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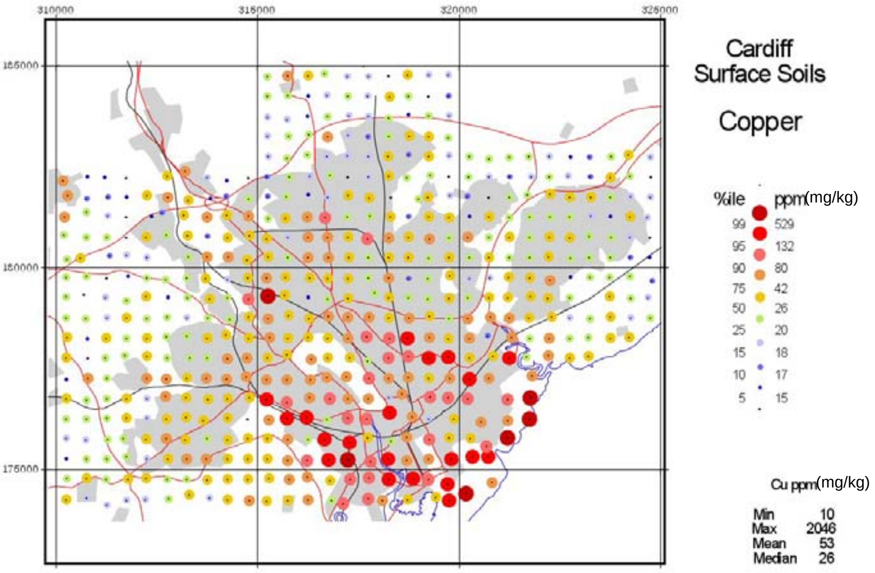
Geochemical baseline data for the urban area of Cardiff

Urban Geoscience & Geological Hazards Programme

Internal Report IR/01/102



BRITISH GEOLOGICAL SURVEY

INTERNAL REPORT IR/01/102

Geochemical baseline data for the urban area of Cardiff

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Key words

G-BASE, soil, geochemistry, urban.

Front cover

Copper in Cardiff surface soils.

Bibliographical reference

BROWN,S.E, 2004. Geochemical baseline data for the urban area of Cardiff. *British Geological Survey Internal Report*, IR/01/102 66pp

Keyworth, Nottingham British Geological Survey 2004

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The soil geochemical data presented in this report (and other urban reports from this series) are from individual sites, which were sampled as part of a baseline geochemical survey. The results should only be used to set a regional context, not as the basis for interpretations concerning specific sites. Interpretations relating to specific sites should be based on follow-up investigations. The data in this report, in addition to all geochemical data held by BGS, are available under licence. Their use is subject to the terms of a licensing agreement.

Foreword

This report is a product of the British Geological Survey's (BGS) Geochemical Surveys of Urban Environments (GSUE) project. The work is funded by the UK Government Office of Science and Technology and is part of the national Geochemical Baseline Survey of the Environment (G-BASE) programme. The report forms part of a publication series, which aims to make GSUE urban soil chemistry data publicly available with a minimum of interpretation, displaying the data as a series of graduated symbol maps.

A number of urban centres have been surveyed to date using systematic soil sampling procedures. These are indicated in the figure below. Wolverhampton, Manchester and Glasgow were sampled as part of larger multi-disciplinary projects.

Urban centres sampled to date by the GSUE project

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Summary

This report presents the results of an urban soil geochemical survey of Cardiff carried out by the British Geological Survey (BGS) during 1994. The study was undertaken as part of the BGS systematic Geochemical Surveys of Urban Environments (GSUE) project. The concentrations of many potentially harmful elements (PHE) such as As, Cd, Cr, Ni and Pb are enhanced in city environments as a result of urbanisation and industrial processes and their distribution is of concern under current UK environmental legislation.

The GSUE data provide an overview of the urban geochemical signature and because they are collected as part of a national baseline programme, can be readily compared with soils in the rural hinterland to assess the extent of urban contamination. The aim of the present study was to generate urban soil geochemistry information for Cardiff to aid planning and development.

Urban surveying was based upon the collection of samples on a systematic 500 m grid. Soils were sampled at a density of 4 per km^2 across the built-up area. Samples were collected from open ground as close as possible to the centre of each 500 m grid cell.

Preliminary interpretations of the data in relation to the underlying geology and past and present industrial history of Cardiff are presented in this report and demonstrate that the majority of metal elements are elevated in the former industrial centre of the city around the docks reflecting anthropogenic influences. However, in general contaminant levels in Cardiff are similar to other city environments in the region.

