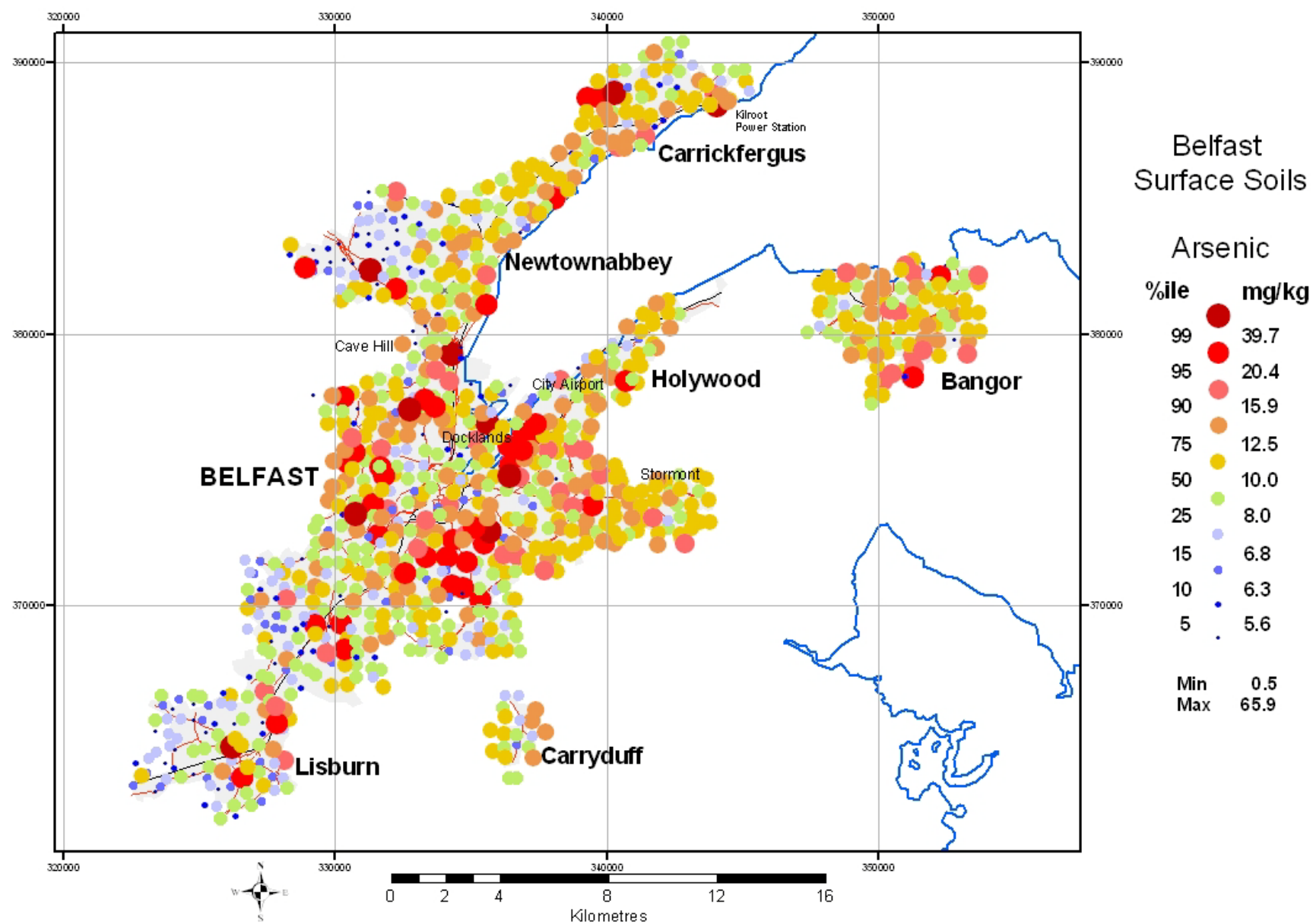
This is a valuable urban geochemistry dataset and would also perhaps provide the resource for a number of applied MSc projects.

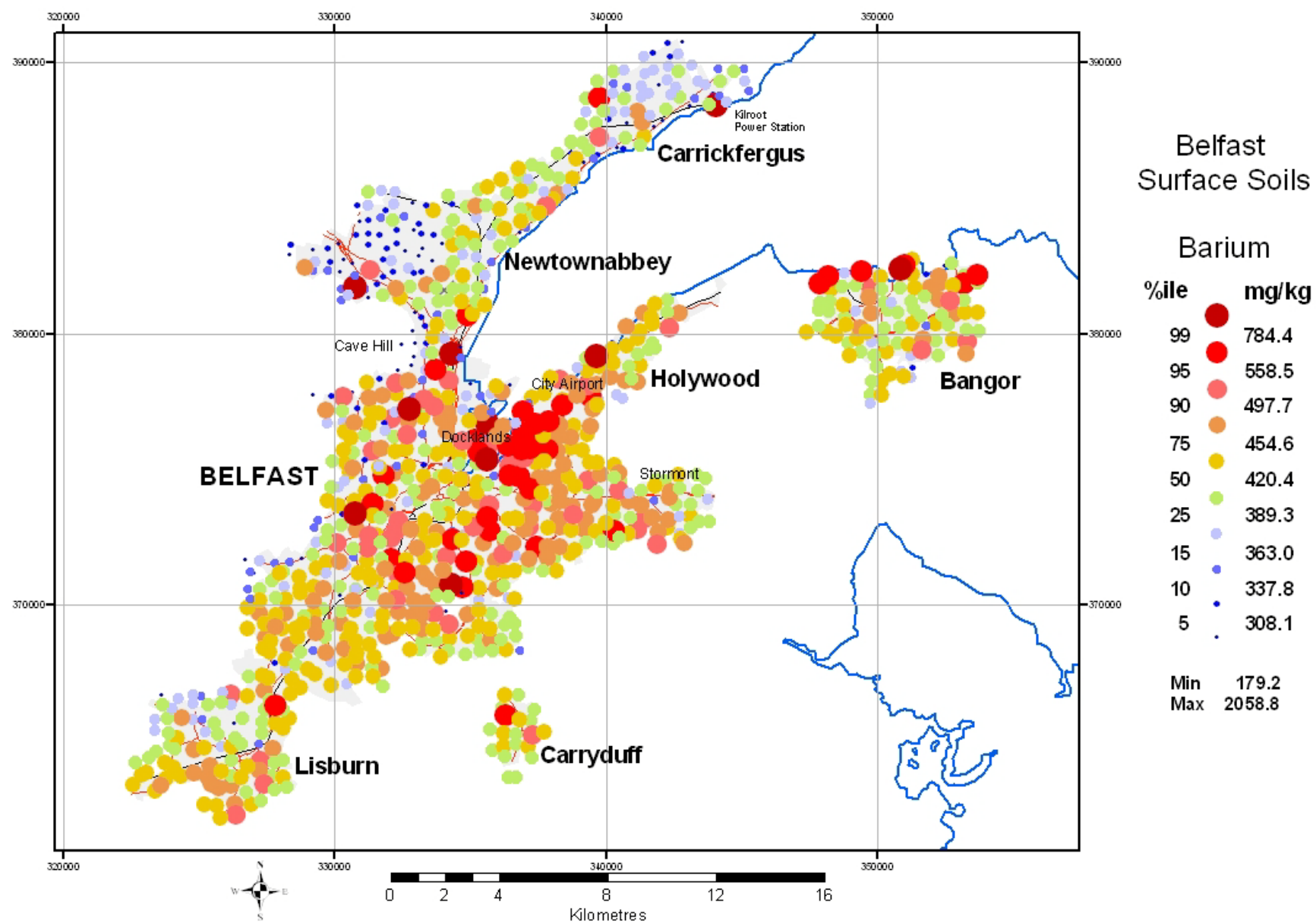
Appendix 1 Graduated symbol maps of the urban soil geochemistry of Belfast

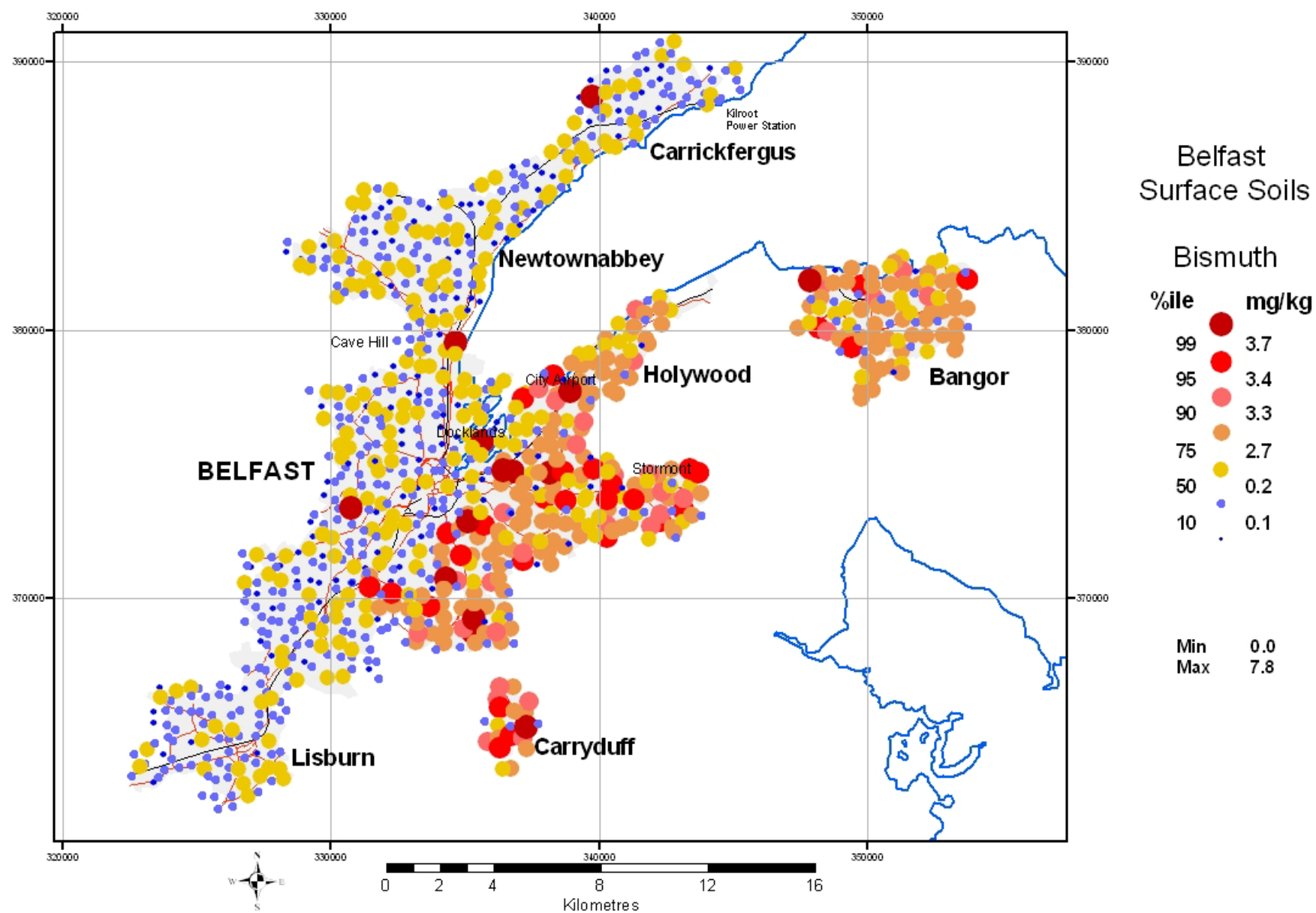
Major elements	Trace elements			
Al ₂ O ₃	Ag	Cs	Ni	Ta
CaO	As	Cu	Pb	Th
Fe ₂ O ₃	Ba	Ga	Rb	Tl
K ₂ O	Bi	Ge	S	U
MgO	Br	Hf	Sb	V
MnO	Cd	I	Sc	W
Na ₂ O	Ce	La	Se	Y
P ₂ O ₅	Cl	Mo	Sm	Zn
SiO ₂	Co	Nb	Sn	Zr
TiO ₂	Cr	Nd	Sr	