1 Introduction

This report summarises the results and methodology of a soil geochemical survey of the urban area of Cardiff, undertaken by the British Geological Survey (BGS) during 1994 as part of the Geochemical Survey of Urban Environments (GSUE) project. The GSUE project forms part of the national strategic geochemical survey of Great Britain and Northern Ireland, the Geochemical Baseline Survey of the Environment (G-BASE) programme (Johnson and Breward, 2004).

The programme is undertaking a systematic regional geochemical survey of soils, stream sediments and stream waters of the British Isles at a sample density in rural areas of 1 per 1.5 – 2 km^2. The data provide information on the surface chemical environment, which can be used to define environmental baselines and the extent of surface contamination and are published as a series of regional geochemical atlases for the country (see for example British Geological Survey, 2001). 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 G-BASE 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 potentially harmful elements (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 bears little relation to the soils, bedrock and superficial cover of the surrounding rural hinterland.

As part of the G-BASE programme, the GSUE project undertakes systematic soil surveys to define citywide geochemical signatures over selected urban areas including that of Cardiff (Figure 1).

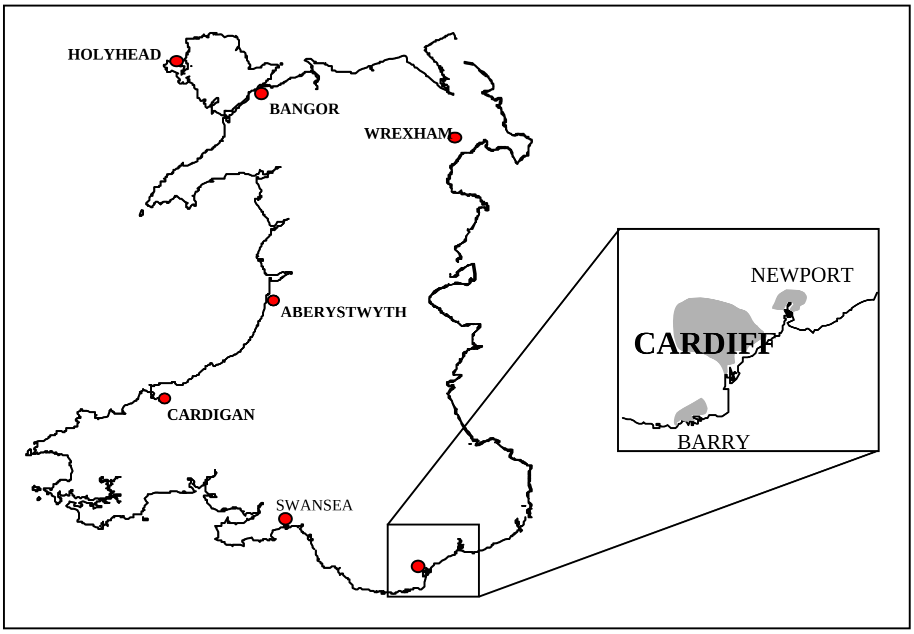


Figure 1 Location map for Cardiff

Cardiff is the capital city of Wales. It is located on the north of the Bristol Channel at the mouth of the River Taff. It has had a varied industrial history related to coal mining and the export of coal and steel manufacture. Today Cardiff remains an important seaport and among its industries are steel, machinery, processed foods, metal products, textiles and paper.

The distributions of approximately 17 major and trace elements including several PHE in the surface environment of Cardiff are described in this report in relation to present and historical land use. The concentrations of the elements are also considered in terms of the underlying geology and placed in context with respect to the typical rural background concentrations obtained from G-BASE regional stream sediment data sets from the surrounding area.

2 Study Area

2.1 HISTORICAL LAND USE

Until the early 19th century Cardiff was still a village with less than 2000 people. This was set to change rapidly with the opening of the Glamorganshire canal, which was used to transport iron from Merthyr to Cardiff. As the iron and coal industries expanded the Taff Railway was opened in 1840 as a more efficient form of transport. At the same time the Bute West Dock was opened.

As the worldwide demand for steam coal from the South Wales Coalfield increased a record 13 million tons of coal were exported from Cardiff Docks in 1913, making it the world's largest port for the export of coal. This prompted the growth of the dockland area, which attracted other industries such as heavy engineering, steelworks and ship repairing. Cardiff was also an important fishing town.

After World War I, the global demand for coal declined, which in turn caused the docklands to fall into radical decline.

In the present day the docks are now being regenerated. This project covers an area of 2700 acres, which equates to approximately 1/6 of Cardiff as a whole (Cardiff County Council, 2005).

2.2 AREA SAMPLED

An area of 127km^2 was surveyed during the summer of 1994, in which a total of 508 surface soils (0.05 - 0.20 m depth) and 499 profile soils (0.35 – 0.50 m depth) were sampled. This extends from grid references 310000m east to 325000m east and from 174000m north to 185000m north, and covers Cardiff city centre and the surrounding suburbs. The survey area is shown in Figures 2 and 3.

2.3 SOLID AND SUPERFICIAL GEOLOGY

Geological information for the Cardiff area was obtained from the BGS 1:50 000 series maps and the BGS digital DigmapGB® data (British Geological Survey, 1986, 1986a). The solid and superficial deposits of the region are shown in Figures 4 and 5.

The oldest rocks exposed within the Cardiff urban area are mudstones and shales of the Ludlow and Wenlock Series (Silurian). These are unconformably overlain by mudstones and red sandstones of the Devonian, to the north of the city. To the west and north-west, the bedrock is predominantly Carboniferous in age, ranging from a relatively thin Carboniferous Limestone and Namurian sequence, which develops into a much more extensive outcrop of Coal Measures, which are predominantly sandstones and mudstones, with productive coal seams.

Unconformably overlying the Coal Measures, and underlying much of the urban area of Cardiff, are rocks of the Mercia Mudstone Group, which here consist of red sandstones and conglomerates in addition to red mudstones. Locally, rocks of Lower Jurassic age (Lias) overlay the Mercia Mudstone Group, and include marine sandstones and mudstones. See Figure 4.

The main Quaternary deposit within the Cardiff urban area, which accounts for around 70% of the superficial cover, is till. Exceptions occur in the valley of the River Taff, which comprises of alluvial deposits and undifferentiated fluvioglacial deposits. To the north east of Cardiff, along the coast are marine/estuarine silts and clays. The main tracts of made ground lie around the dock area. See

Figure **5**.

2.4 SOIL TYPE

The National Soil Resources Institute (formerly the Soil Survey of England and Wales) produces soil maps for much of the UK landmass, however urban and industrial areas have not been surveyed for soil type. Therefore no information exists on soil type for the main urban area of Cardiff.

Some soil characteristics are reported as part of the GSUE survey. Basic information for the urban soils of Cardiff was recorded on computer-compatible field cards (see Appendix A), which are completed at site during sampling according to standard procedures (Johnson et al., 2003). These contain data such as soil colour, texture, sample depth, clasts that are contained within the soil, as well as land use and any physical contamination that is observed. The field cards are completed using a set of standard database-compatible codes (Harris and Coats, 1992) and the information is held on the BGS corporate geochemistry database.