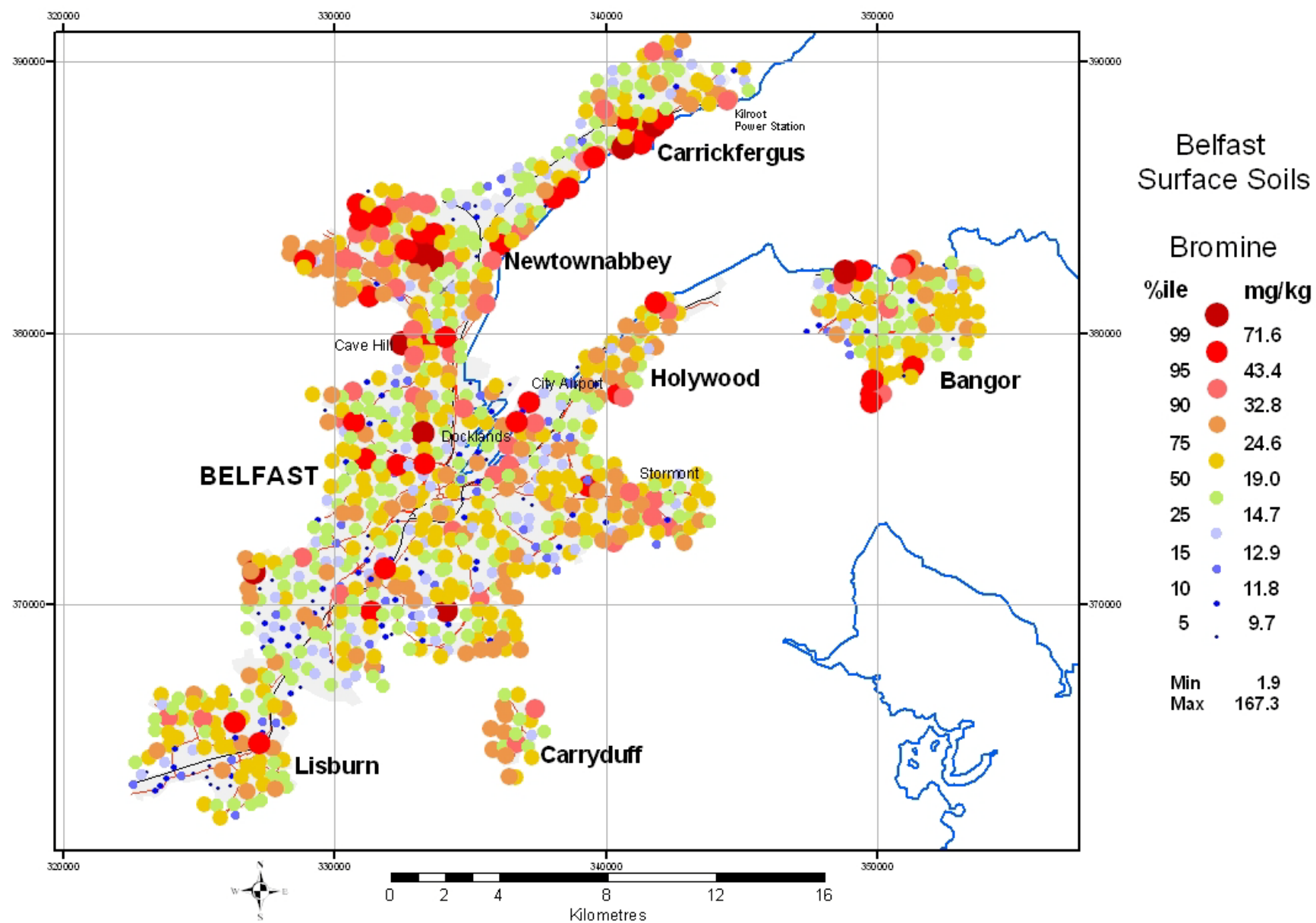


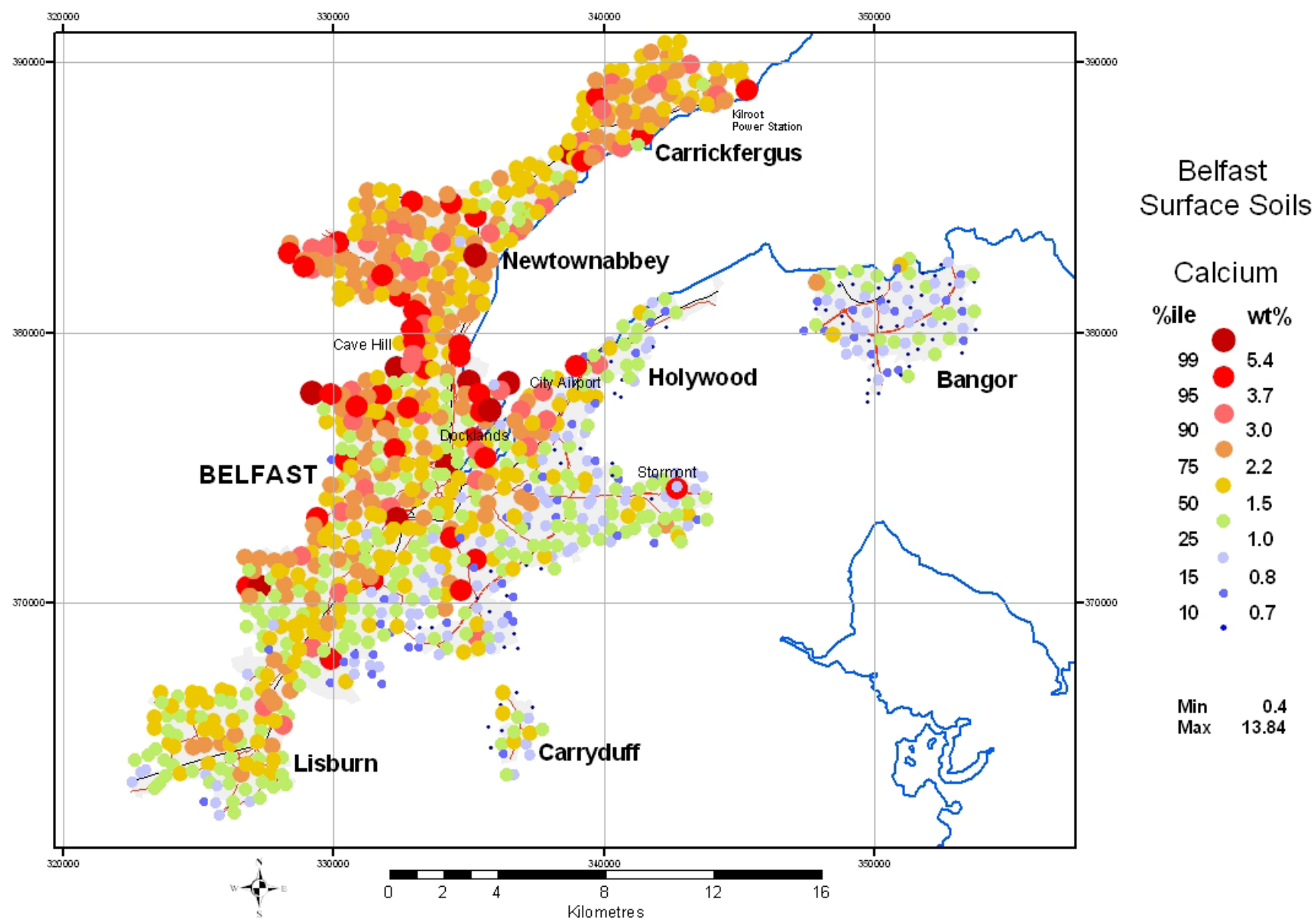


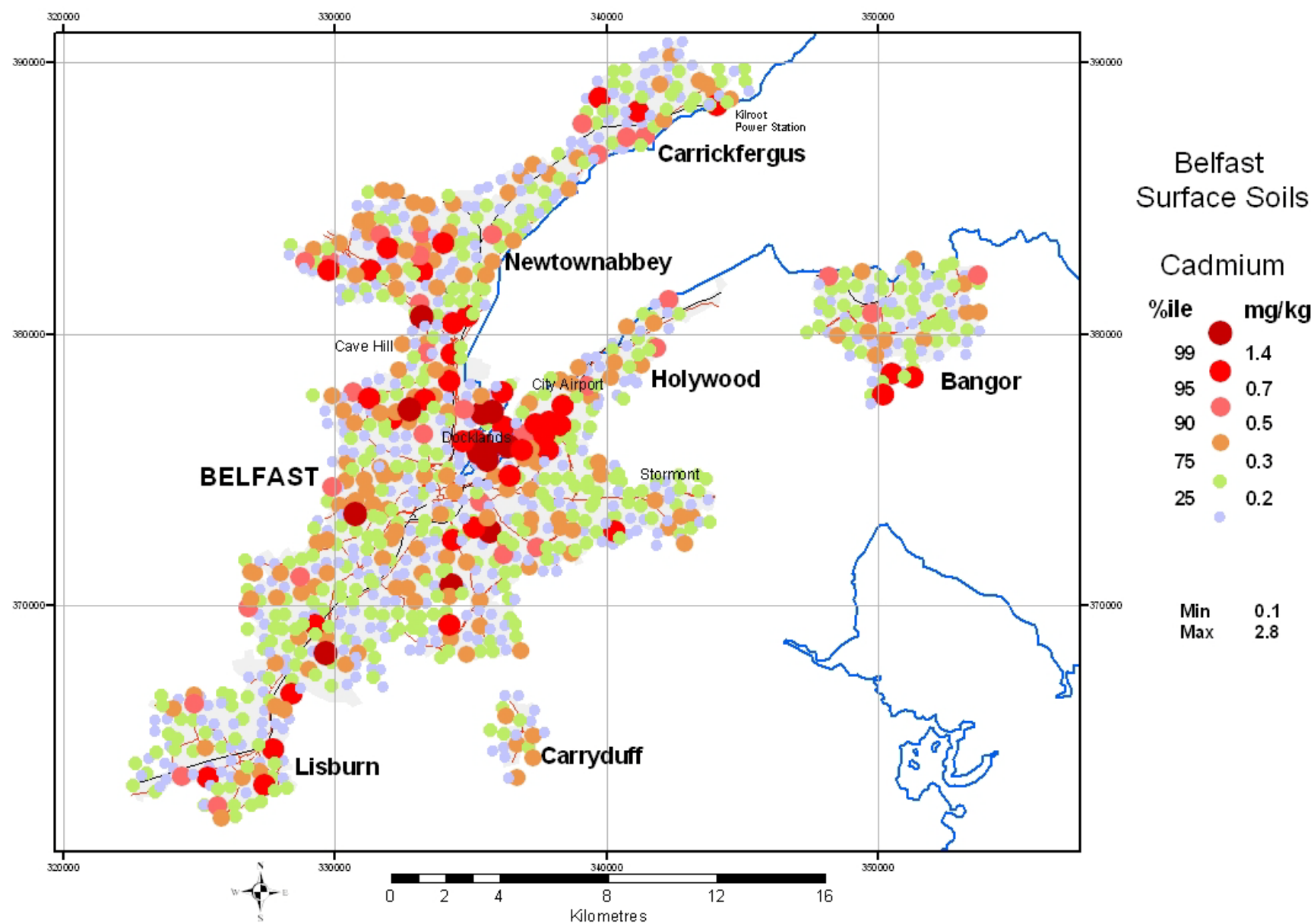


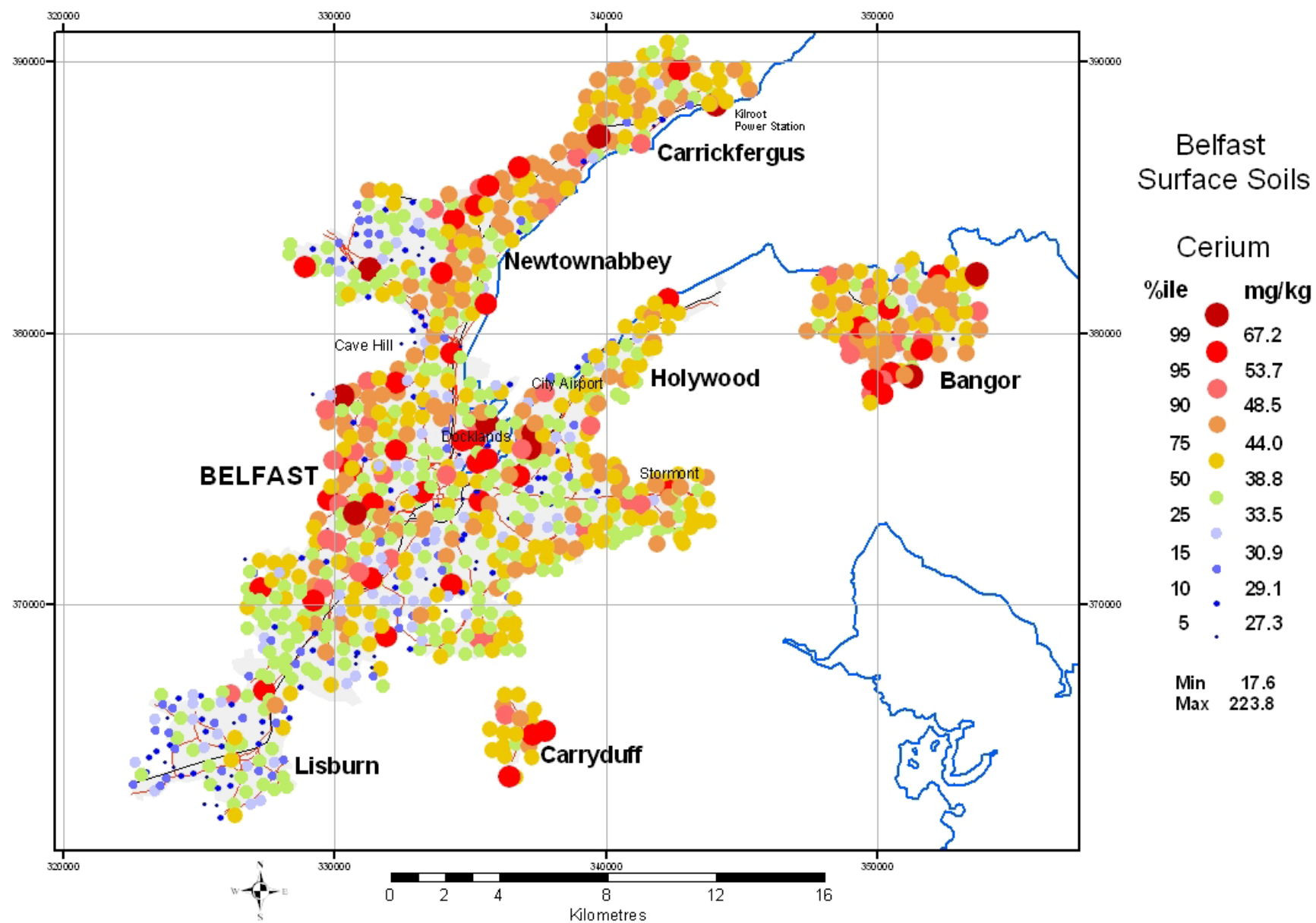


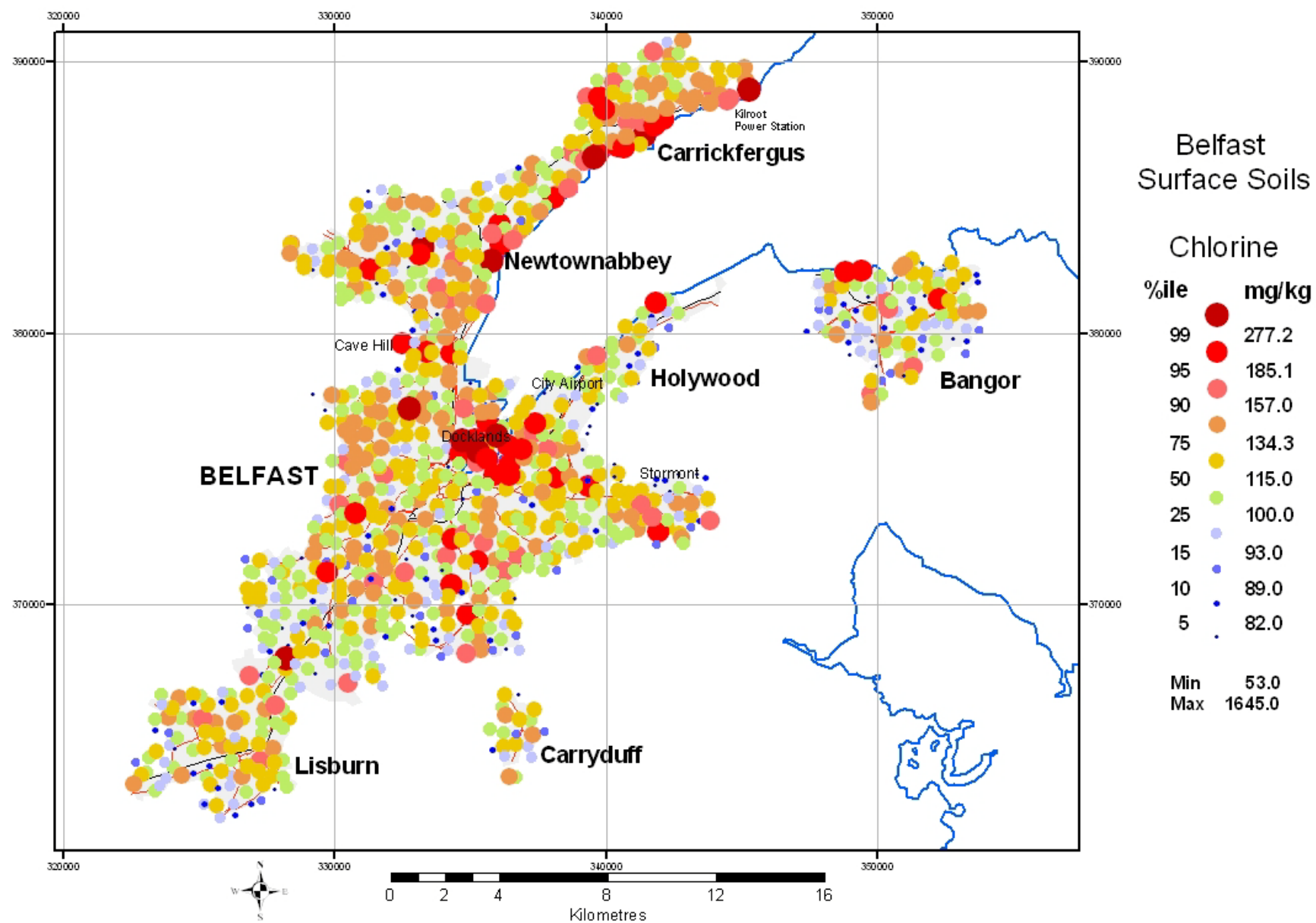


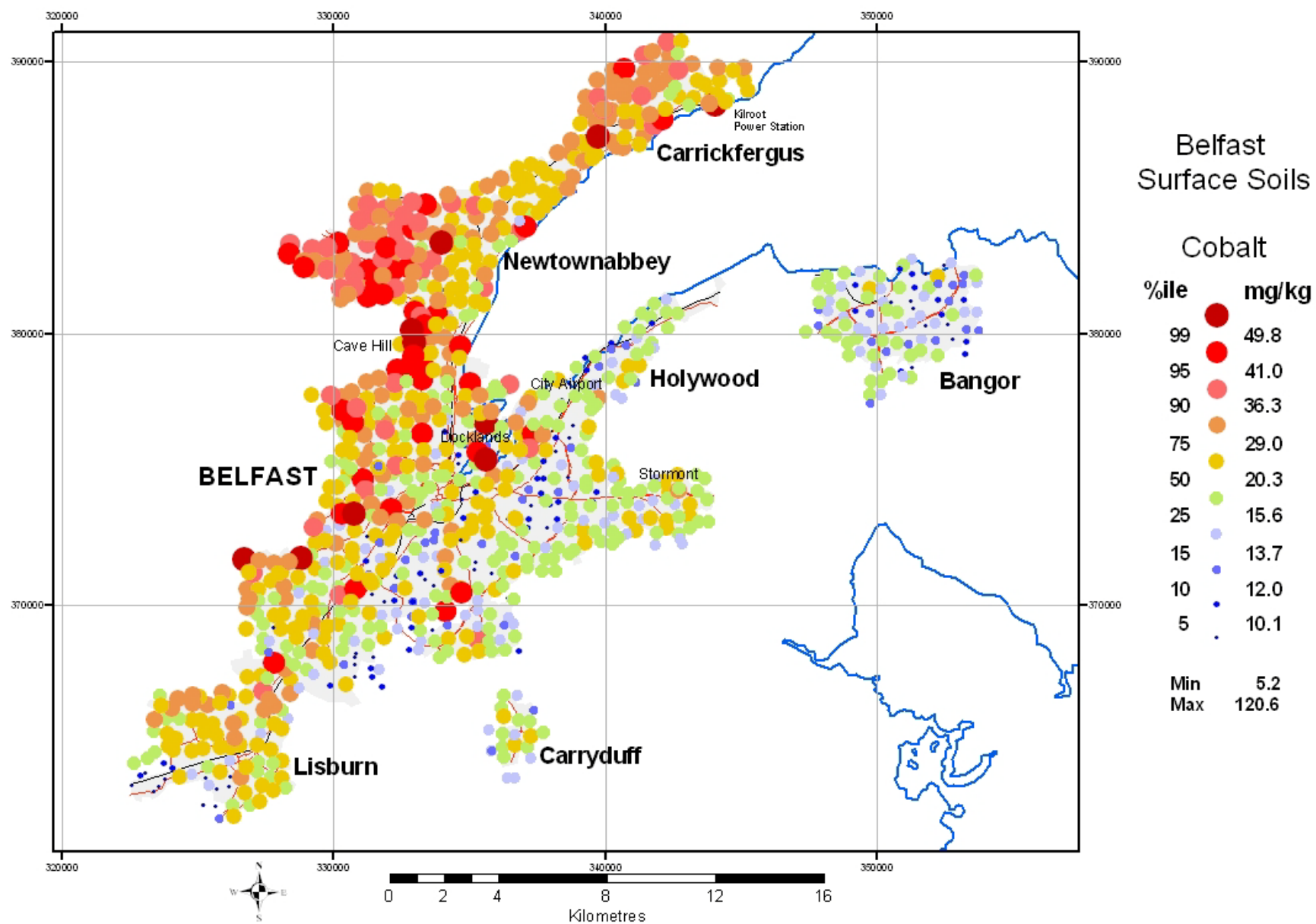


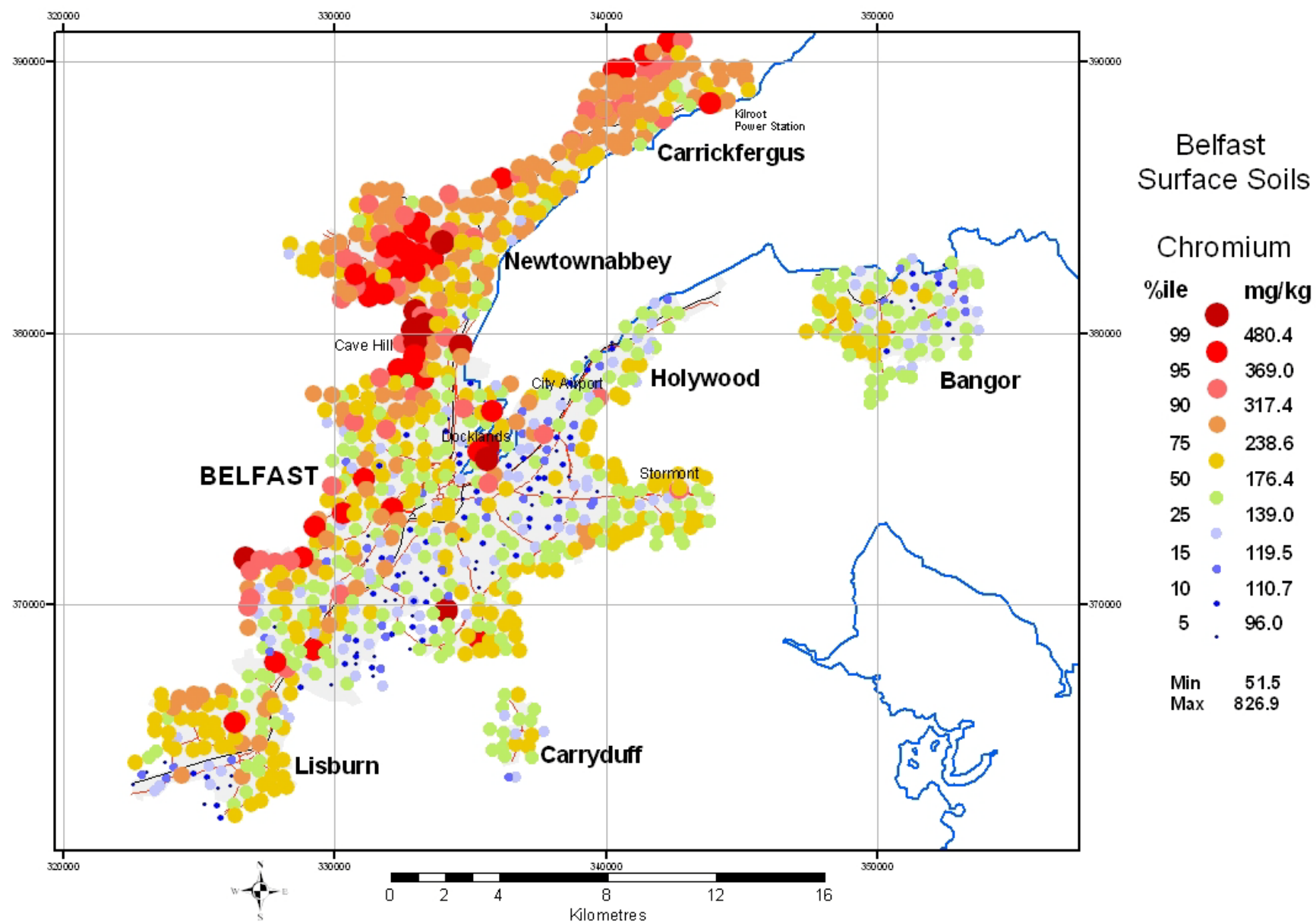


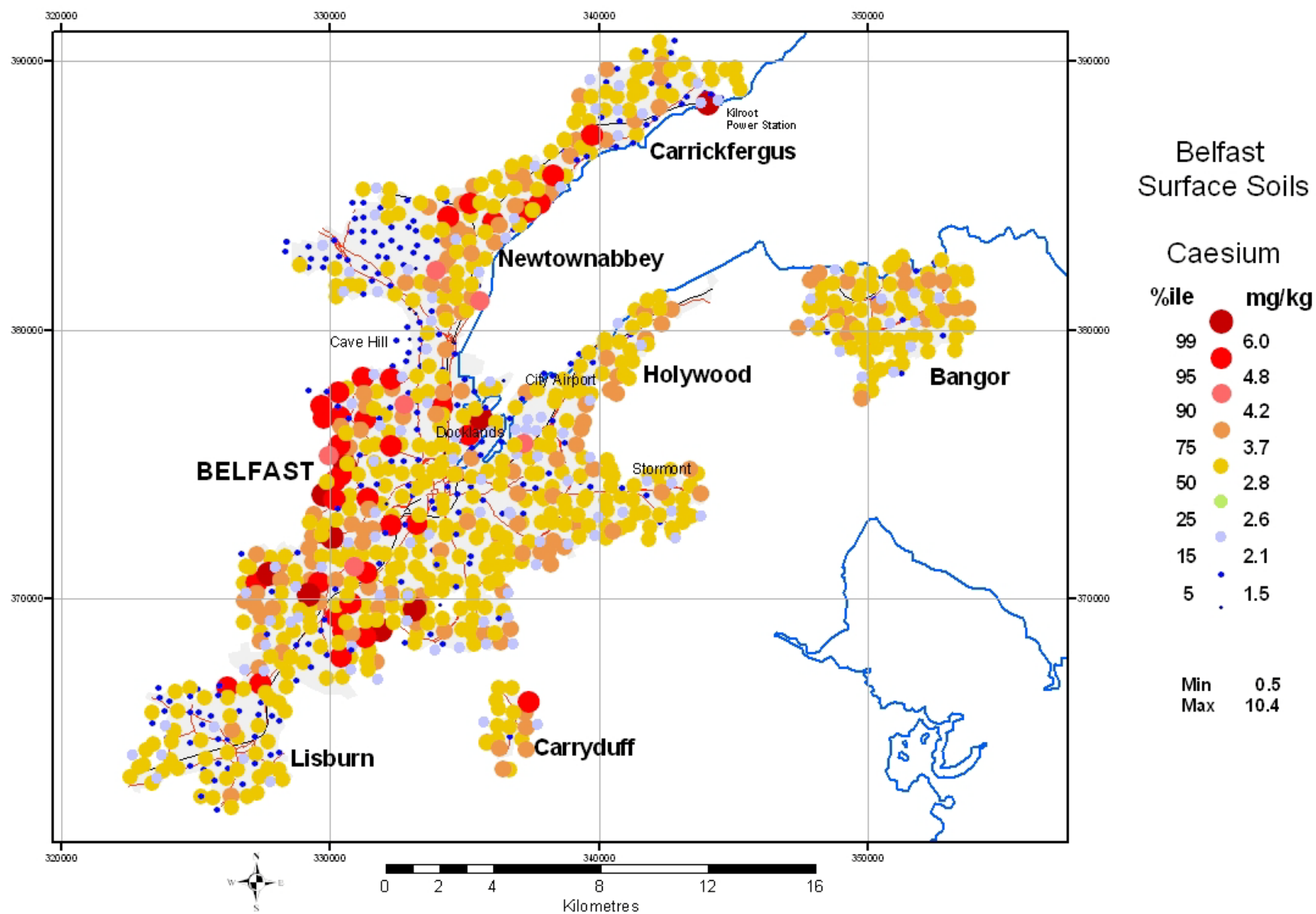


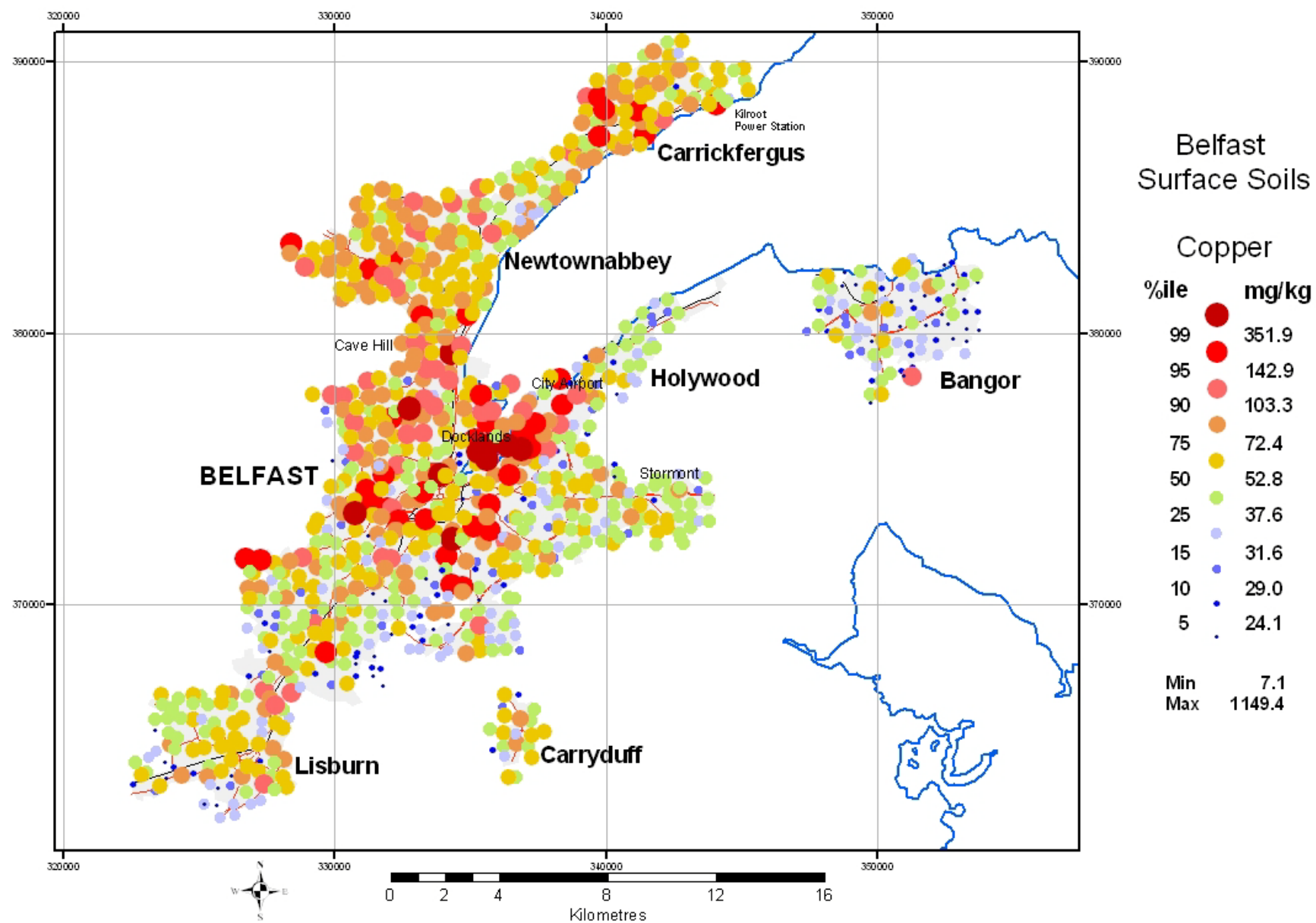


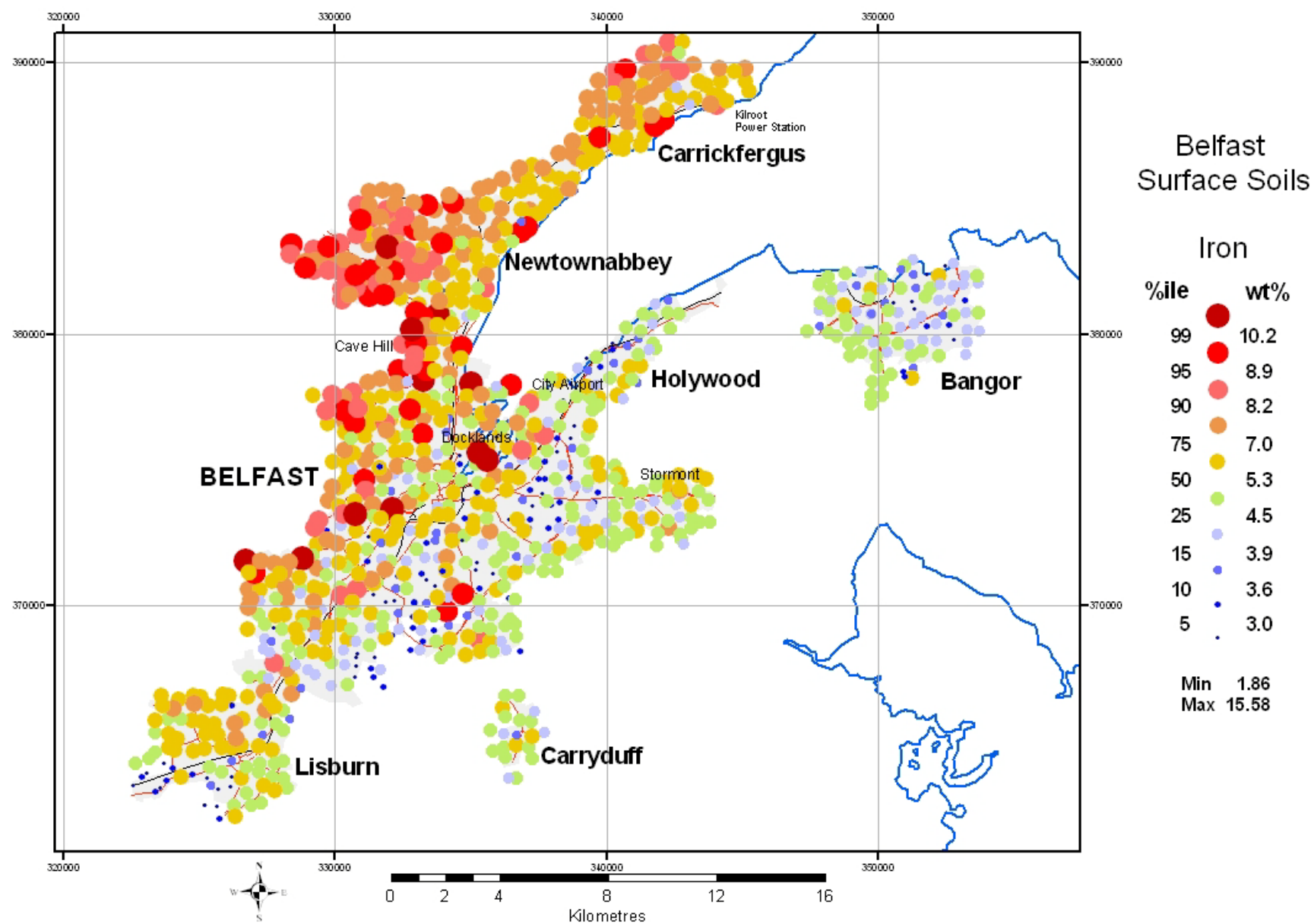


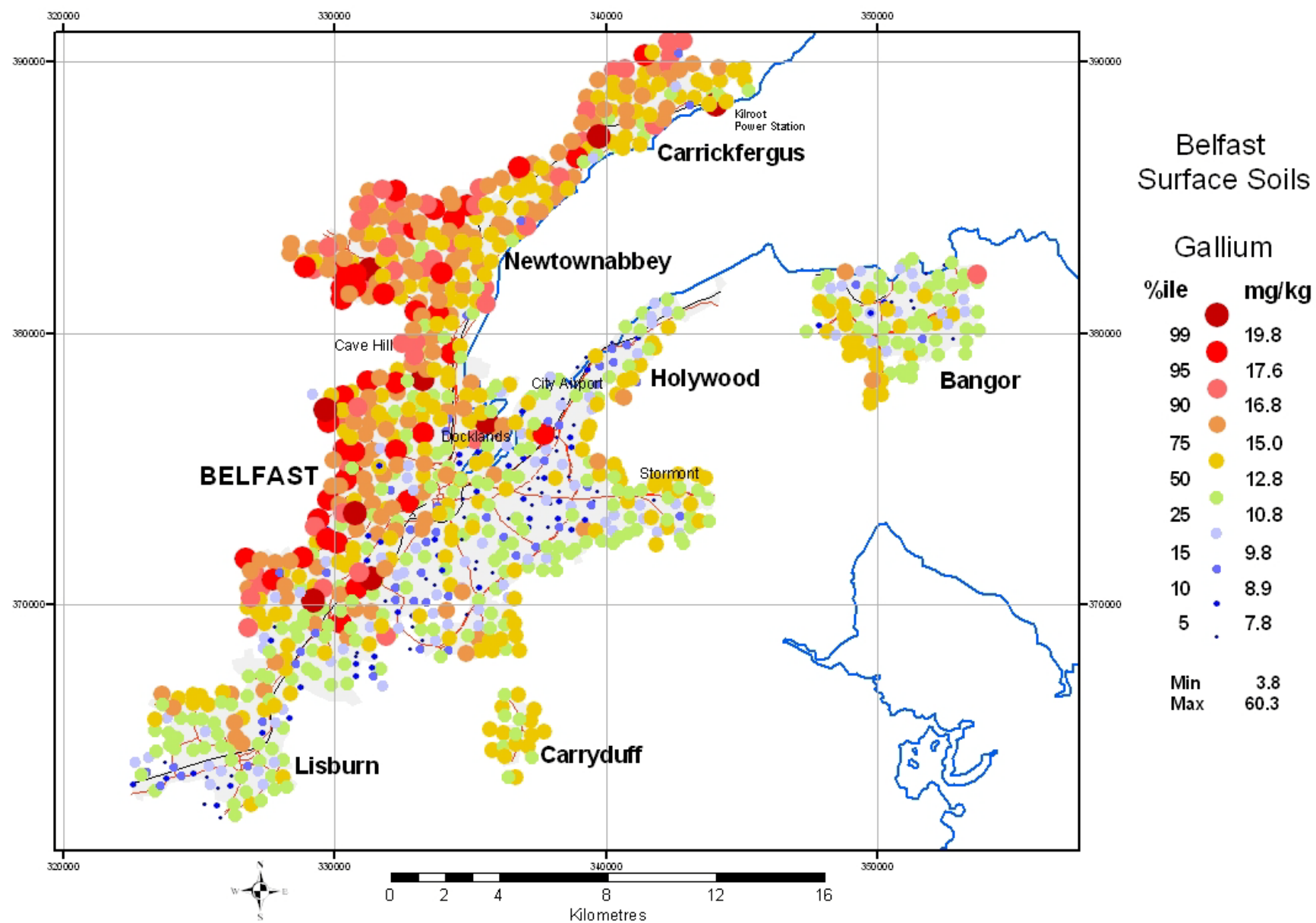


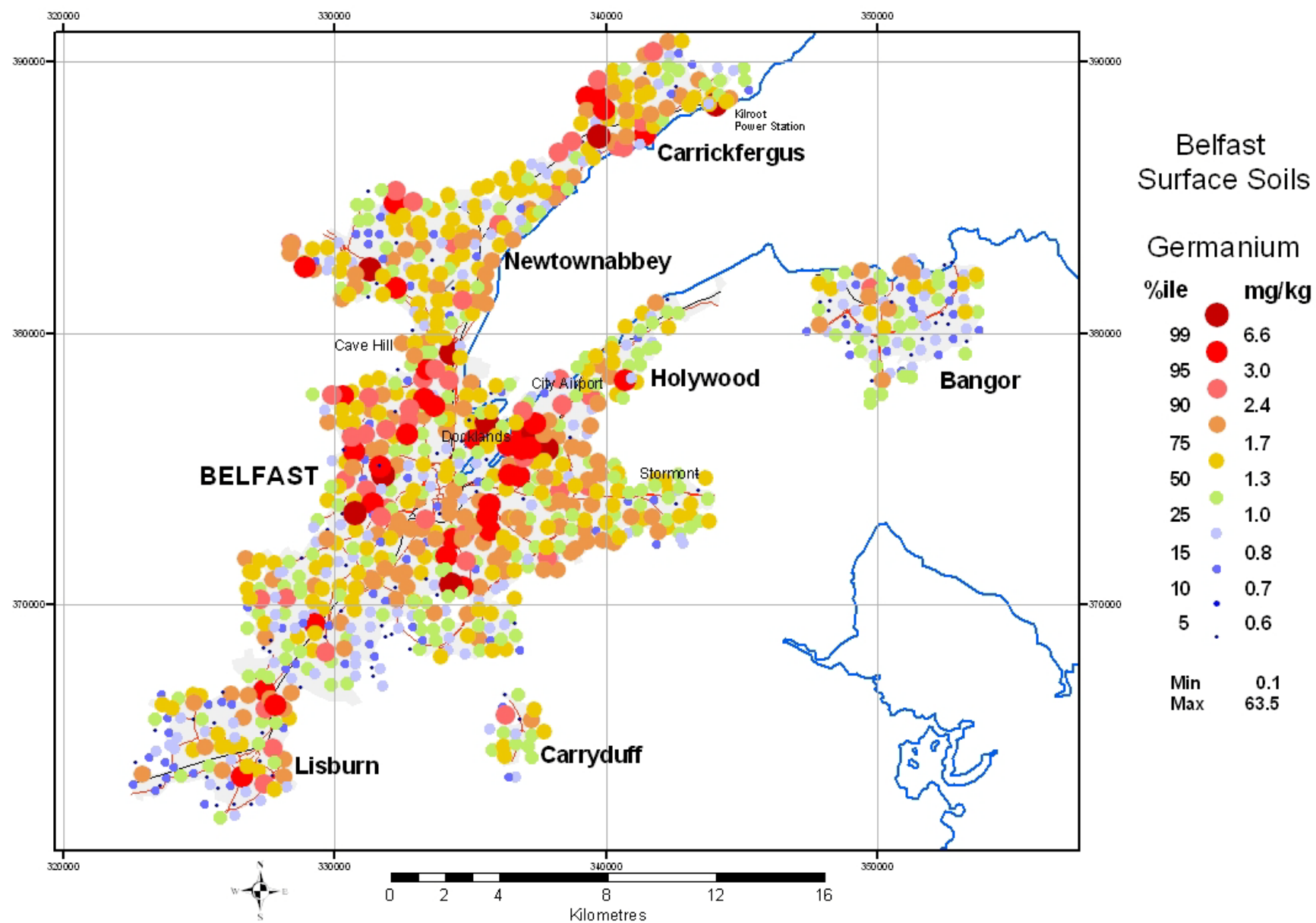


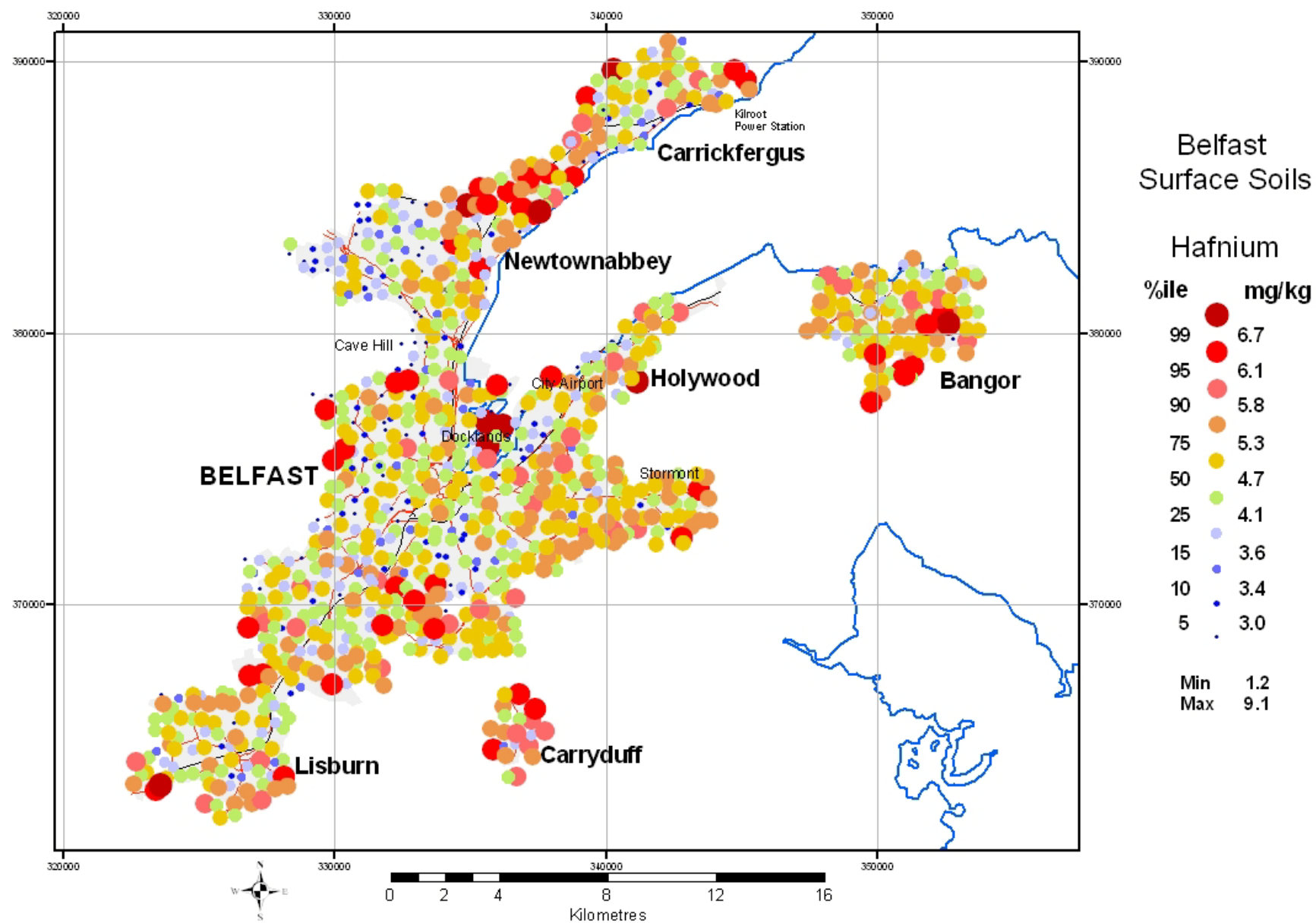


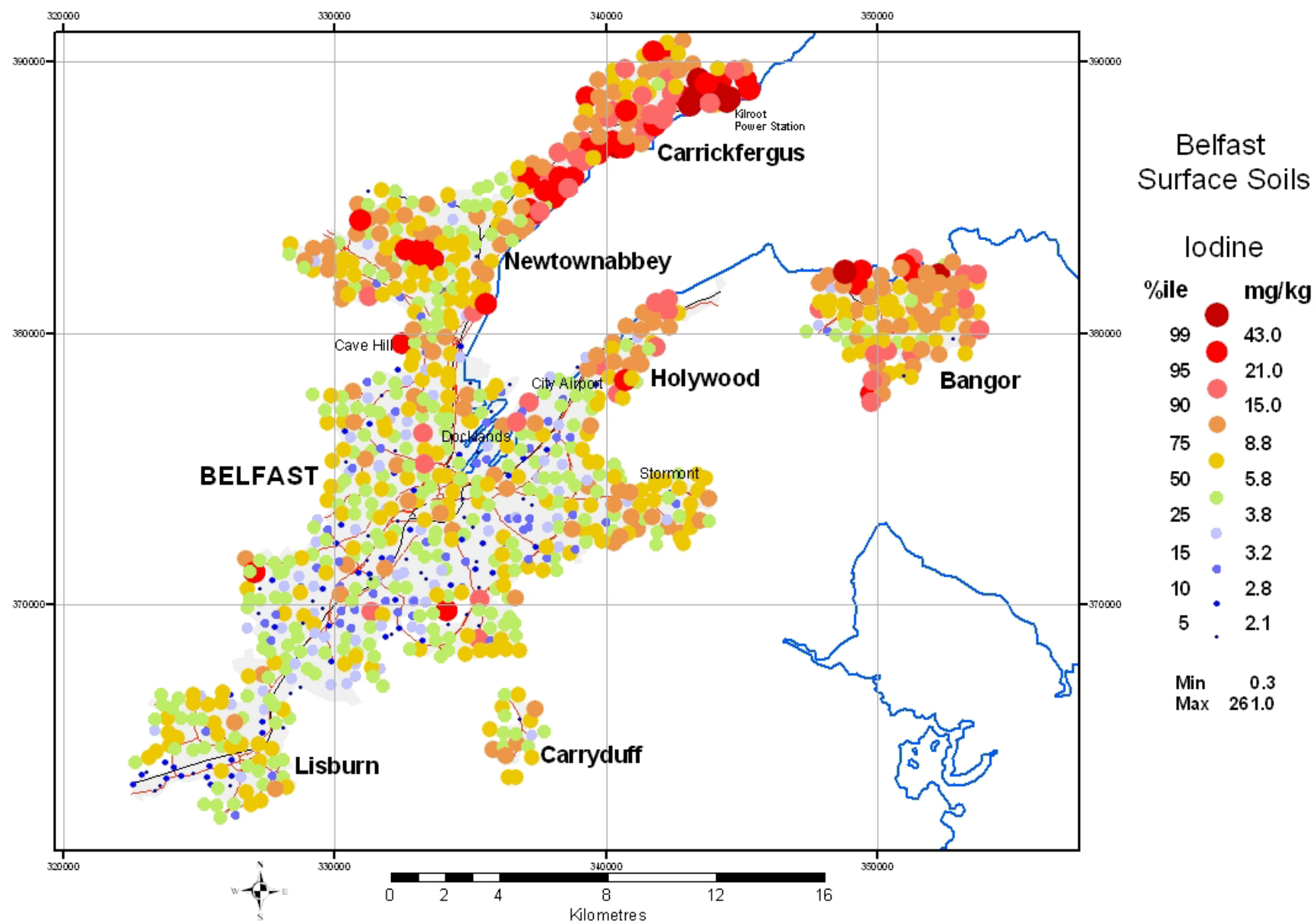


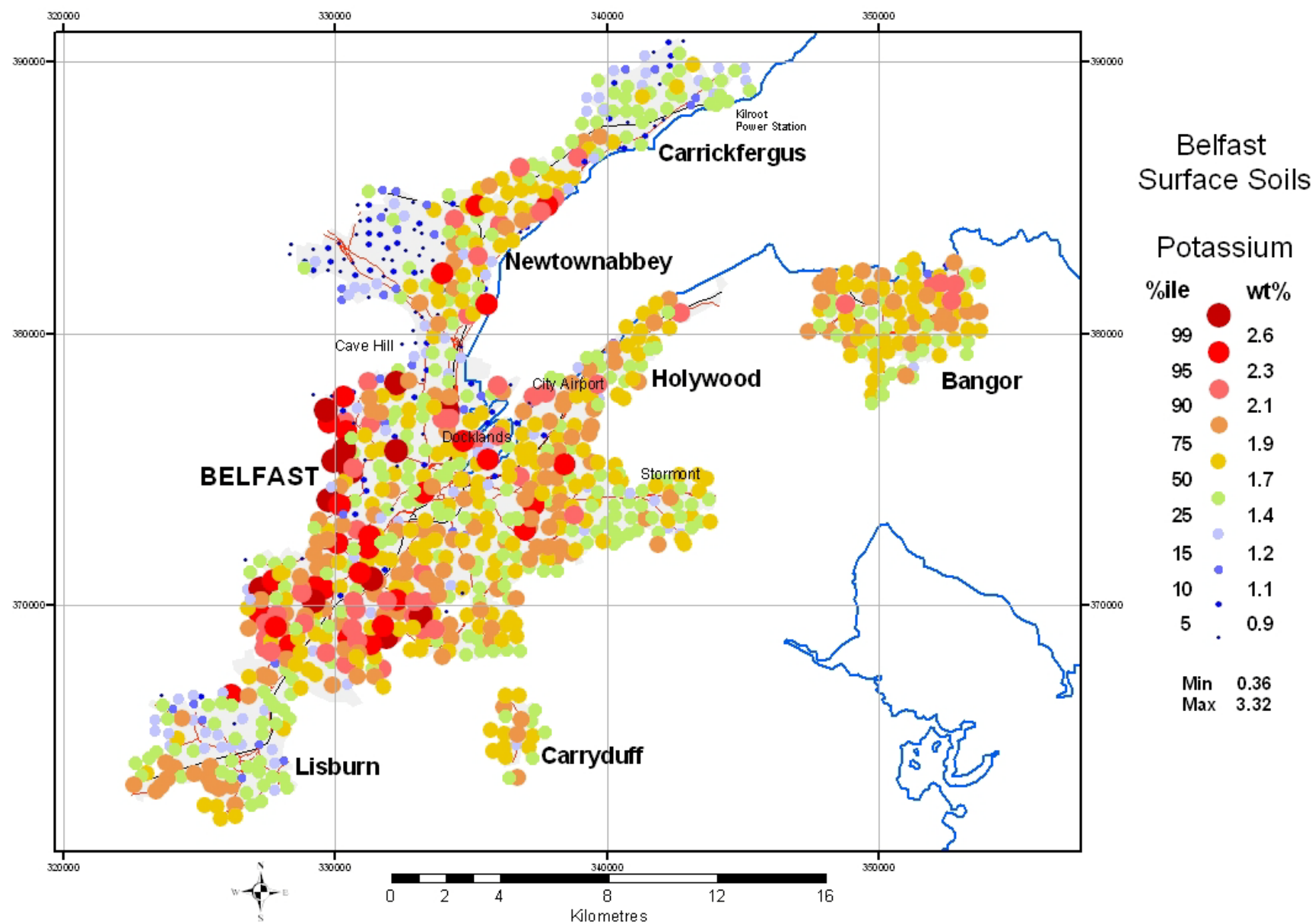


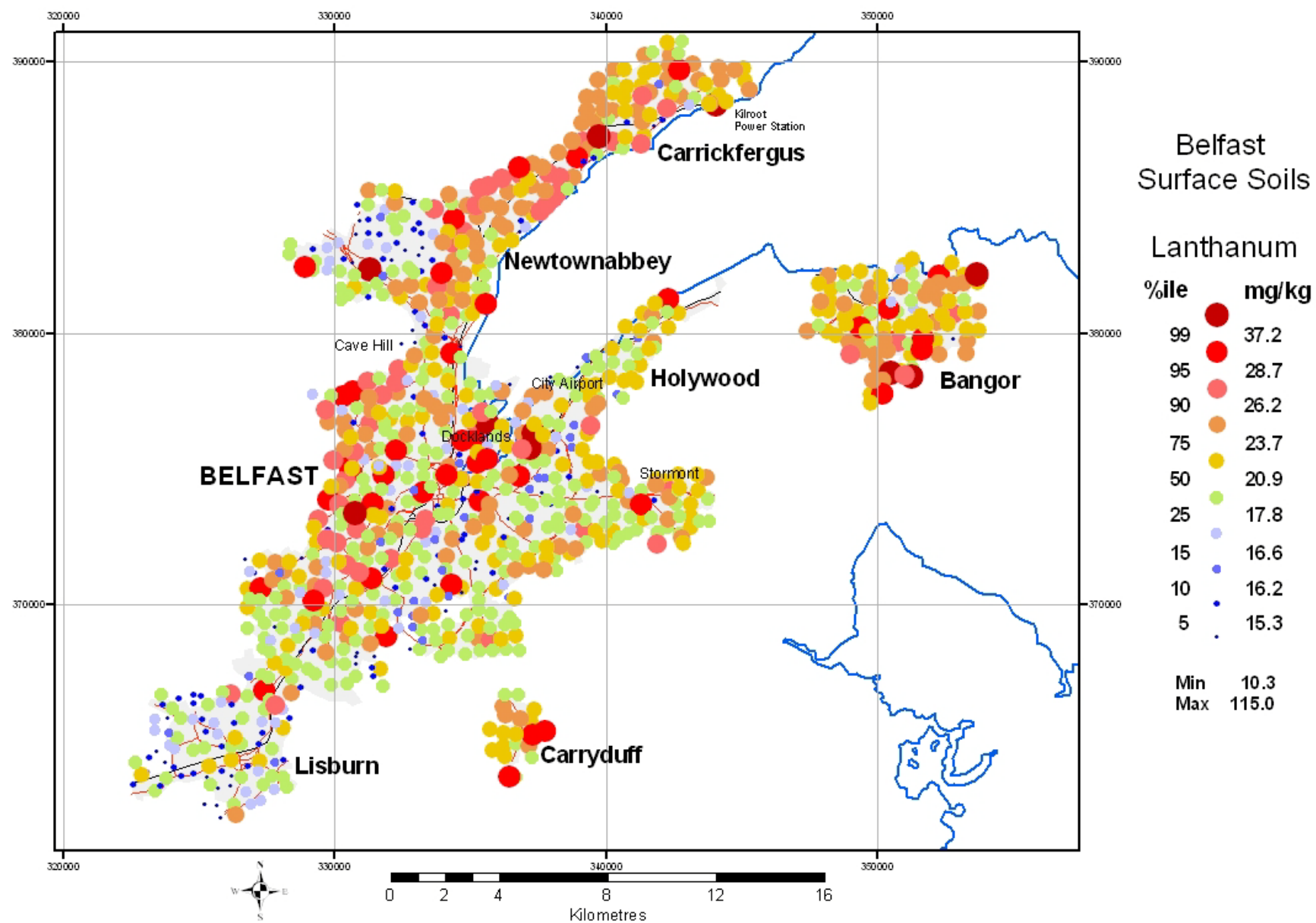


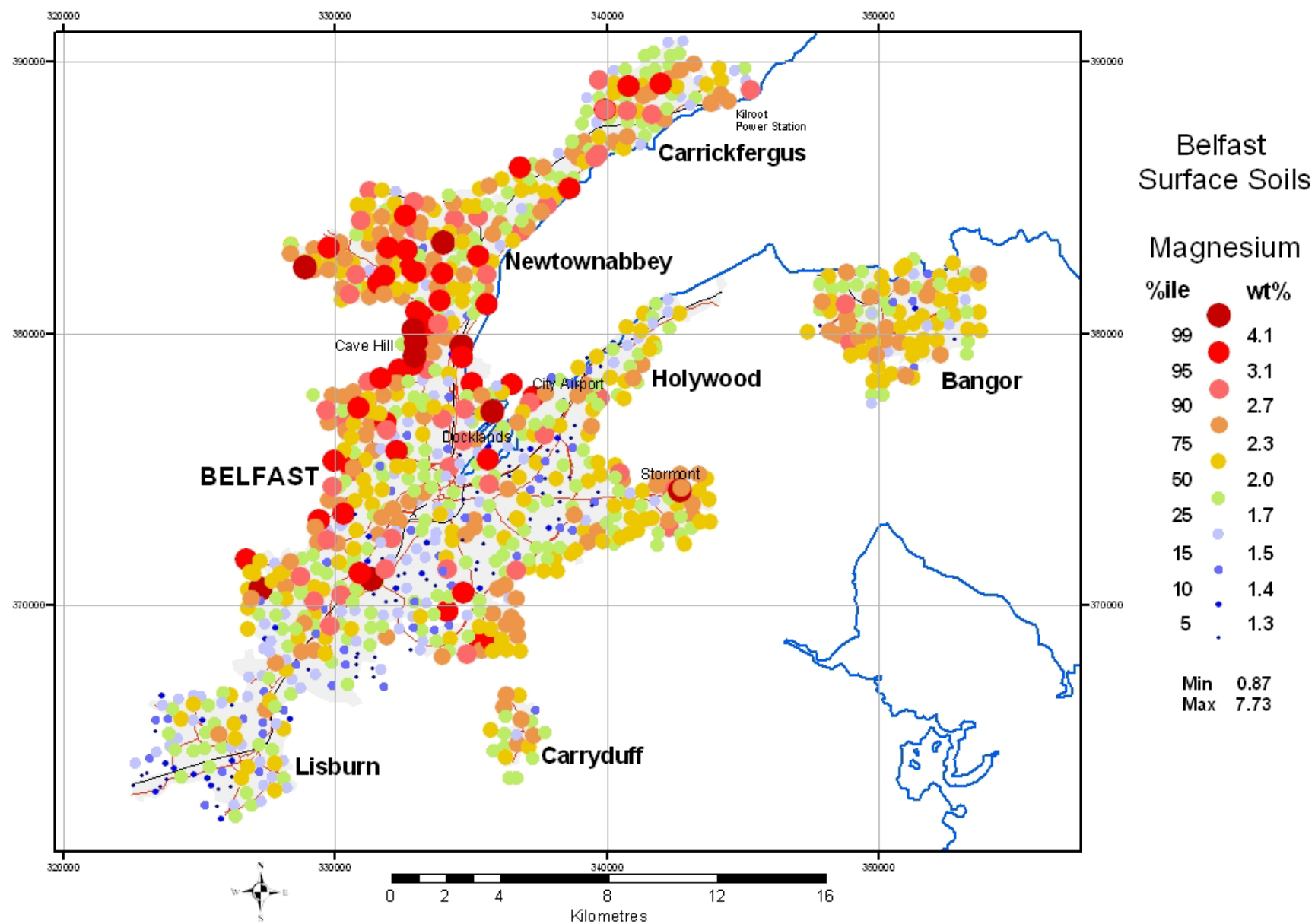


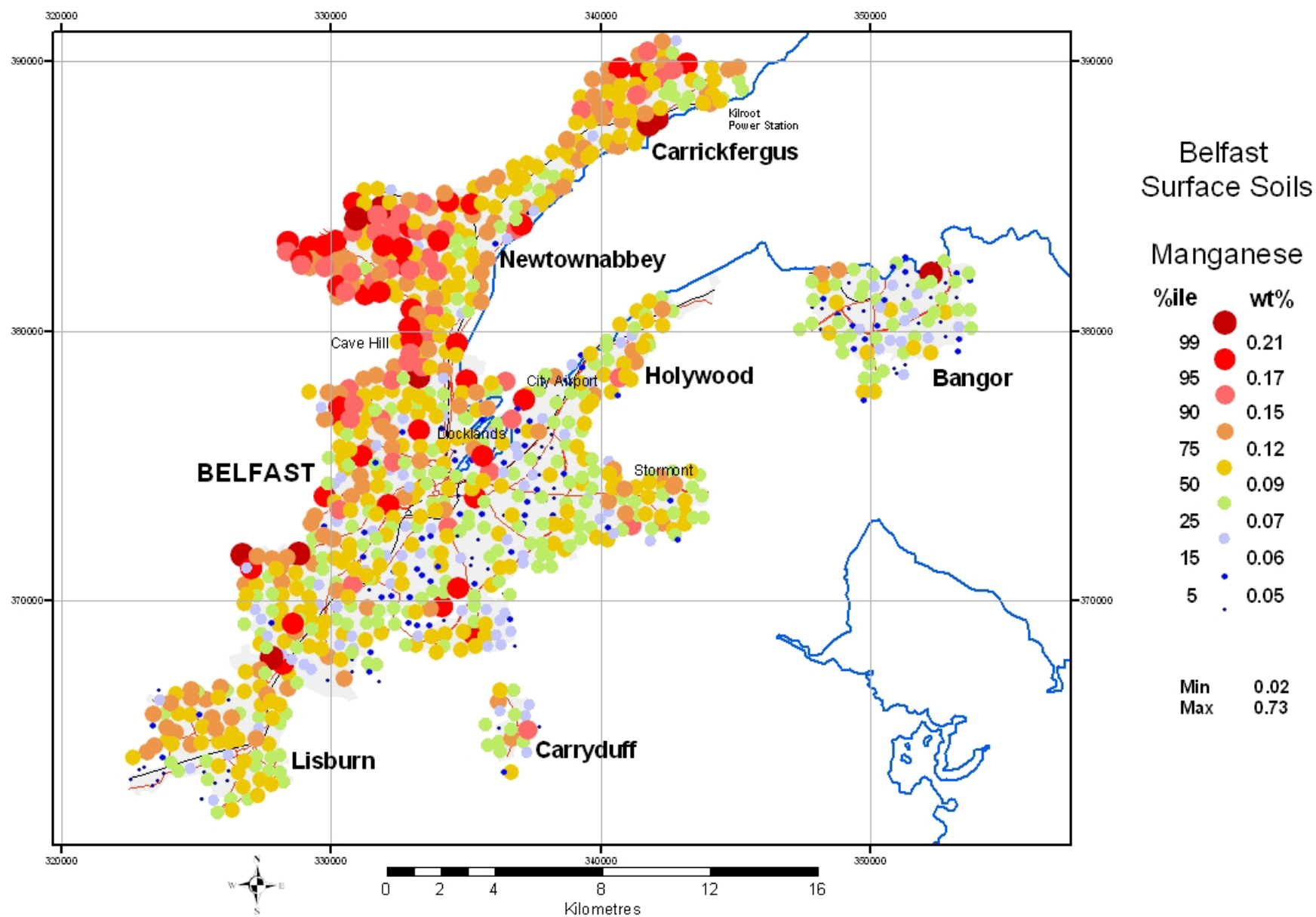


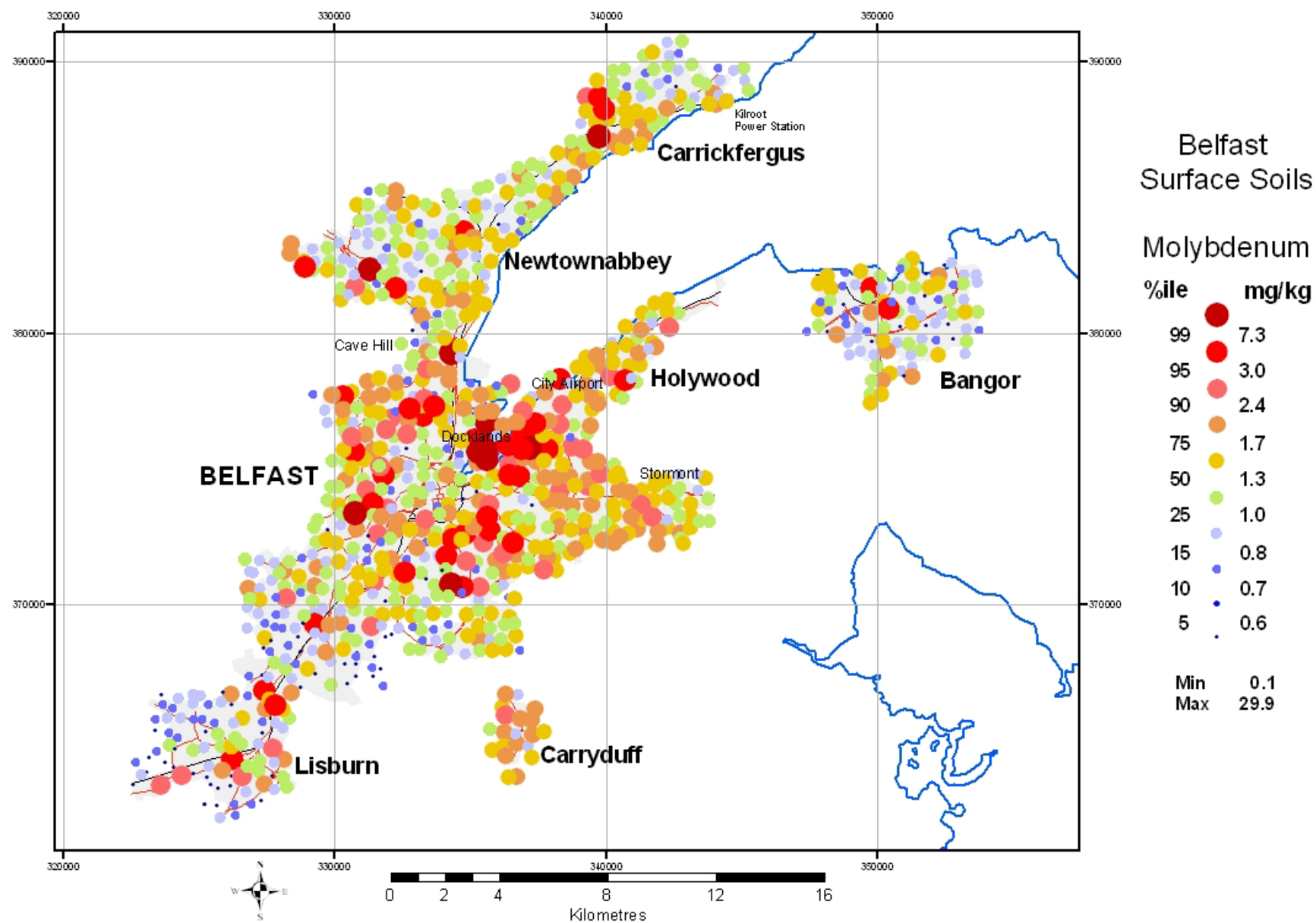


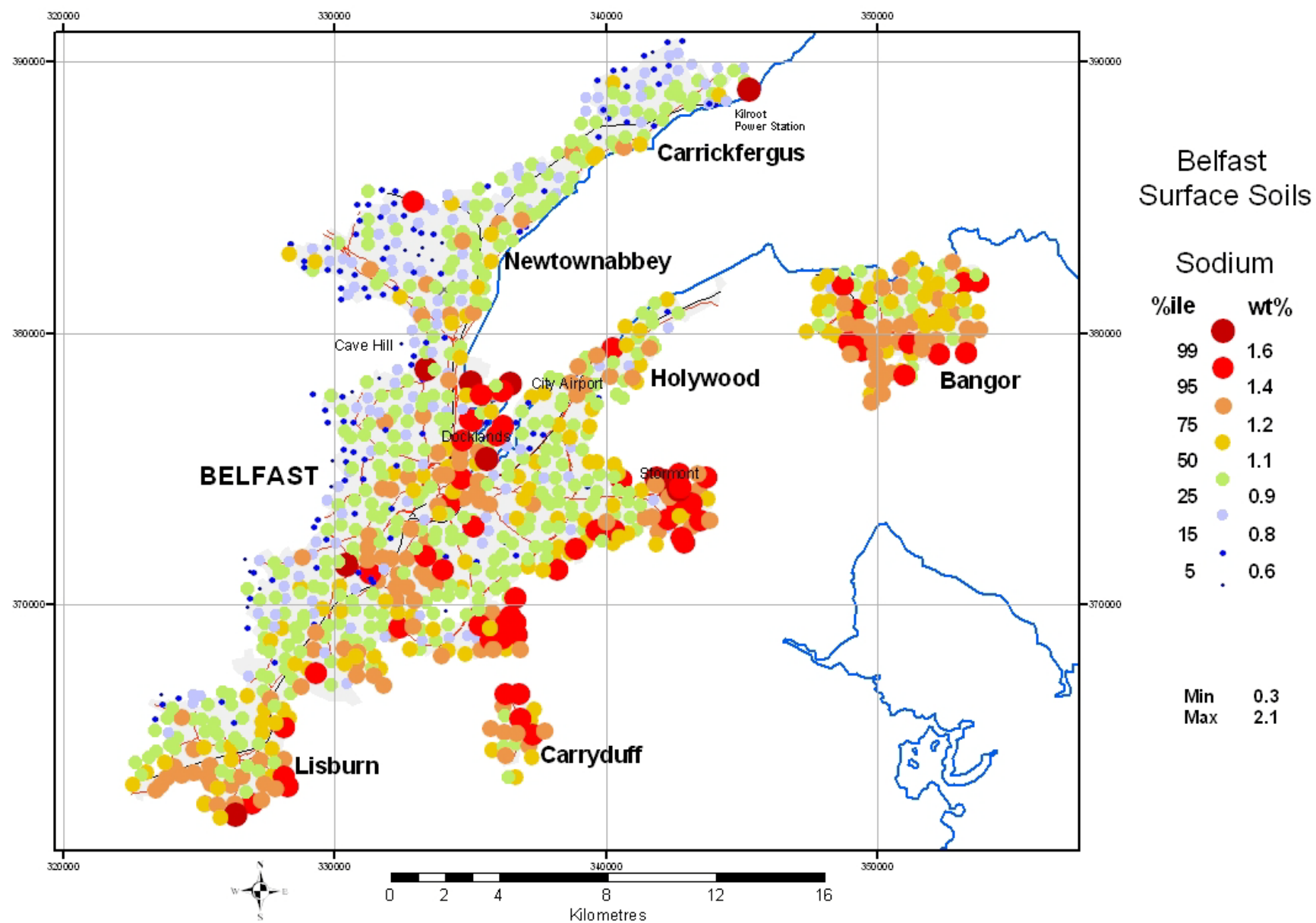


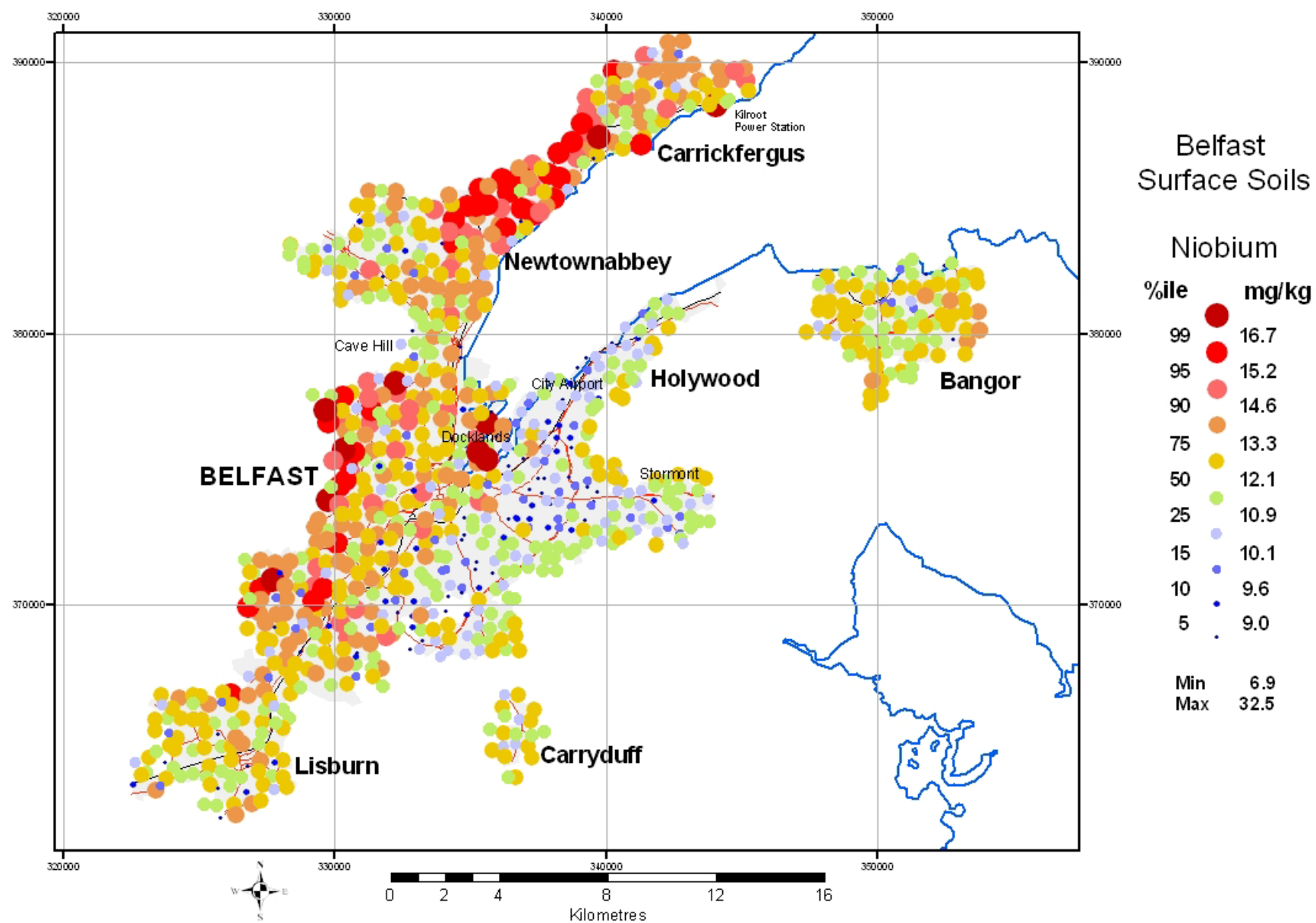


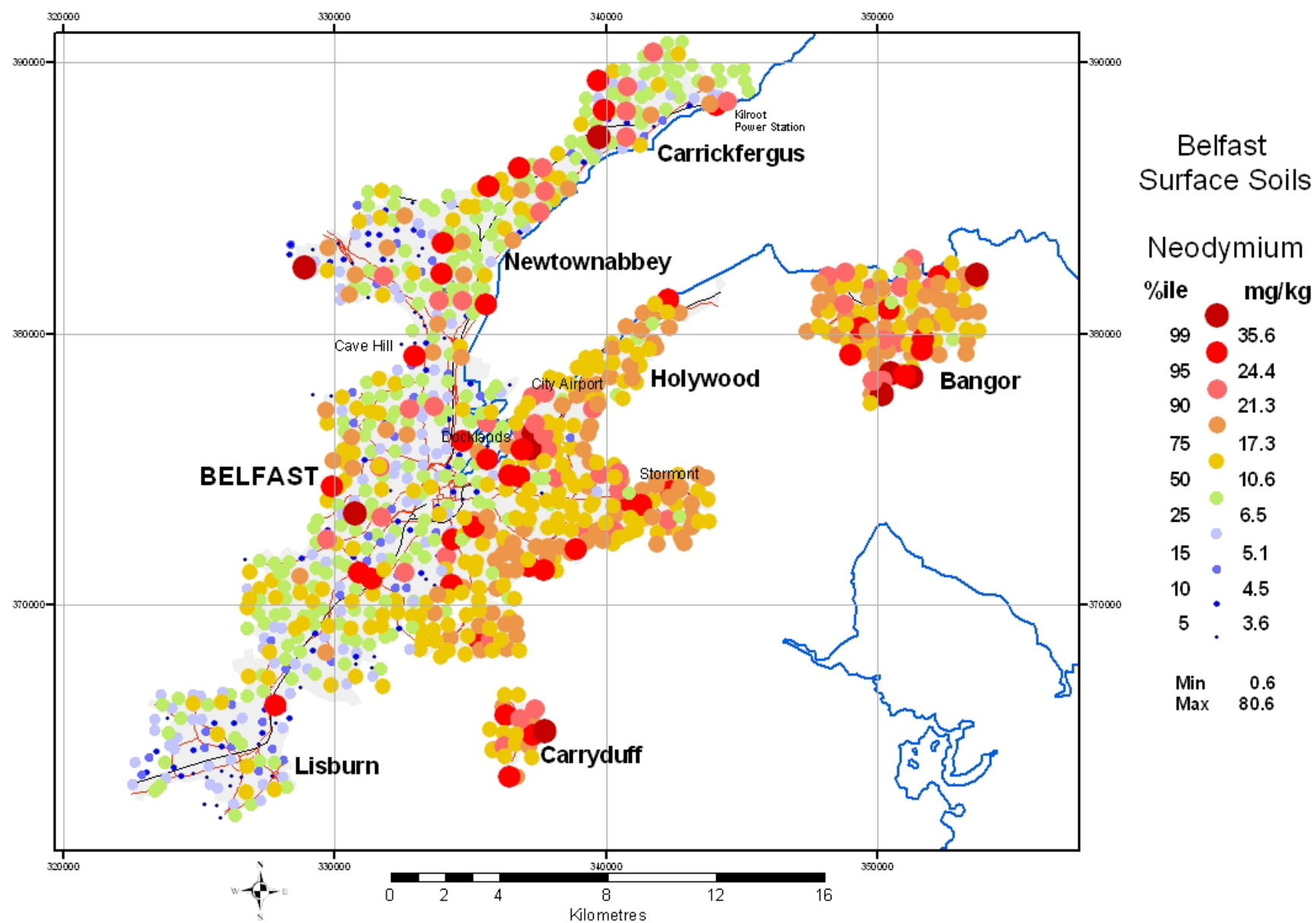


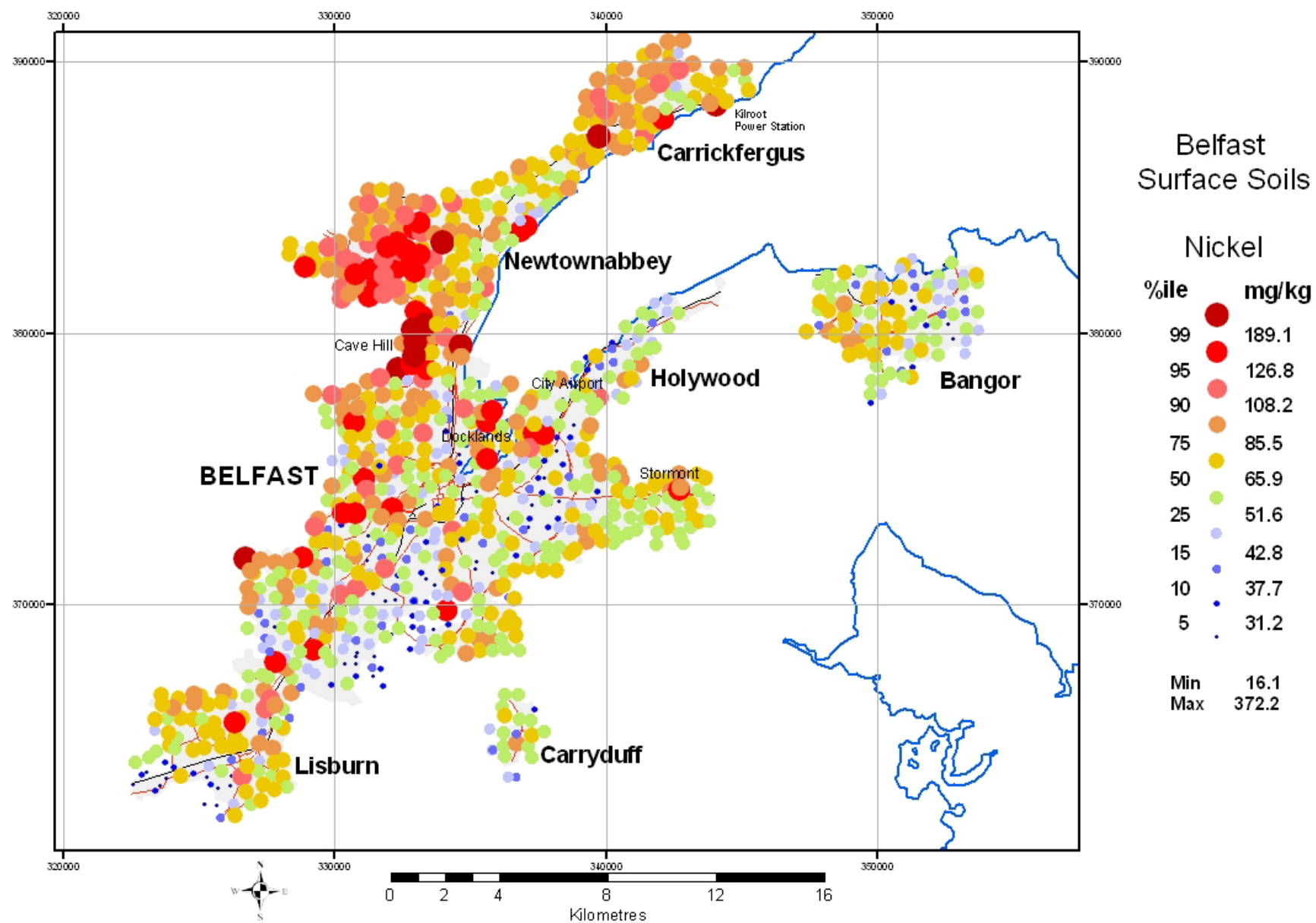


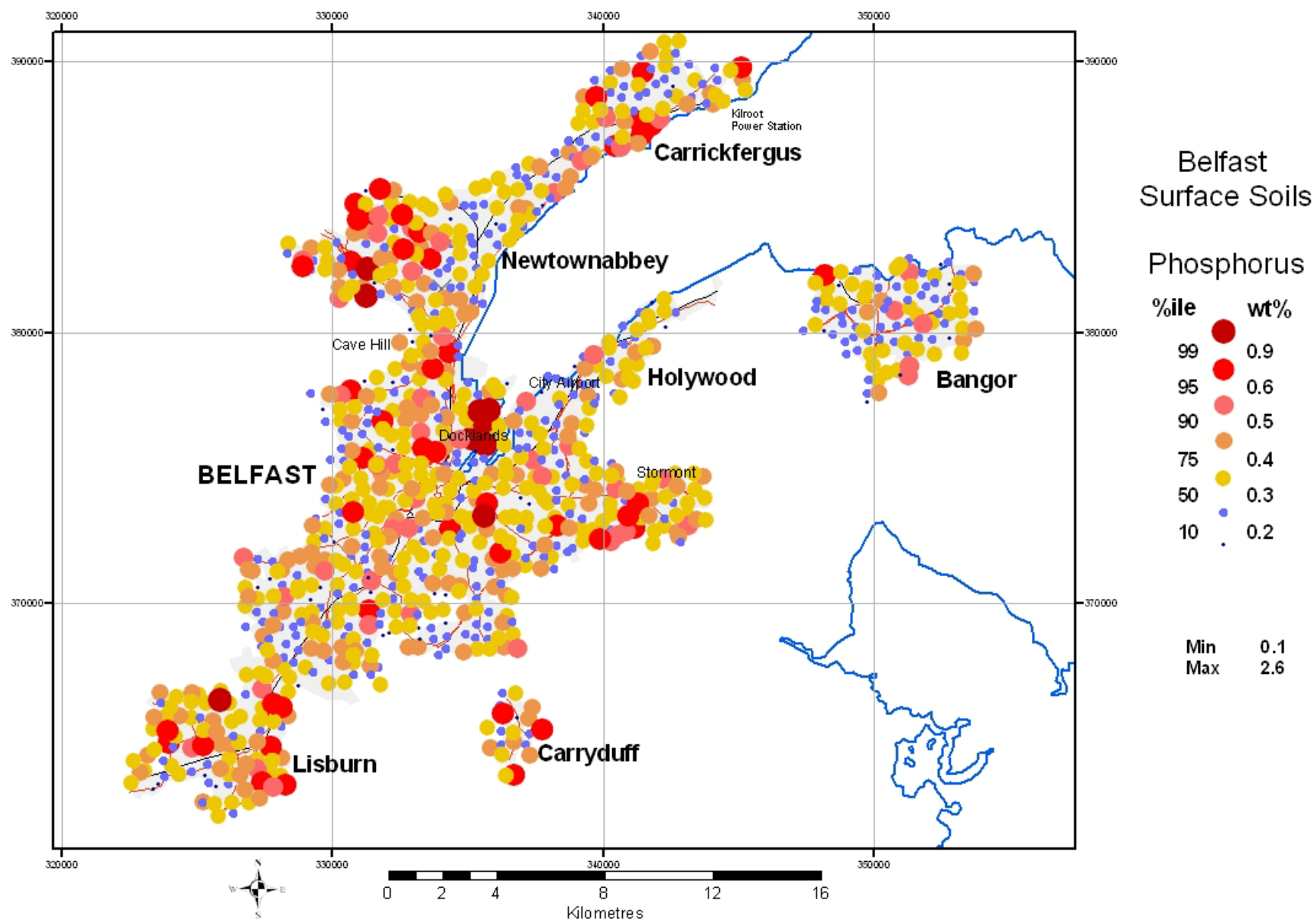


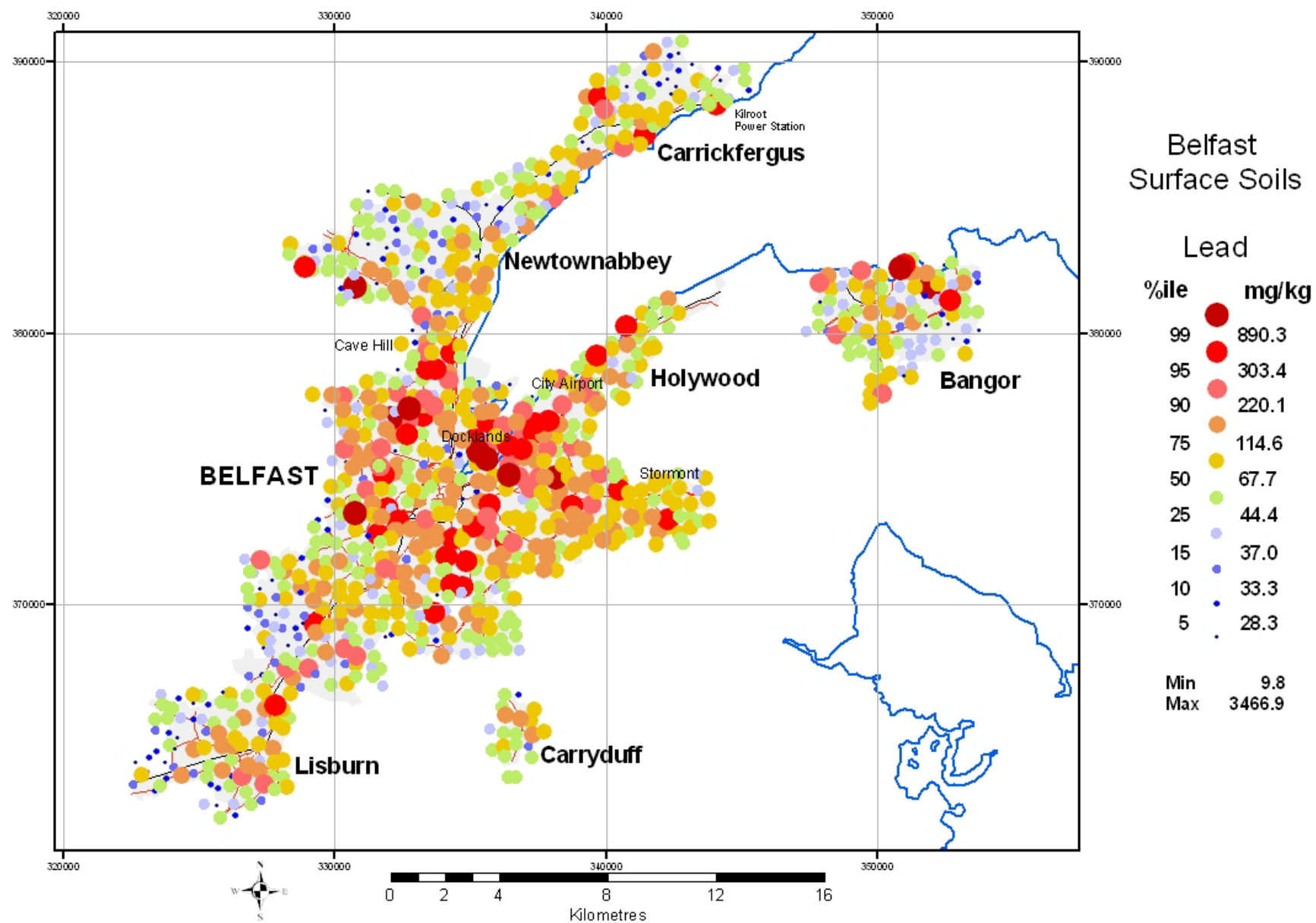