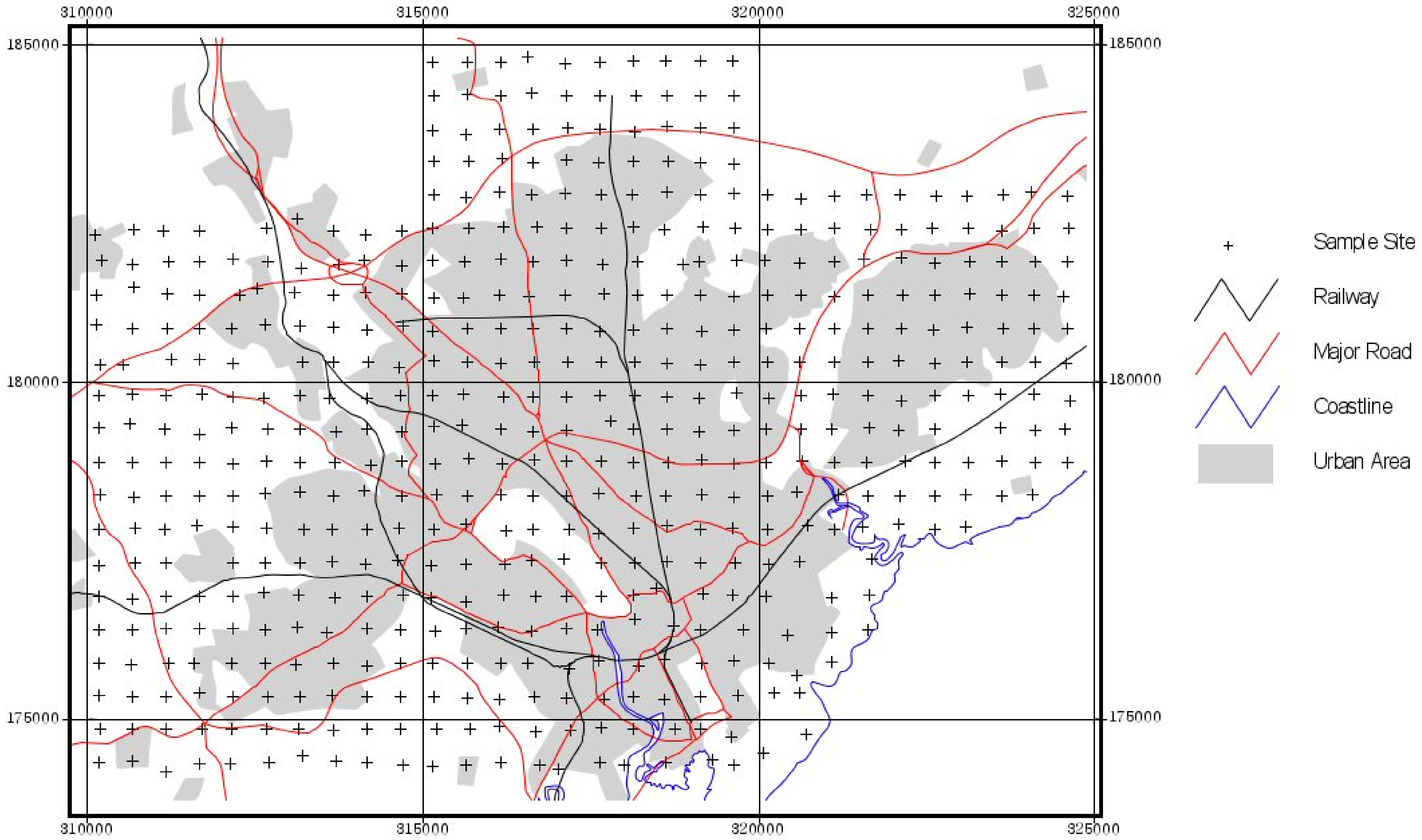


Figure 2 Map of the sampling area

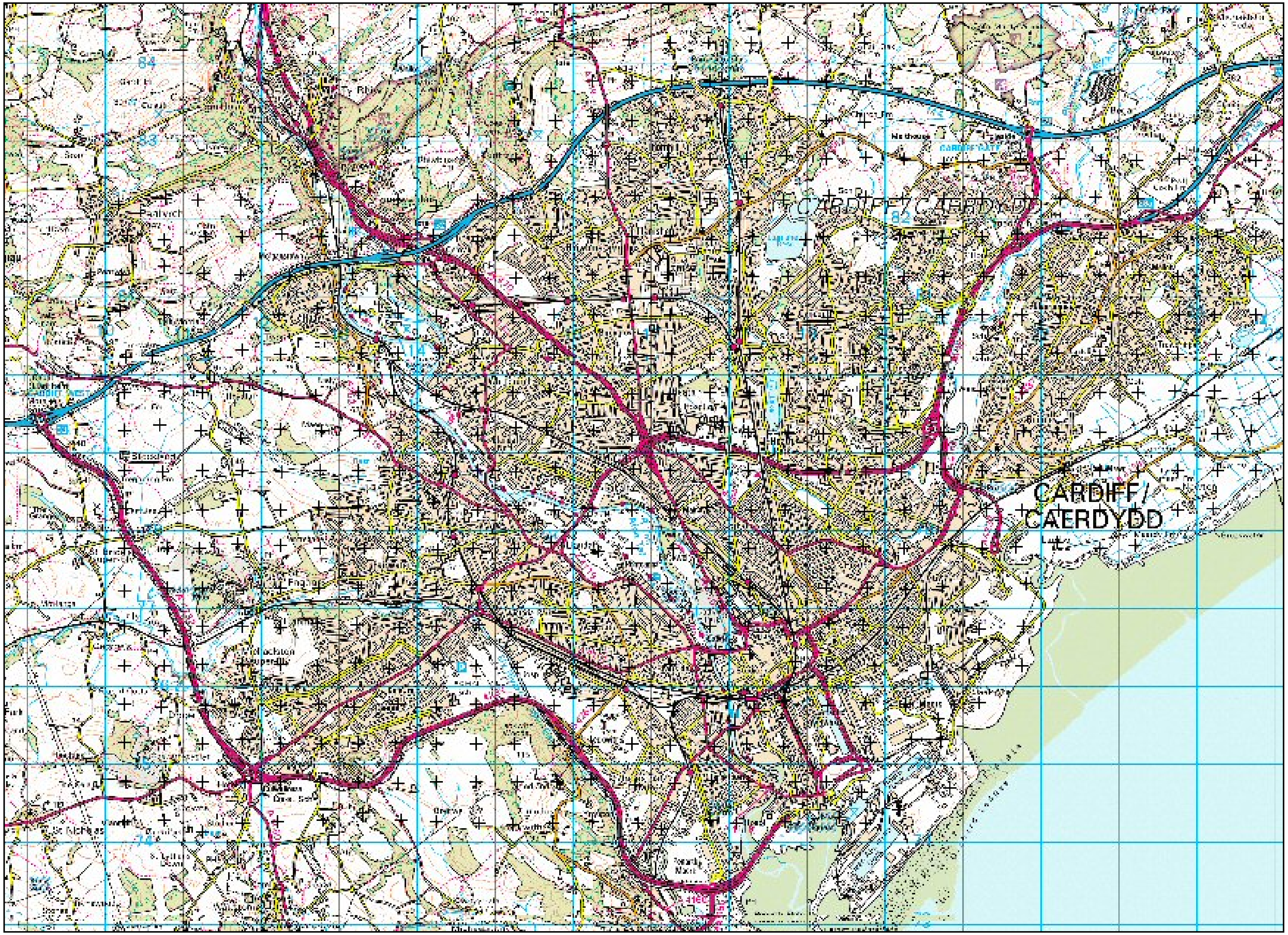


Figure 3 Topographic map of Cardiff (1:50,000 Ordnance Survey©)

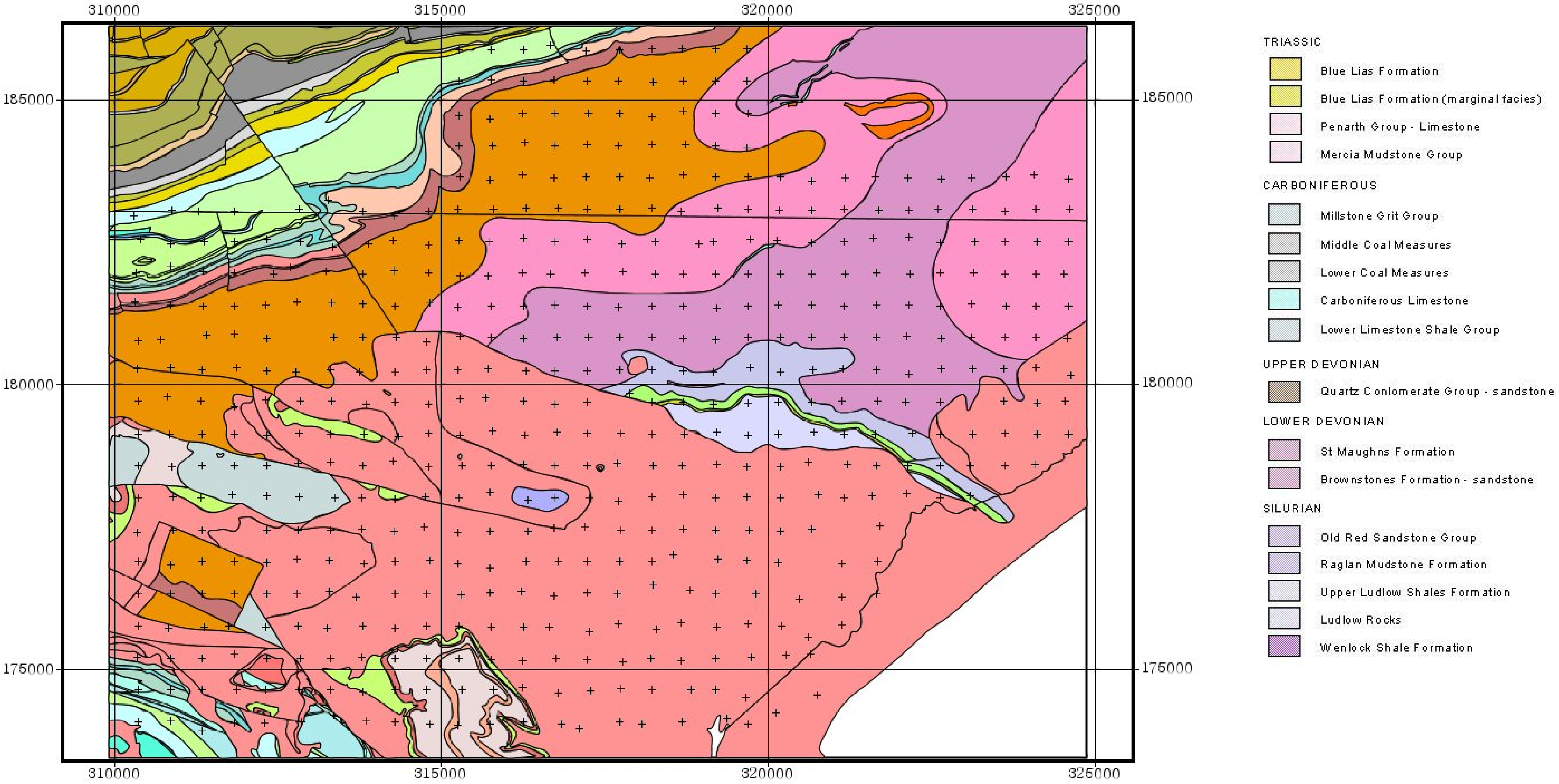


Figure 4 Solid geology map of Cardiff (1:50,000 British Geological Survey©)