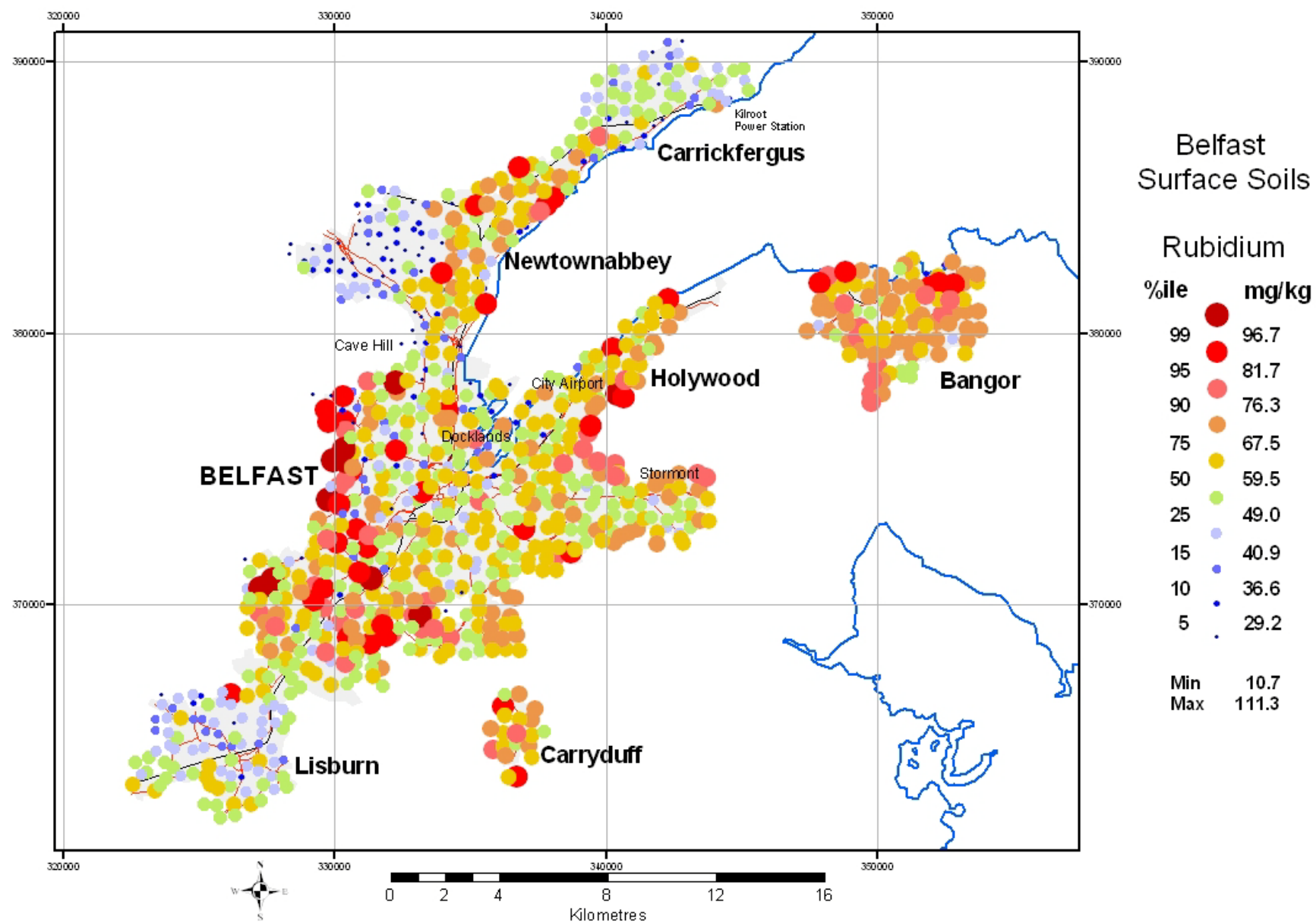


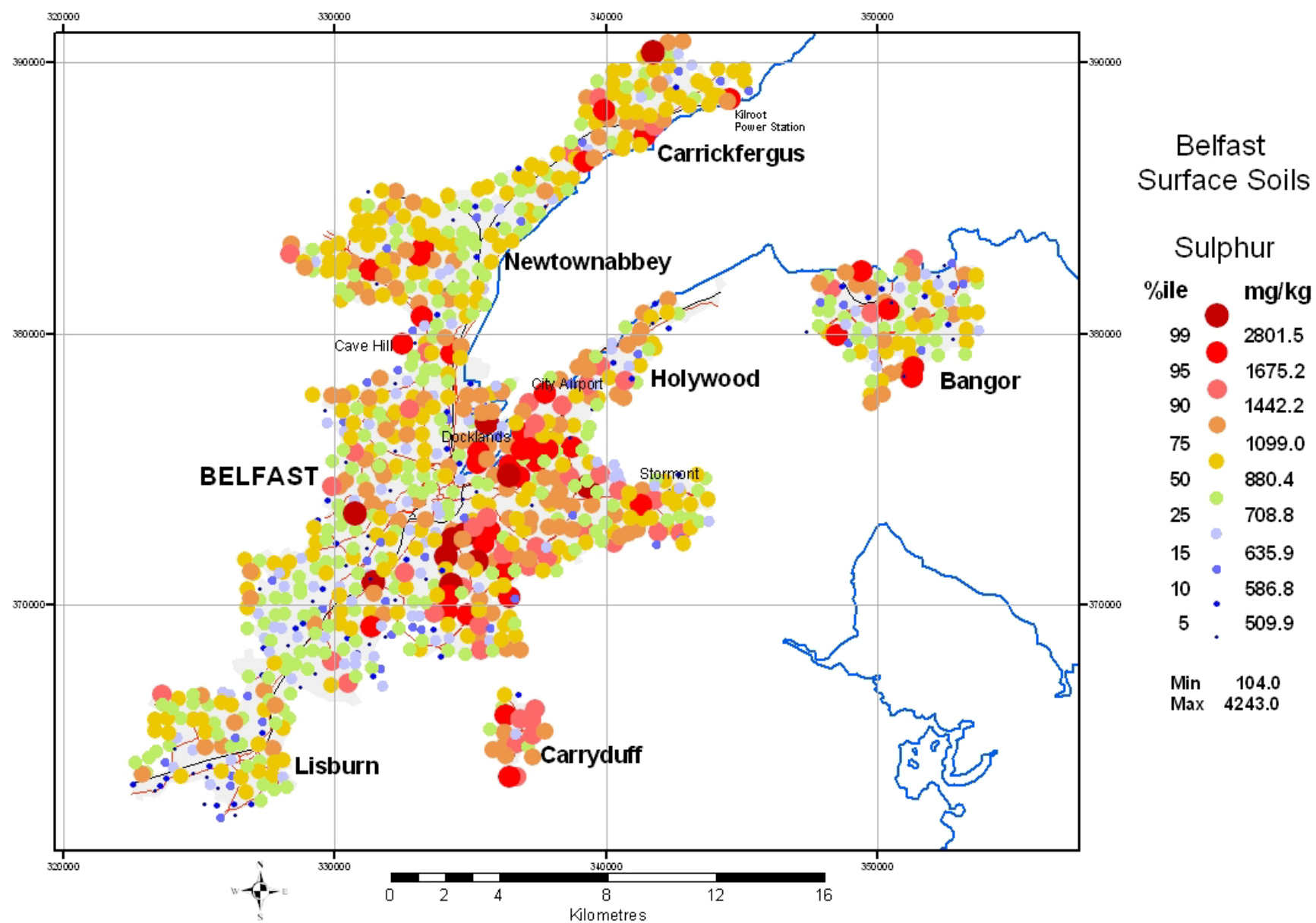


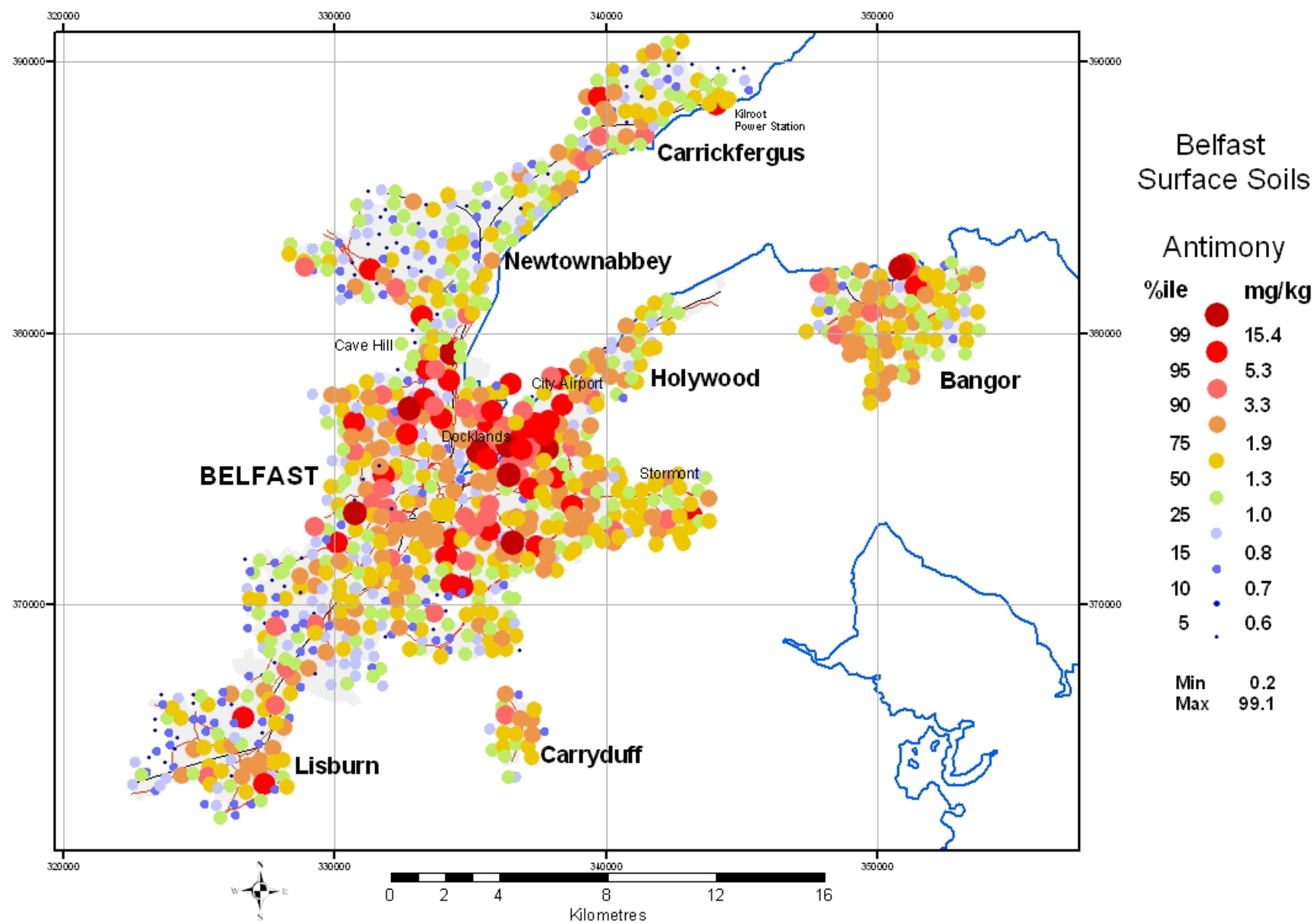


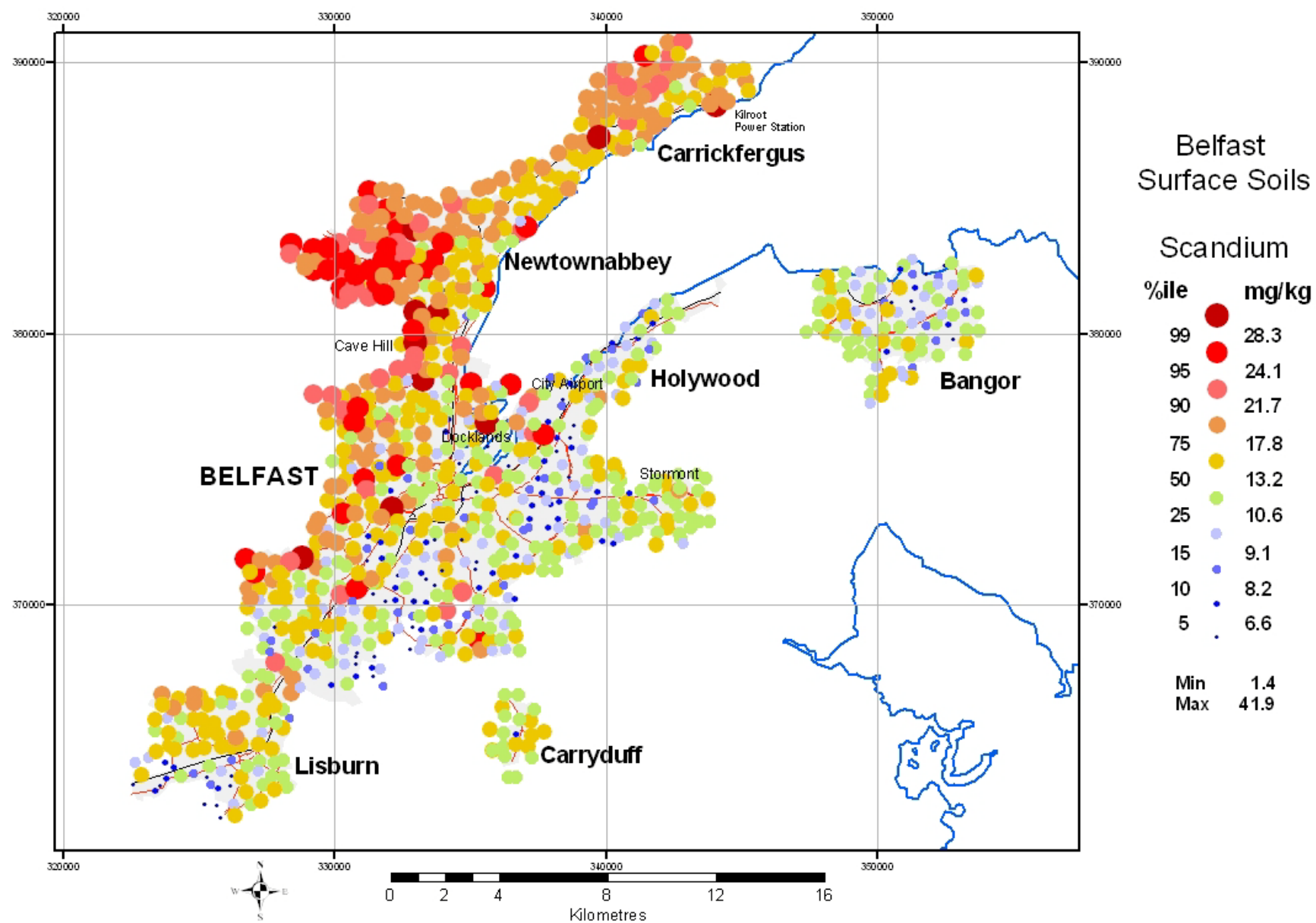


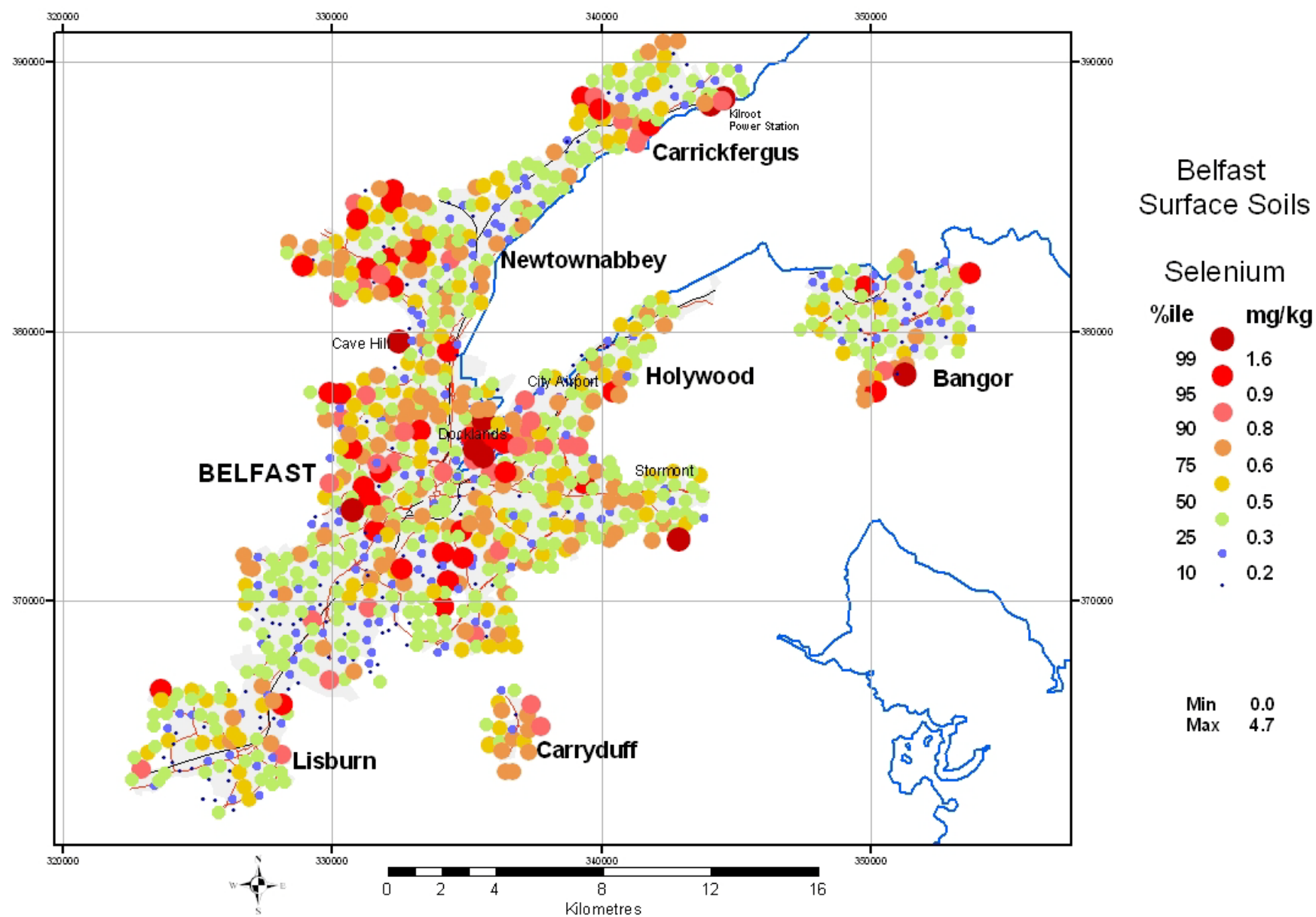


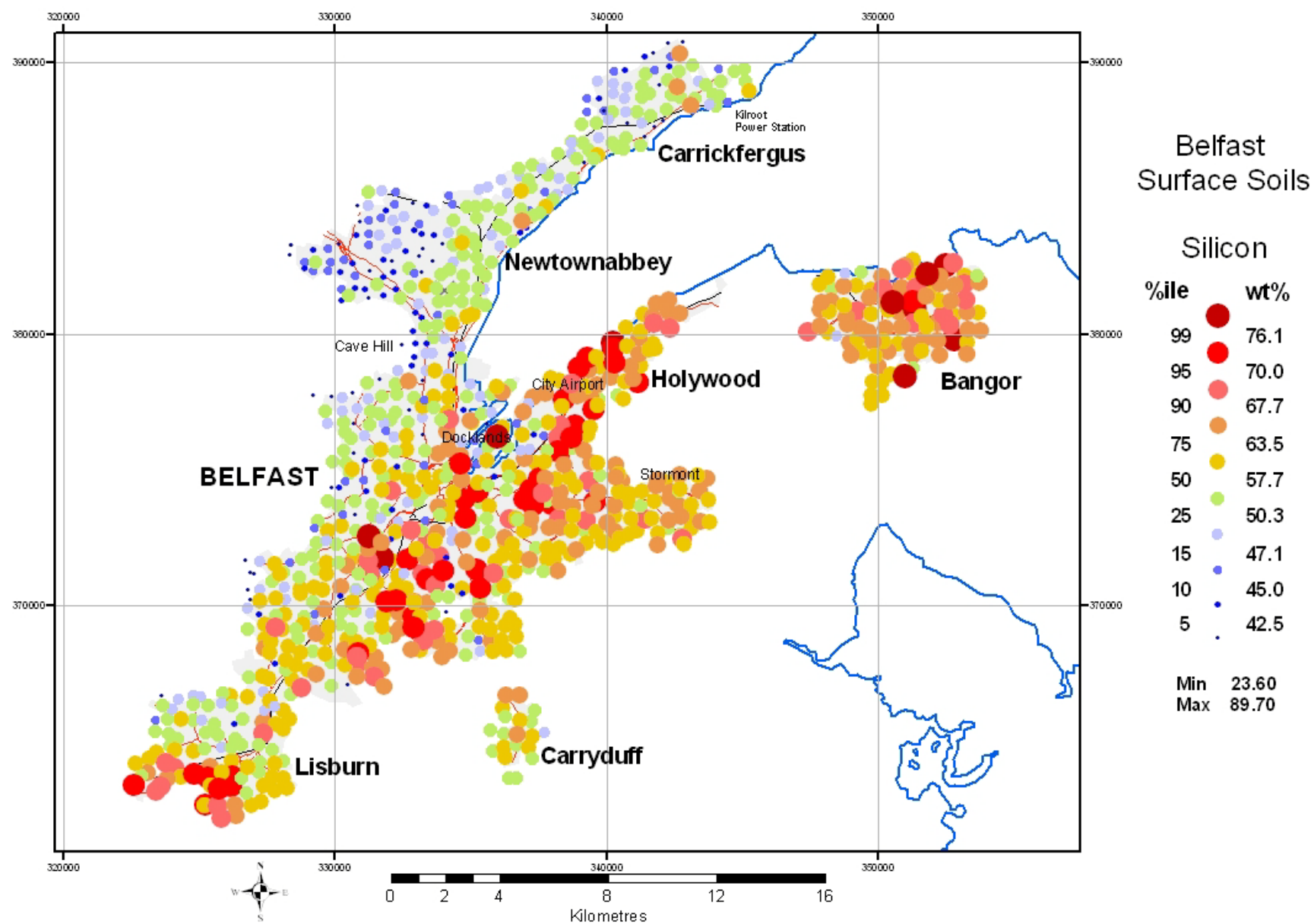


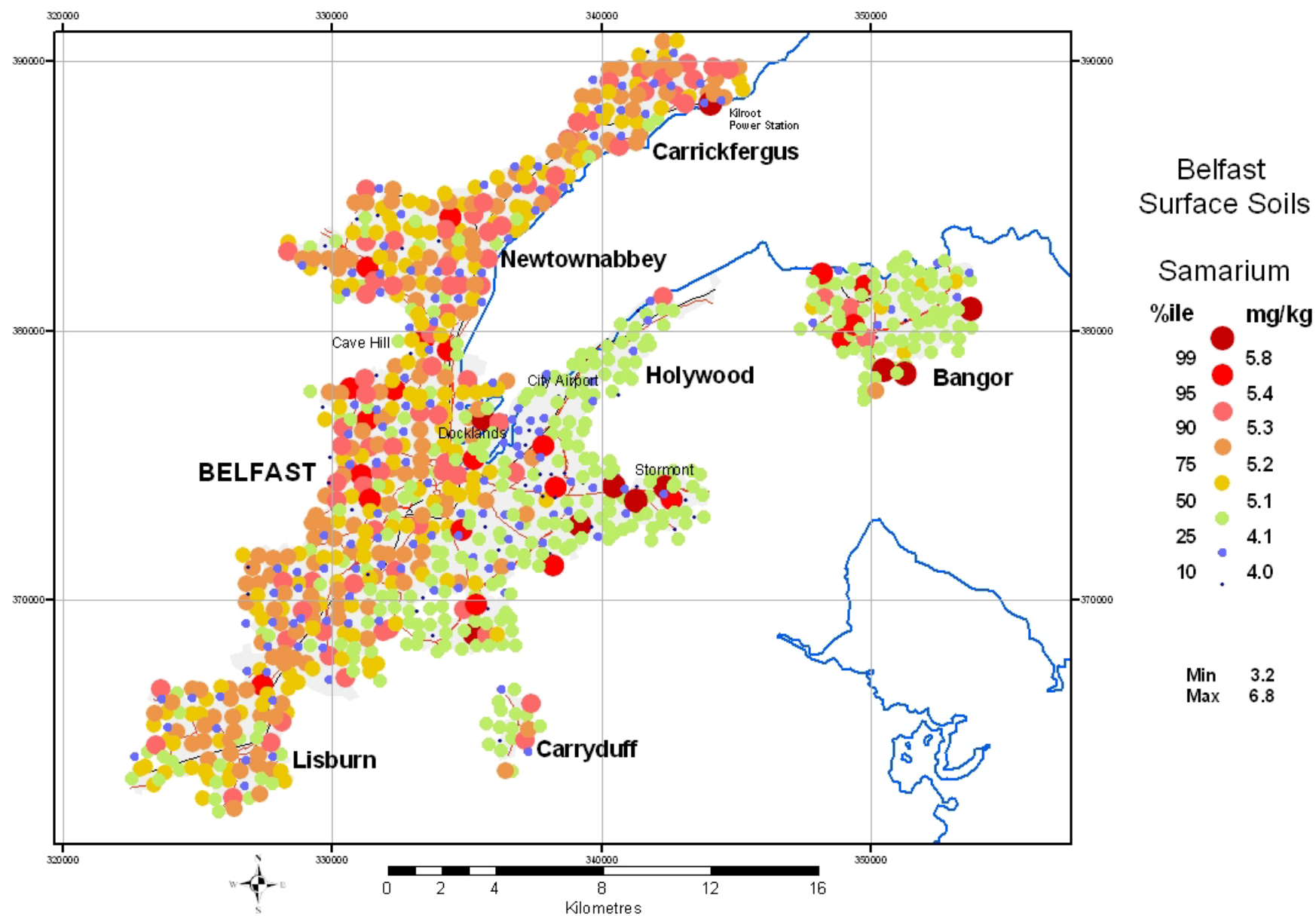


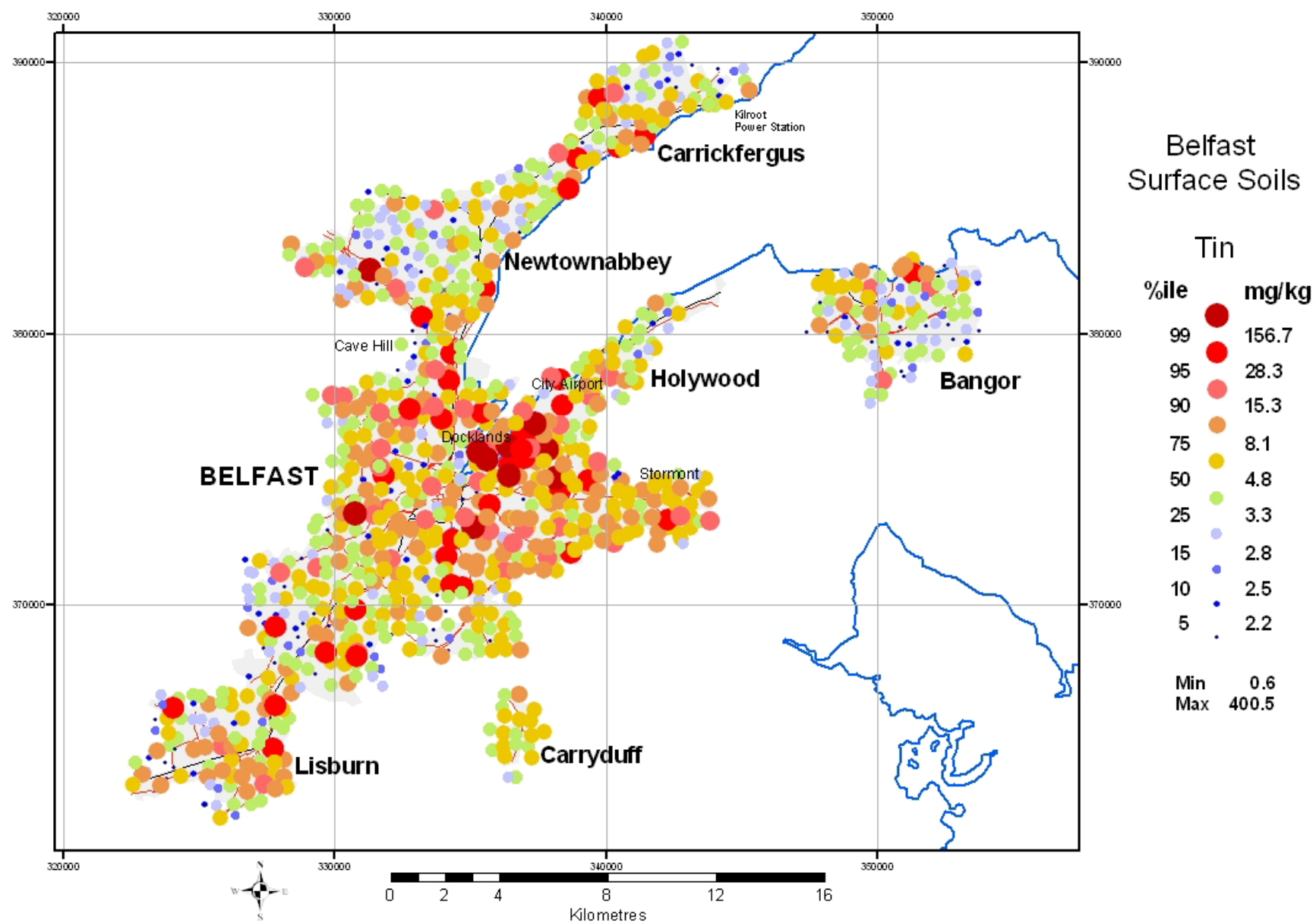


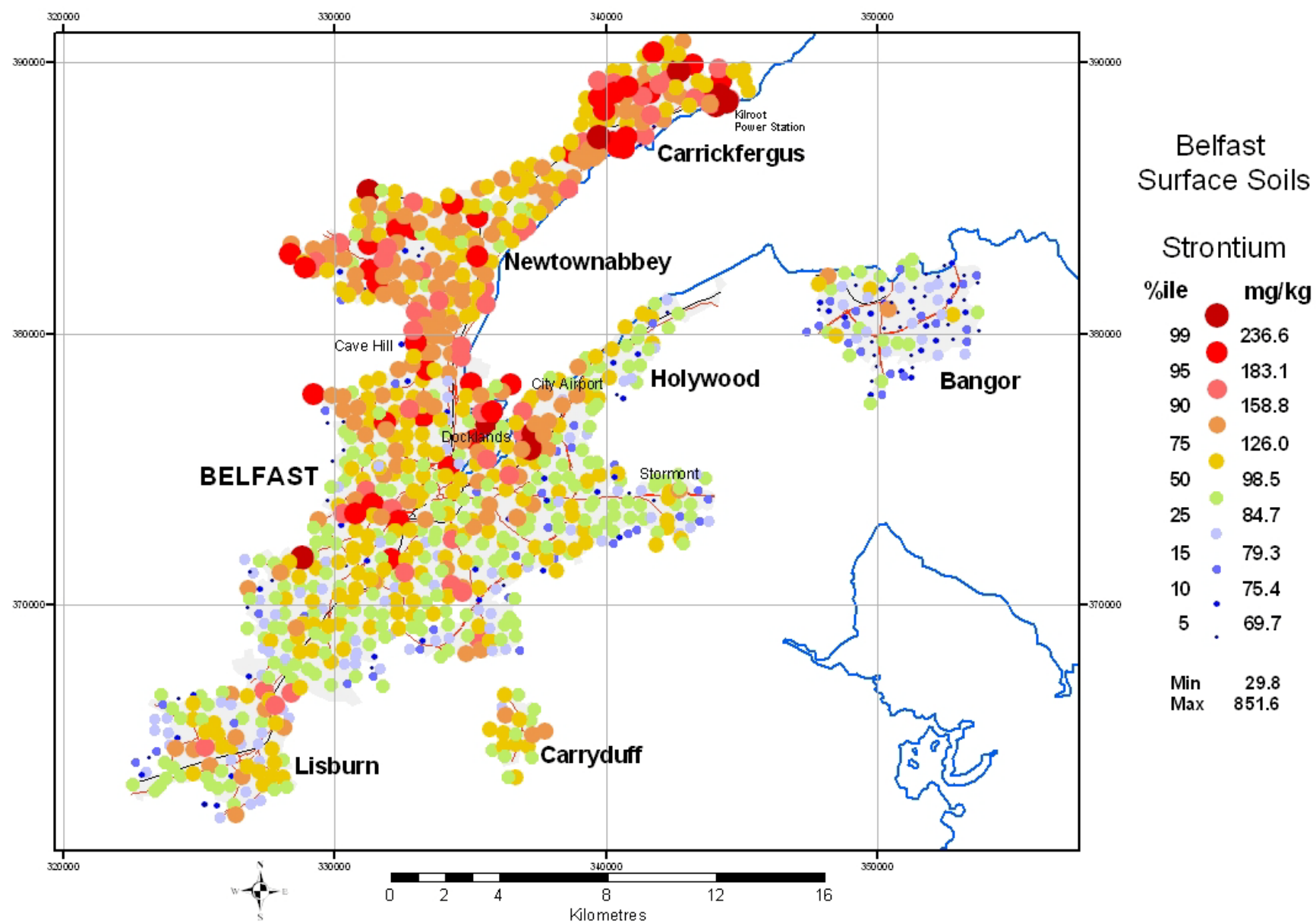


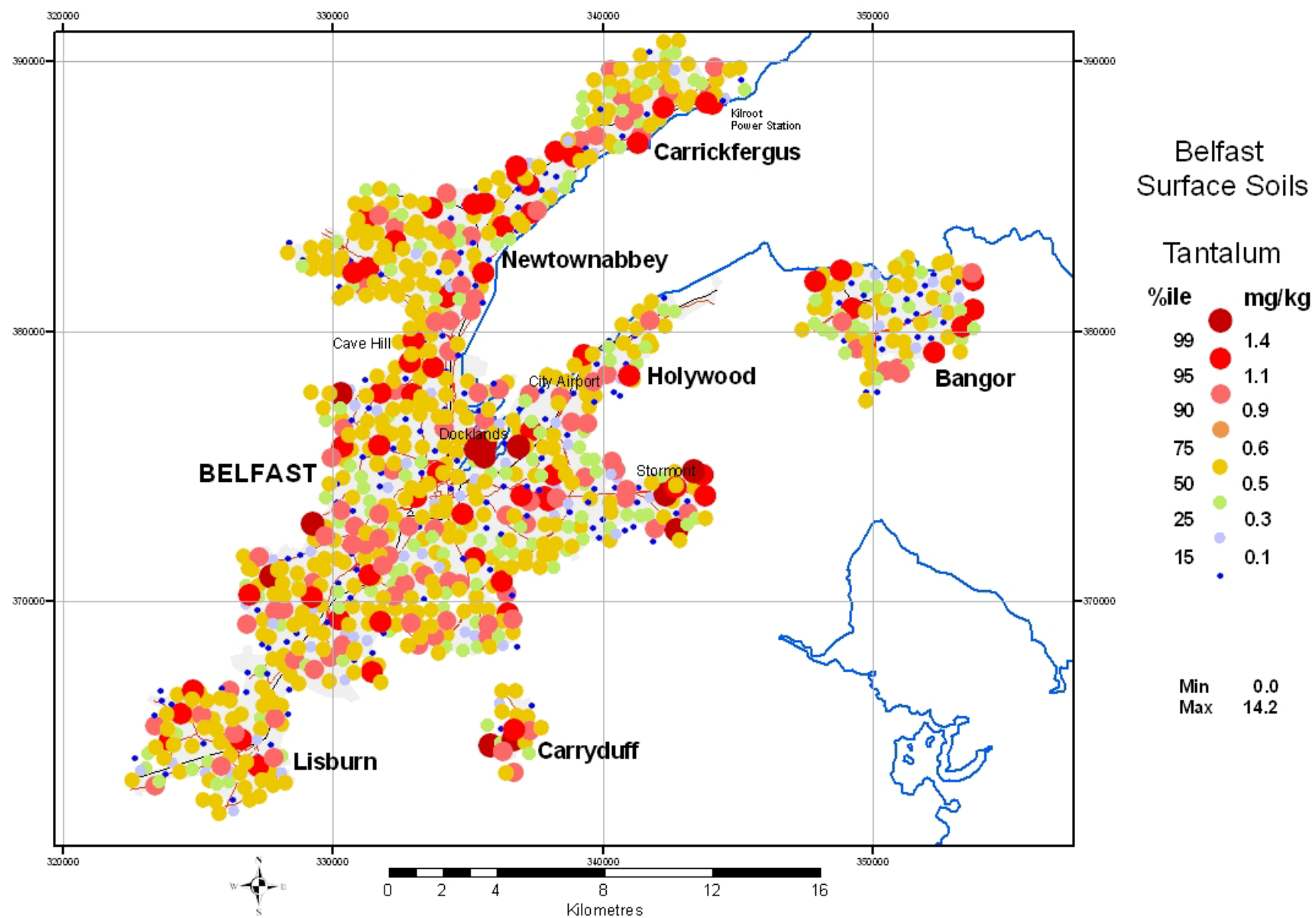


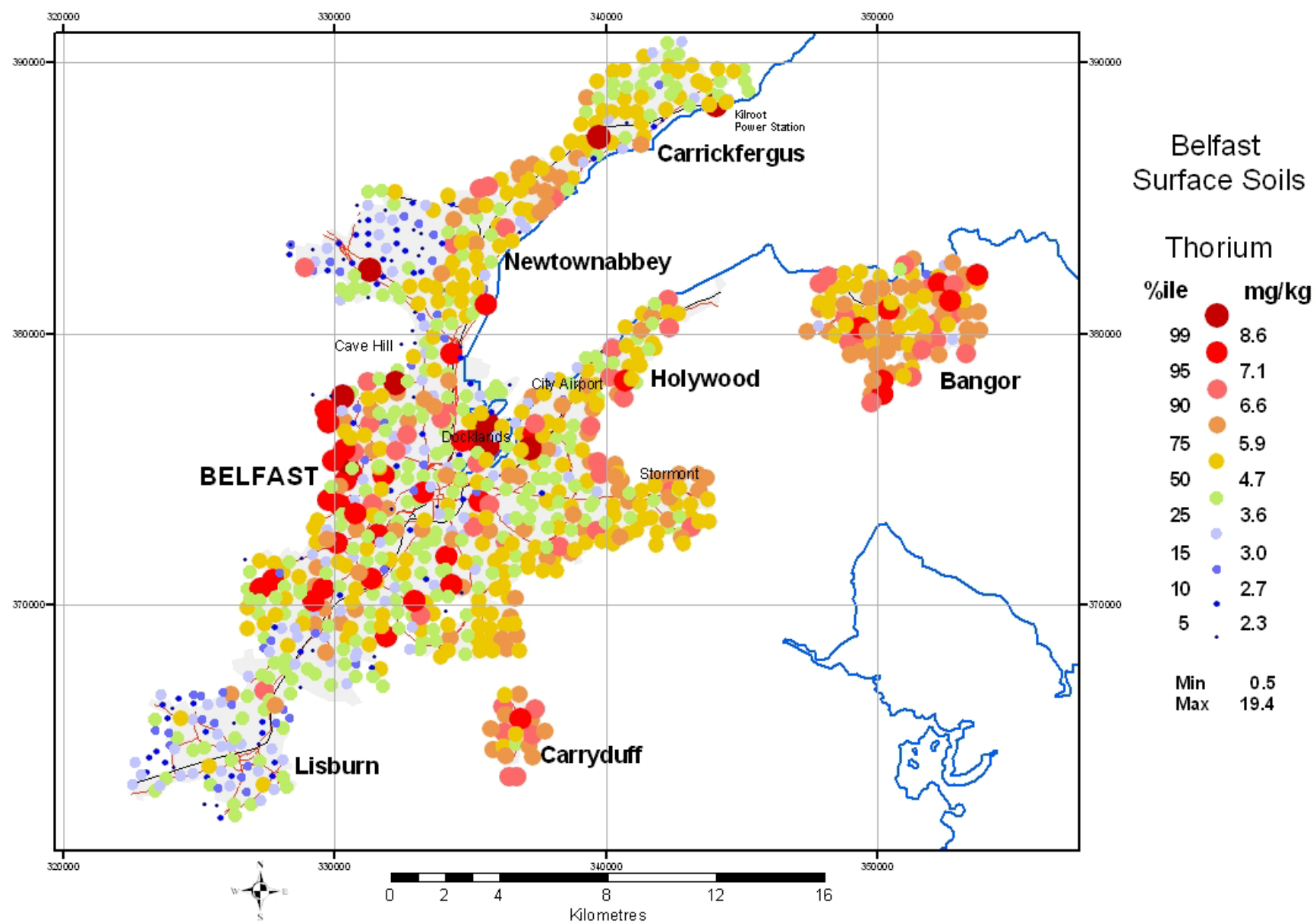


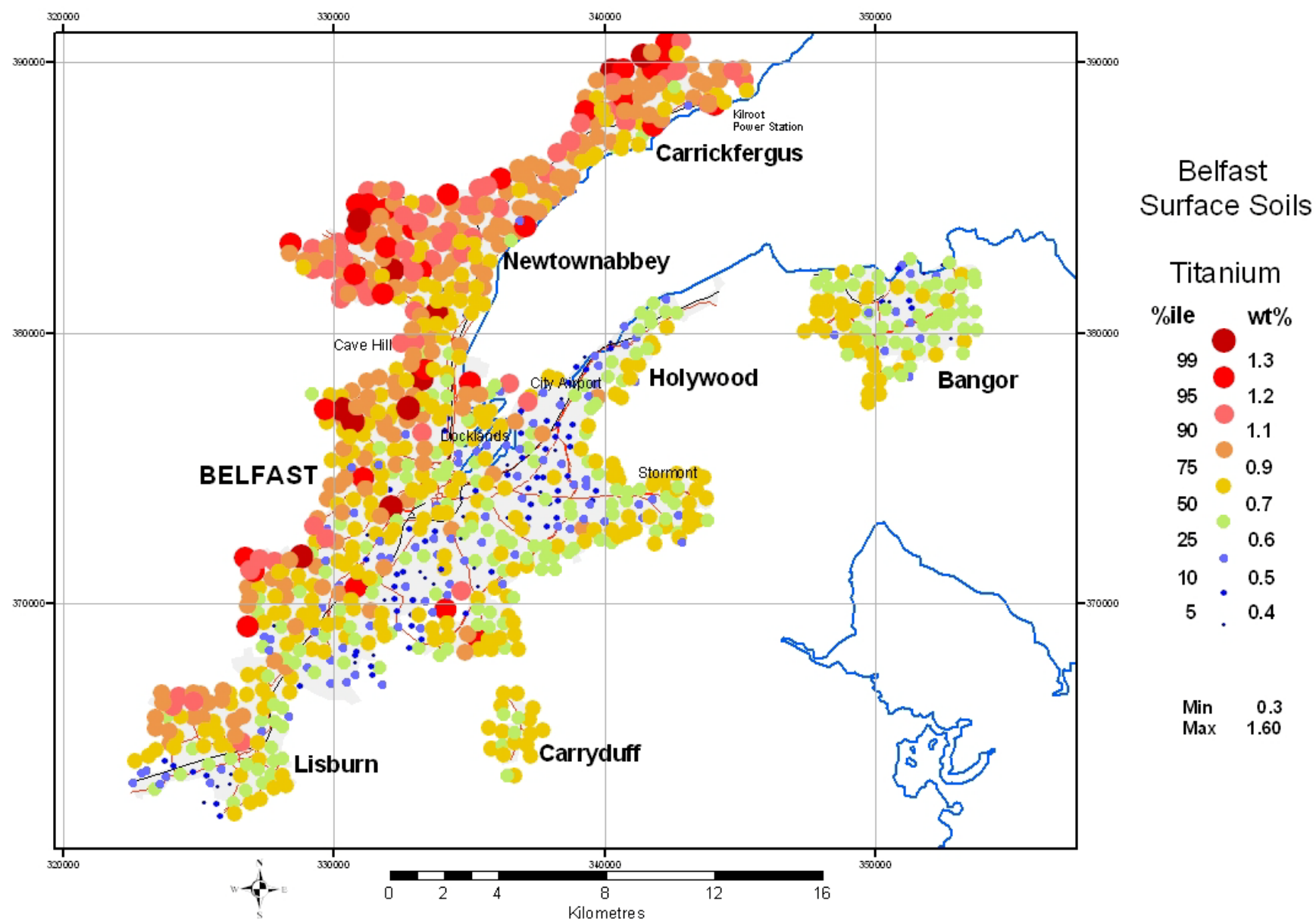


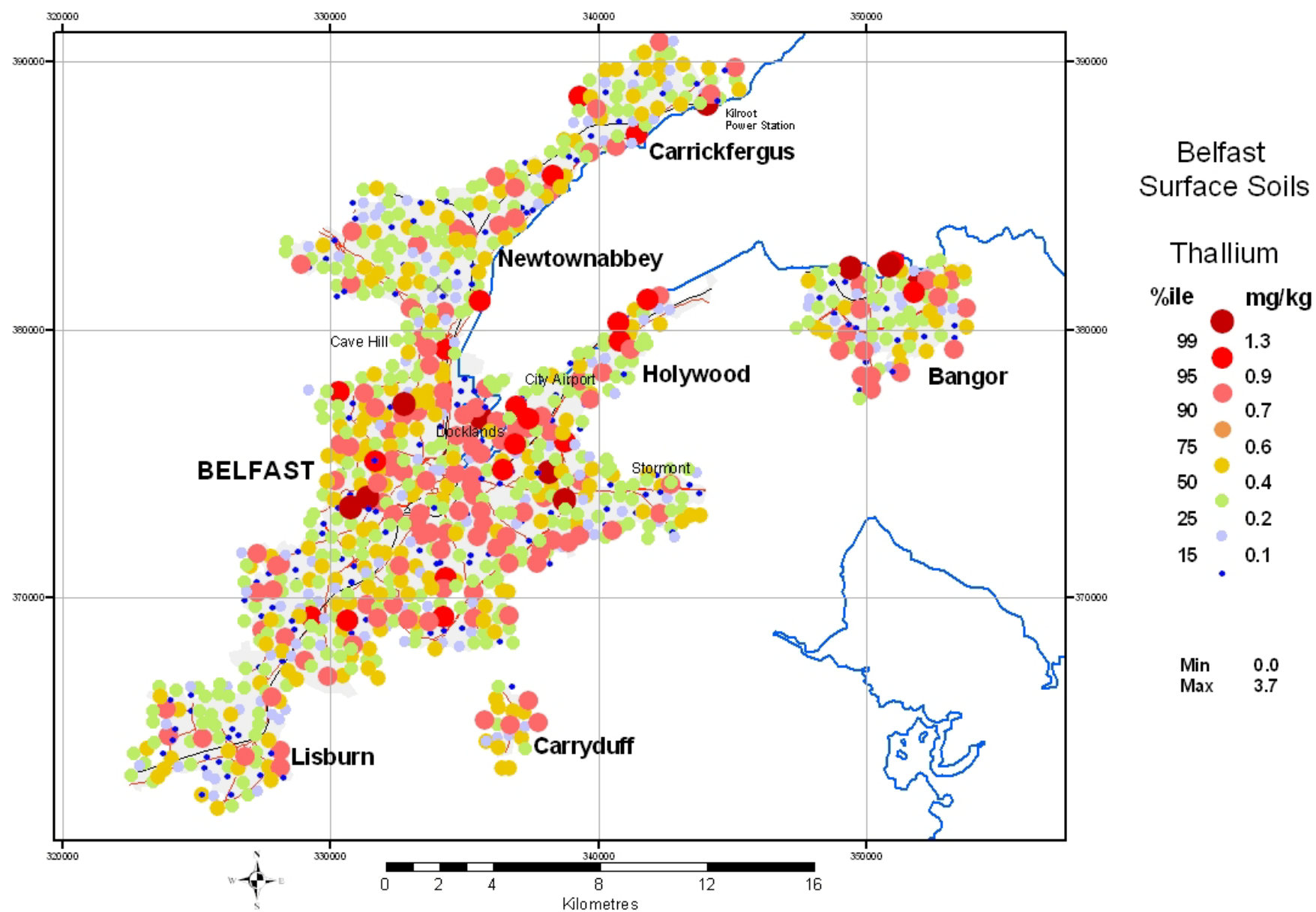


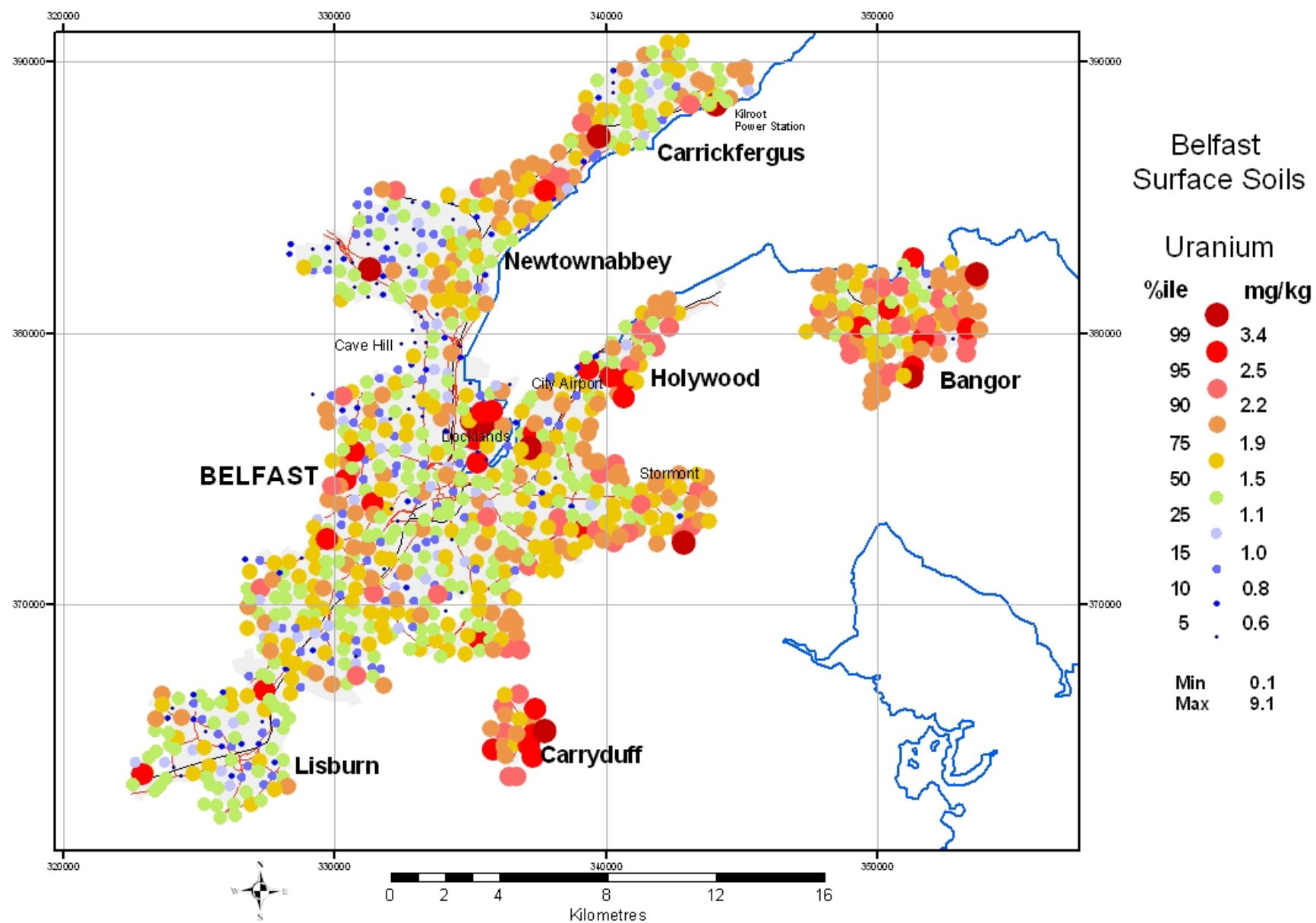


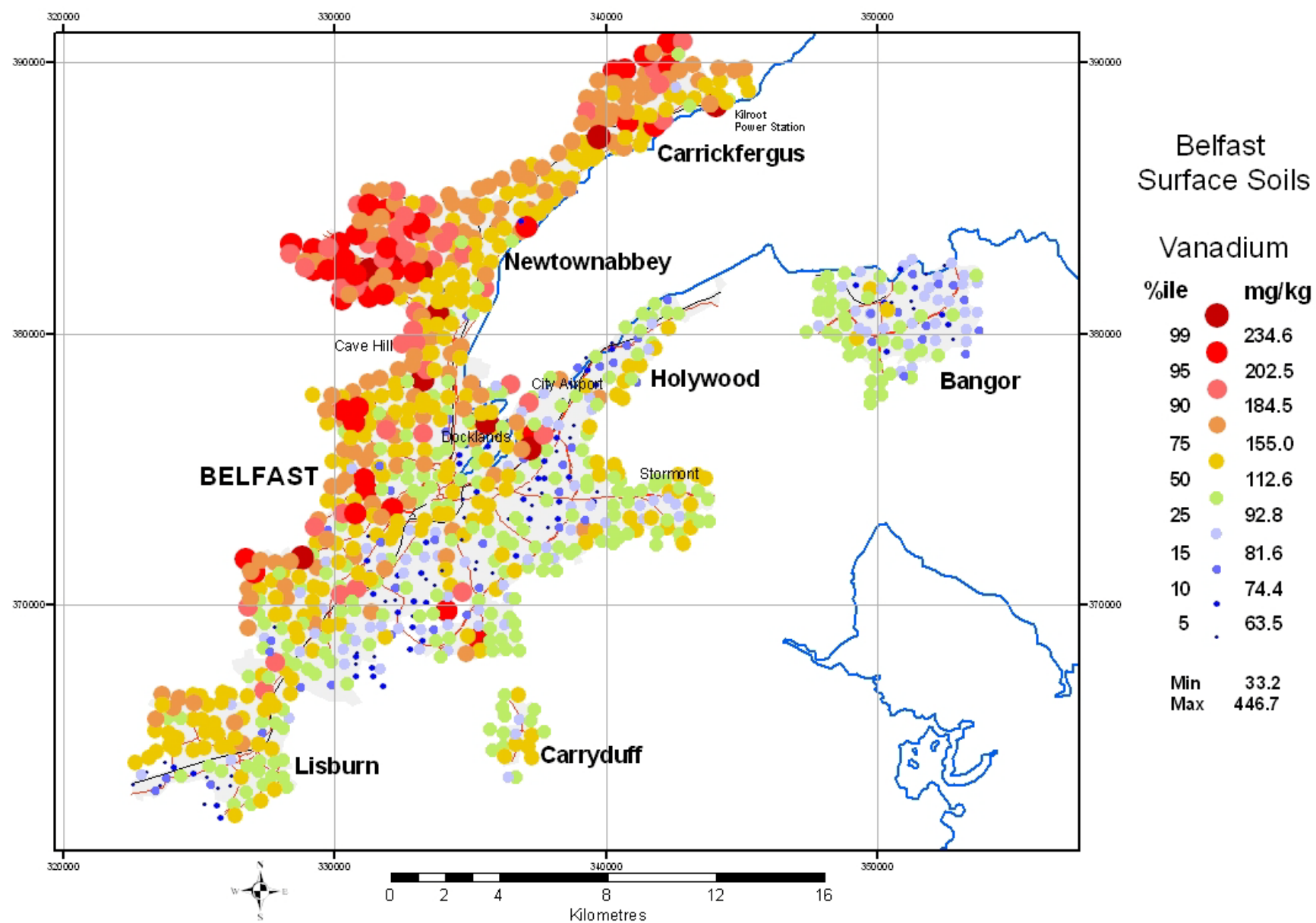


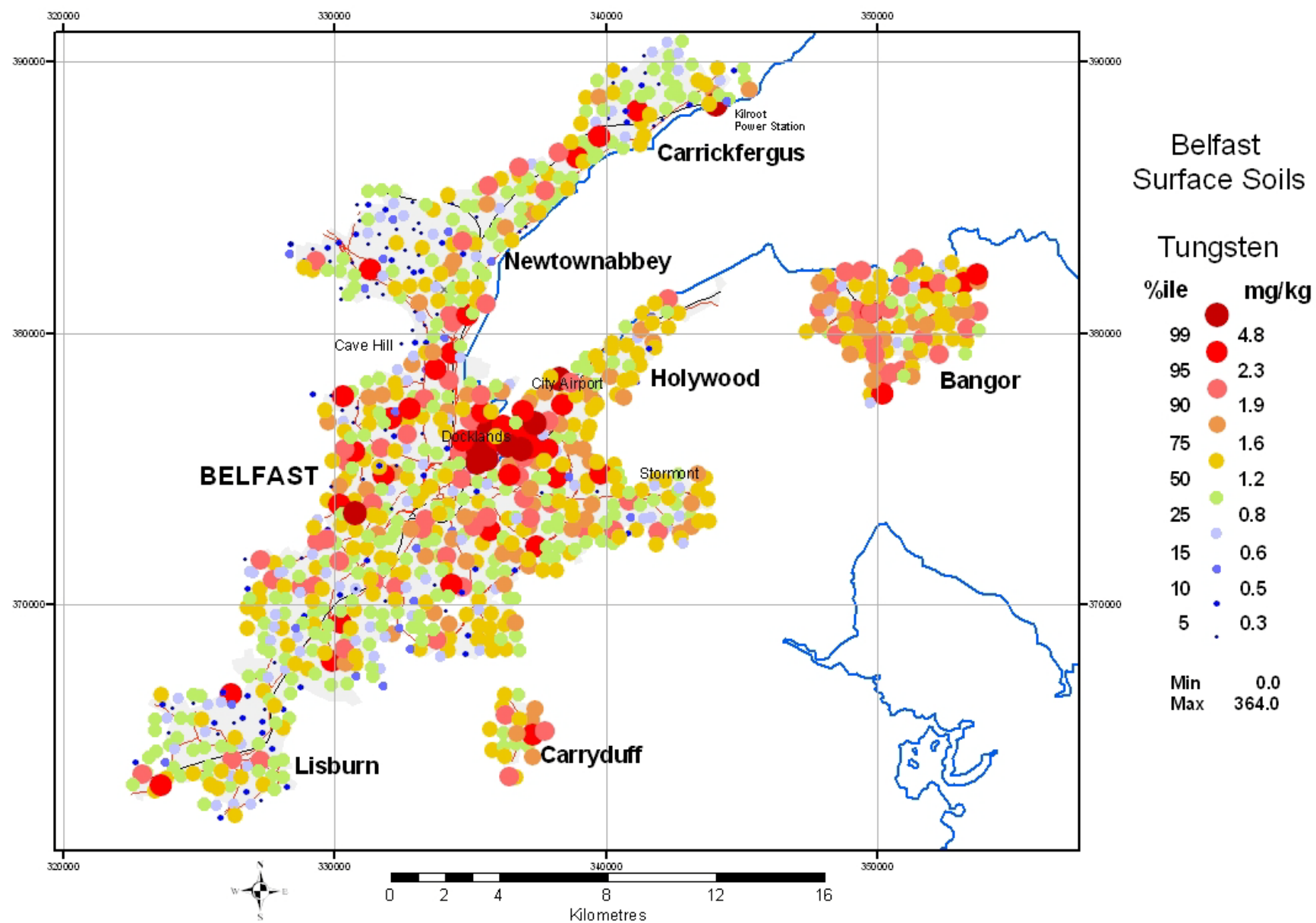


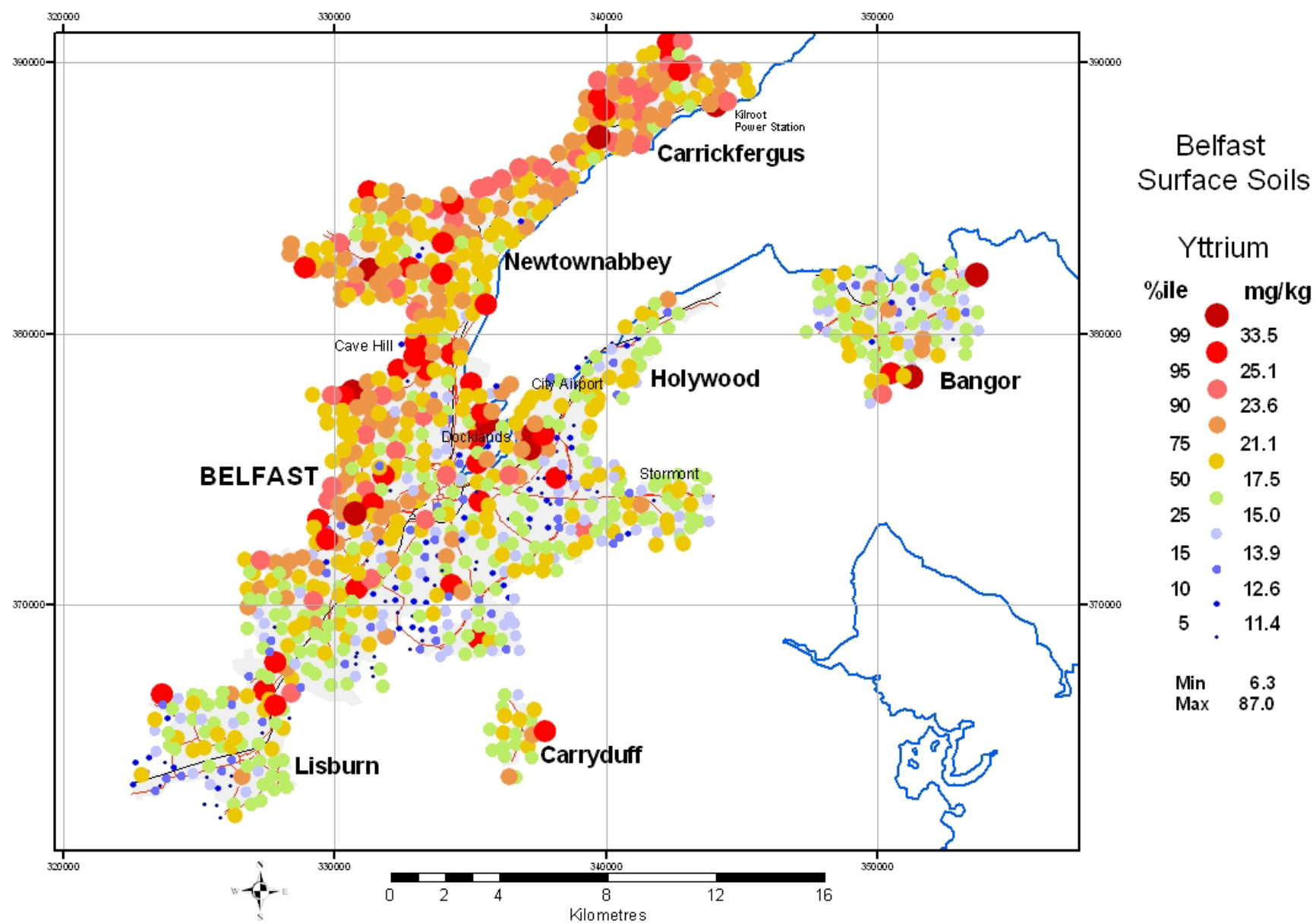


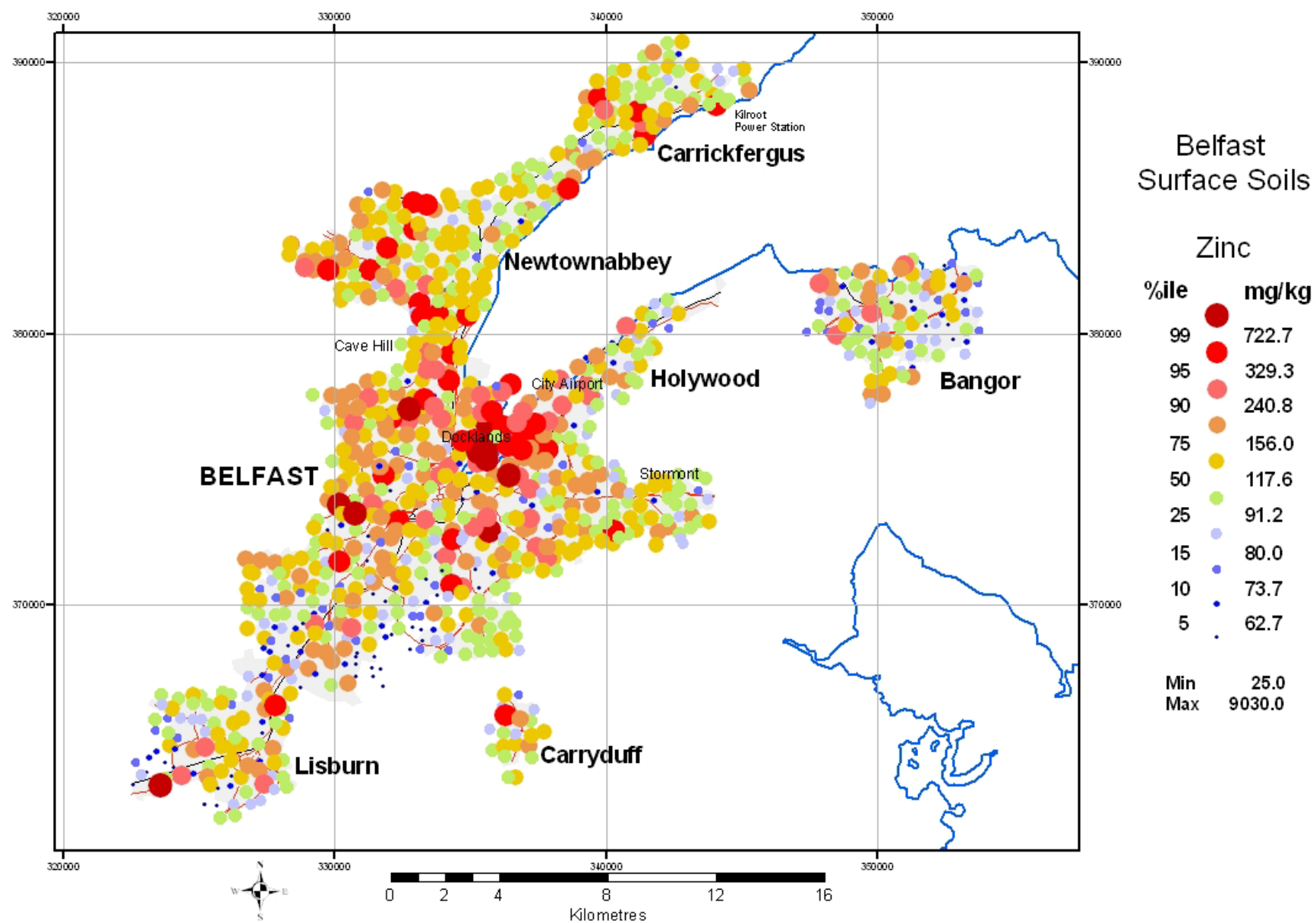


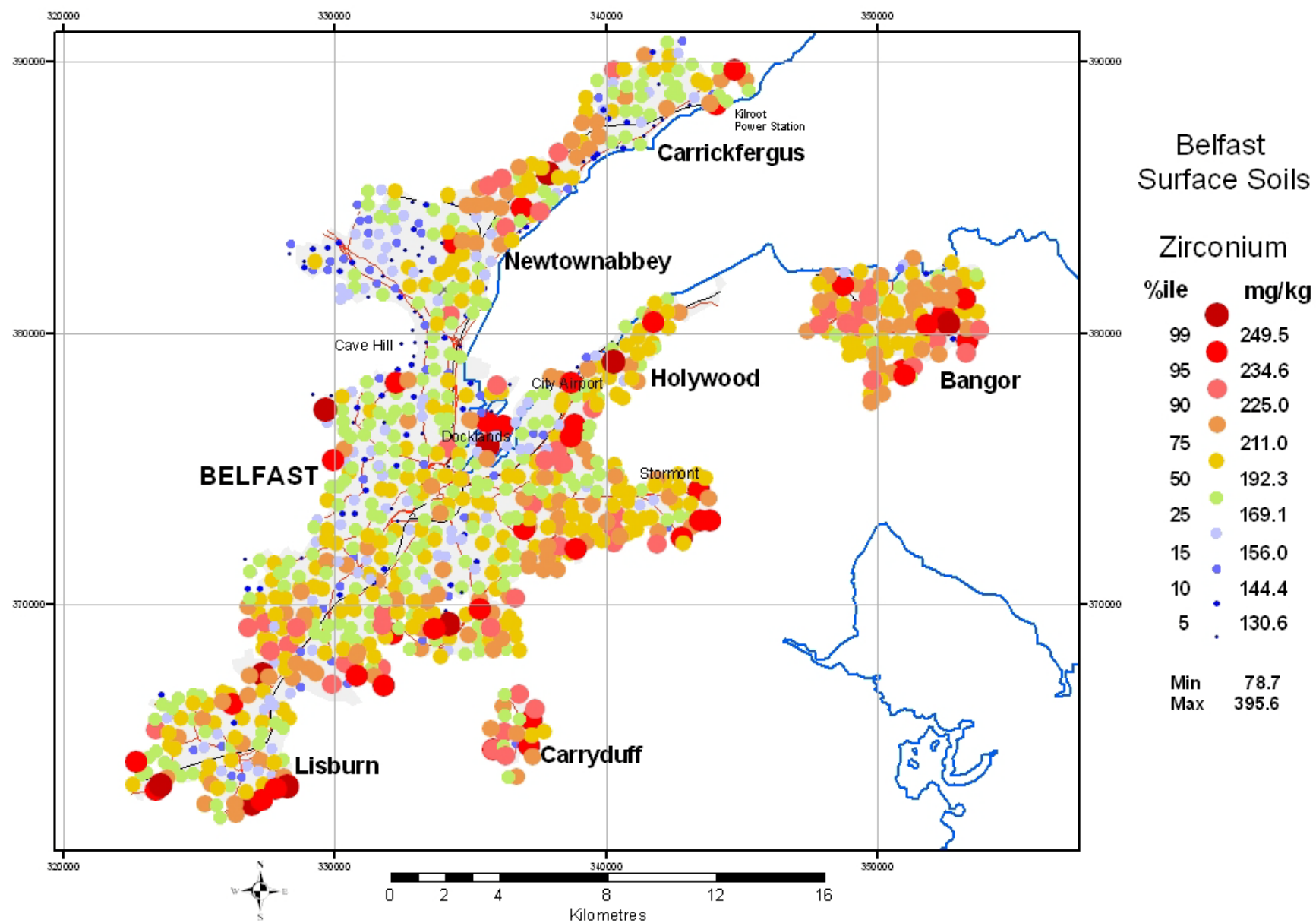












References

British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: <http://geolib.bgs.ac.uk>.

Appleton, J. D. (1995). *Potentially Harmful Elements from Natural Sources and Mining Areas: Characteristics, Extent and Relevance to Planning and Development in Great Britain.*, British Geological Survey, Keyworth, Nottingham.