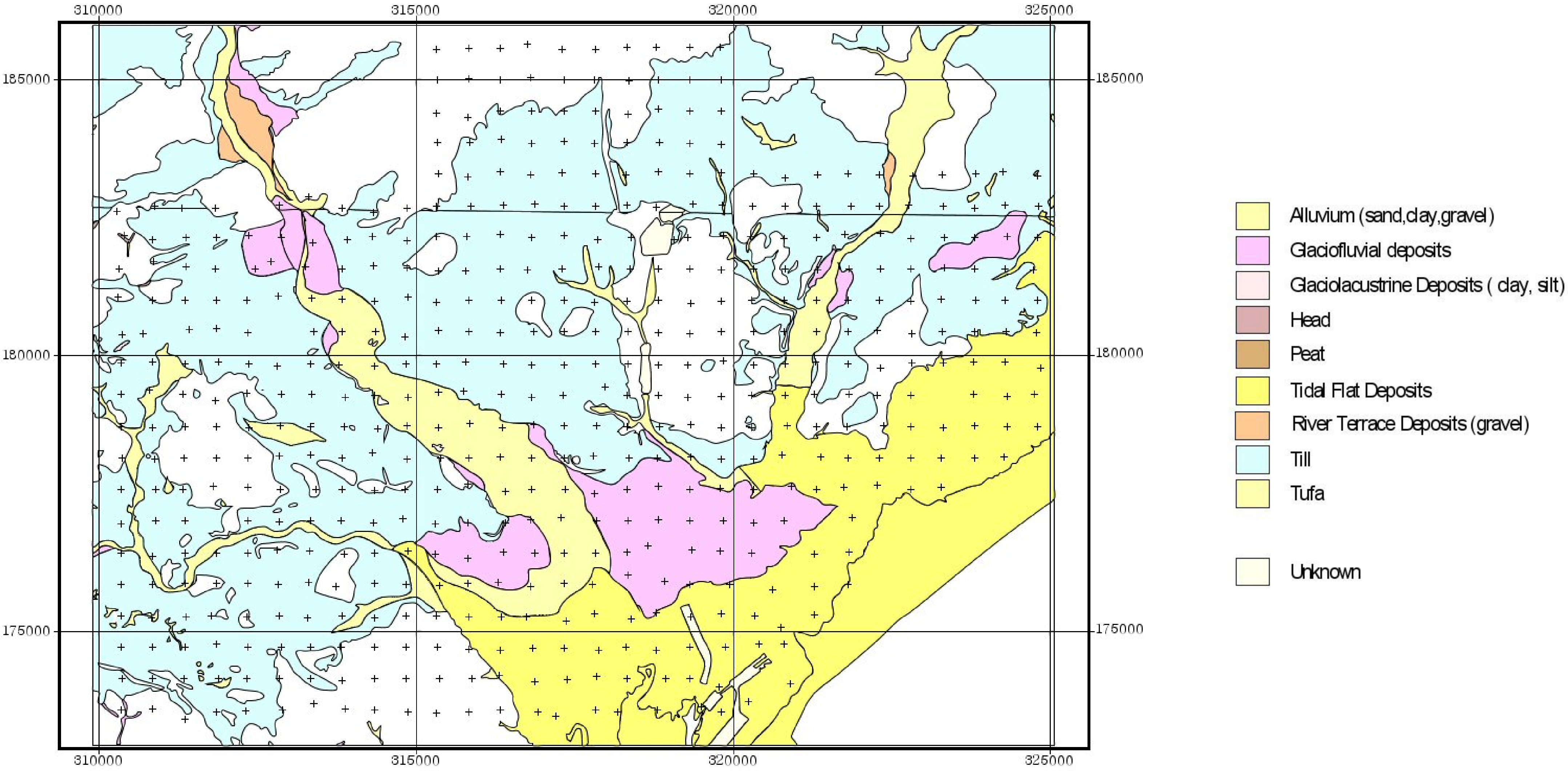


Figure 5- Superficial deposit map of Cardiff (1:50, 000 British Geological Survey©)