BBC. (2002). "Titanic shipyard to axe more jobs." From http://news.bbc.co.uk/1/hi/northern_ireland/2305407.stm.

Bridge, D. M., J. N. Carney, et al. (1998a). *Geology of the country around Coventry and Nuneaton*, London: The Stationery Office.

Brown, S. E. (2004). *Geochemical baseline data for the urban area of Cardiff*, British Geological Survey, Keyworth, UK: 63pp.

Cruickshank, J. G. (1997). *Soil and Environment: Northern Ireland*. Belfast, UK, Department and Agriculture Northern Ireland.

D'Arcy, B. J., J. B. Ellis, et al. (2001). *Diffuse Pollution Impacts*. Lavenham, Surrey, CIWEM, Terence Dalton Publishers.

Davies, B. E. (1995). *Heavy Metals in Soils*. B. J. Alloway. London, Blackie Academic & Professional: 206-223.

ENVIRONMENT AGENCY. 2009a. Using soils guideline values. Science report SC050021/SGV introduction. <http://publications.environment-agency.gov.uk/pdf/SCHO0309BPQM-e-e.pdf>

ENVIRONMENT AGENCY. 2009b. *Soil guideline values for inorganic arsenic in soil*. Science Report SC050021/arsenic SGV. <http://publications.environment-agency.gov.uk/pdf/SCHO0409BPVY-e-e.pdf>

ENVIRONMENT AGENCY. 2009c. *Soil guideline values for inorganic nickel in soil*. Science Report SC050021/nickel SGV. <http://publications.environment-agency.gov.uk/pdf/SCHO0409BPWB-e-e.pdf>

ENVIRONMENT AGENCY. 2009d. *Soil guideline values for inorganic cadmium in soil*. Science Report SC050021/cadmium SGV. <http://www.environment-agency.gov.uk/static/documents/Research/SCHO0709BQRO-E-E.pdf>

ENVIRONMENT AGENCY. 2009e. *Soil guideline values for inorganic selenium in soil*. Science Report SC050021/Selenium SGV. <http://publications.environment-agency.gov.uk/pdf/SCHO0309BPQH-e-e.pdf>

Farago, M. E., P. Kavanagh, et al. (1996). "Platinum metal concentrations in urban road dust and soil in the United Kingdom." *Journal of Analytical Geochemistry* **354 (5-6)**: 660-663.

Fordyce, F. M., S. E. Brown, et al. (2005). "Urban geochemical mapping in Great Britain." *Geochemistry: Exploration, Environment, Analysis* **5 4**: 325-336.