3 Methodology

3.1 SOIL SAMPLING

Sample sites were arranged on a systematic grid pattern at a density of 4 samples per km^2 across the built-up area whereby each BNG kilometre square as defined from 1:25 000 scale topographic maps (Ordnance Survey®) 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 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 constructions). Typical locations for sampling included gardens, 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 cell, contamination was not purposefully avoided as the aim of the survey was to provide an overview of the urban geochemistry and not to establish a 'near natural' geochemical baseline.

Soil samples were collected using a Dutch style hand auger with a 15 x 3 cm bore. 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 depth of 0.35 – 0.50 m (Johnson et al., 2003). Both A and S samples comprised a composite of 3 sub-samples collected on the diagonal of a 2 x 2 m square. Duplicate sampling is described in section 3.3.2 of this report.

As indicated in section 2.4, information about the soils recorded at each site on field cards and the sample locations are stored in the BGS corporate geochemical database where they can be retrieved via a user-friendly PC software interface (Harris and Coats, 1992).

3.2 SAMPLE PREPARATION

Samples were air dried and then oven dried at temperatures below 40ºC and then sieved. Surface soils were sieved to obtain the <2 mm fraction and profile soils to obtain the <150 µm fraction to be compatible with G-BASE regional <150 µm stream sediment data. The sieved material was coned and quartered and a split of the sample was ground using an agate ball mill until 95% reached a grain size finer than 53 µm. A 12 g split of the ground material was combined with 3 g of elvacite binder and pressed into a pellet for analysis by X-Ray Fluorescence Spectrometry analysis (XRFS) (see section 3.4).

Excess sieved and ground sample material is retained in the National Geoscience Records Centre at the BGS.

3.3 ERROR CONTROL PROCEDURES

The accuracy and precision of the geochemical data were monitored using the methods of (Plant et al,.1975), which are briefly described below.

3.3.1 Random numbering of samples

Samples were allocated numbers according to a random numbering system (Plant, 1973) but were analysed in numerical order. This allows any systematic error in either sampling or analytical methodologies to be identified and attributed to the appropriate process. At each site the A and the S samples were assigned unique numbers according to the random number lists. Therefore within each batch of one hundred samples there were 50 A and 50 S samples.

3.3.2 Duplicate and sub-samples

Within each batch of one hundred samples, a pair of sample numbers were assigned to a sampling duplicate, resulting in a field duplicate pair for both A and S samples. Duplicate samples were collected using identical sampling methodology adjacent to the original sample. 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.

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 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 variation in element concentrations across the survey area). All of the analyses considered were part of a single randomised dataset and therefore a random nested model of ANOVA was used (Snedecor and Cochran, 1989).

Due to the relatively low number of duplicate samples collected in a single urban area, the ANOVA calculations were performed using replicate soils collected from 11 different urban centres: Cardiff, Swansea, Stoke, Telford, York, Hull, Doncaster, Mansfield, Scunthorpe, Lincoln and Sheffield (Lister, 2002; Lister, In Prep). A total of 50 replicate sets were measured for urban profile soils, while up to 37 were measured for urban surface soils. All elements except Cd and U (both depths) and TiO_2 (surface soils) were log transformed to improve the fit of the data to a Gaussian distribution. The ANOVA calculations were performed using the NESTED procedure from the statistical software package, MINITAB^{TM}. The results of the ANOVA indicate that for most elements the between-site variability is greater than 80% of the total variance (Table 1). This suggests that geochemical variation is the principal control on element concentrations in urban areas. The between-site variance of Cd is significantly lower than the other elements, with nearly half the variation in the surface soils attributed to residual factors. This is an indication of analytical error, most likely to result from low overall concentrations with respect to the detection limit.