Fordyce, F. M., Nice, S.E, Lister, T.R, O Dochartaigh, B.E, Cooper, R, Allen, M, Ingham, M, Gowing, C, Vickers, B.P, Scheib, A.J. (In prep). *Urban Soil Geochemistry of Glasgow.*, British Geological Survey, Keyworth, Nottingham, UK.

GSNI (1991). *Quaternary Geological Map*, British Geological Survey, Keyworth, Nottingham, UK.

GSNI (1997). *Solid Geology (Second Edition)*, British Geological Survey, Keyworth, Nottingham, UK.

Hooker, P. J., R. A. Ellison, et al. (2000). *Some guidance on the use of digital environmental data.*, British Geological Survey, Keyworth, Nottingham.

Ingham, M. N. and B. A. R. Vrebo (1994). "High productivity geochemical XRF analysis." Advances in X-ray Analysis **37**: 717-724.

Johnson, C. C. (2002). Within site and between site nested analysis of variance (ANOVA) for Geochemical Surveys using MS EXCEL, British Geological Survey, Keyworth, UK: 45pp.

Johnson, C. C. (2005). 2005 G-BASE Field Procedures Manual, British Geological Survey, Keyworth, UK: 130pp.

Kelly, J. J. P., I. Thornton, et al. (1996). "Urban Geochemistry: a study of the influence of anthropogenic activity on the heavy metal content of soils in traditionally industrial and non-industrial areas of Britain." Applied Geochemistry **11**: 363-370.

Knights, K. V. (2006). A report on the Tellus urban field campaigns of Belfast Metropolitan areas and Londonderry, 2006. M. E. Young. Belfast, UK, GSNI.

Lister, T. R. and C. C. Johnson (2005). G-BASE data conditioning procedures for stream sediment and soil chemical analyses. Keyworth, Nottingham, UK, British Geological Survey: 75pp.

Mitchell, W I (Ed.).2004. 'The Geology of Northern Ireland – Our natural foundation'. Geological Survey of Northern Ireland, Belfast.

Monaci, F. and R. Bargagli (1997). "Barium and other trace metals as indicators of vehicle emissions." Water, Air and Soil Pollution **100 (1-2)**: 89-98.

Monaci, F., F. Moni, et al. (1999). "Biomonitoring of airborne metals in urban environments: new tracers of vehicle emission, in place of lead." Environmental Pollution **107**: 321-327.

NISRA. (2004). "Northern Ireland Census 2001." from http://www.nisranew.nisra.gov.uk/census/pdf/ks_sett_tables.pdf.

Petkov, P., T. Palichev, et al. (1999). "A study of the mechanism of action of antismoke additives for diesel fuels." Oxidation Communications **22(2)**: 194-206.

Plant, J. A. (1973). "A random numbering system for geological samples." Transactions of the Institute Mining & Metallurgy **82**(Section B): 64-65.

Smyth, D. (2008). Methods used in the Tellus Geochemical Mapping of Northern Ireland. C. C. Johnson. Belfast, GSNI: 90.

Snedecor, G. W. and W. G. Cochran (1989). Statistical Methods. Ames, Iowa, USA, Iowa State University Press.

Ward, N. I. (1990). "Multielement contamination of British motorway environments." Science of the Total Environment **93**: 393-441.

Weiner, E R. 2000. Applications of Environmental Chemistry. Lewis Publishers (CRC Press LLC) Boca Raton, Florida, USA.

Wikipedia. (2008). Belfast from <http://en.wikipedia.org/wiki/Belfast>

Young, M. E. (2007). "Tellus." Earthwise **25**: 16-17. British Geological Survey.