Table 1 ANOVA percentage of variance in surface and profile soils from 11 urban centres attributable to between-site, between-sample and residual variance

Surface Soils		Variance			Profile Soils		Variance		
Element	Number of Replicate Sets	Between Site (%)	Between Sample (%)	Residual (%)	Element	Number of Replicate Sets	Between Site (%)	Between Sample (%)	Residual (%)
Sb	16	88.03	1.15	10.82	Sb	50	87.68	3.05	9.27
As	37	97.69	2.02	0.29	As	50	97.87	1.82	0.31
Ba	37	97.63	1.79	0.58	Ba	50	97.39	2.56	0.05
Cd	27	47.88	6.77	45.35	Cd	50	65.44	3.95	30.61
Cr	37	94.14	3.07	2.79	Cr	50	93.46	5.55	0.99
Co	37	96.35	0.00	3.65	Co	50	94.00	5.62	0.38
Cu	37	97.63	1.66	0.72	Cu	50	98.87	1.08	0.06
Fe_2O_3	37	97.69	2.06	0.25	Fe_2O_3	50	96.62	3.36	0.01
Pb	27	97.48	2.23	0.29	Pb	50	96.51	3.43	0.06
MnO	37	98.28	1.39	0.33	MnO	50	96.03	3.92	0.05
Mo	33	94.24	0.71	5.05	Mo	50	93.59	3.23	3.17
Ni	37	98.06	1.59	0.34	Ni	50	95.96	3.83	0.21
Sn	36	93.45	2.91	3.63	Sn	50	95.77	2.42	1.81
TiO_2	37	96.58	2.65	0.77	TiO_2	-	-	-	-
U	37	85.95	1.24	12.81	U	47	76.92	10.99	12.09
V	37	97.89	1.79	0.32	V	50	97.85	2.09	0.06
Zn	37	94.77	5.16	0.07	Zn	50	92.64	7.34	0.02

3.3.3 Standards

Standards were included in the analytical runs to monitor the accuracy of the results. These were assigned a unique number at the sample preparation stage and were treated identically to the other samples. For the Cardiff data set 17 standards were included in the analysis of the A samples and 9 were included with the S samples. The standards used were the G-BASE in-house bulk soil standards S13, S15 and S24.

The inclusion of standards allows the data to be normalised to the G-BASE regional data set for Wales, which, consists of the XRFS analyses of approximately 21,000 samples (British Geological Survey, 2001).

3.4 ANALYTICAL PROCEDURES

All samples were analysed at the BGS laboratories for a range of elements by Wavelength Dispersive X-ray Fluorescence Spectrometry (Ingham and Vrebos, 1994). Three sequential XRF spectrometers were used. A Philips PW1480 fitted with a 216 position sample changer and a 3 kW/100kV tungsten anode X-ray tube was used to determine Cd, Sn and Sb. Two Philips PW2400 spectrometers fitted with 102 position sample changers and with 3 kW/60 kV rhodium anode x-ray tubes were used to determine TiO_2, MnO, Fe_2O_3, V, Cr, Co, and Ba in one suite and Ni, Cu, Zn, As, Mo, Pb, and U in another.

The elements determined and the lower limits of detection (LLD) and upper and lower reporting limits (URL and LLR) for each analyte are shown in Table 2

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.

Table 2 Lower (LLD) and upper reporting limits (URL) values for XRFS of G-SUE urban soil samples

Analyte	LLD (mg/kg)	LLR (wt %)	URL (mg/kg)	URL (wt %)
TiO_2*	-	0.010	-	100.0
MnO	-	0.010	-	10.0
Fe_2O_3	-	0.01	-	100.0
V	2	-	20000	-
Cr	1.5	-	250000	-
Co	2	-	10000	-
Ni	1	-	4000	-
Cu	1	-	6500	-
Zn	1	-	10000	-
As	1	-	10000	-
Mo	0.4	-	1000	-
Cd	1	-	500	-
Sn	1	-	10000	-
Sb	1	-	10000	-
Ba	3	-	600000	-
Pb	1	-	10000	-
U	<1	-	650	-

*A soils only.

3.5 DATA INTERPRETATION

Once full error control and data quality procedures were completed, the spatially registered Cardiff geochemical data were loaded into an Arcview© GIS software package. Graduated symbol geochemical maps for surface and profile soils categorised according to percentiles of the data distribution (Appendix B) were then generated (see Appendix C).

4 Geochemical Interpretation

4.1 BACKGROUND LEVELS

In order to aid the interpretation of the geochemical data for Cardiff it is useful to be aware of typical background concentrations of elements in the surrounding rural environment to place the urban data in context**.** Regional soil sampling was not carried out routinely in the G-BASE survey of Wales and although direct comparisons of soil and stream sediment data are not possible, the G-BASE stream sediment data set for Wales, none-the-less provides a useful overview of background concentrations of elements in the surface environment. The median elemental concentrations for 18,927 Welsh stream sediment samples are shown in Table 3. For comparison, Table 4 shows the median elemental concentrations of the surface and profile soils from the urban area of Cardiff.

The median value of a geochemical dataset provides an indication of the typical concentrations for elements across the area, removing the influence of outliers caused by isolated regions of contamination. However, it should be noted that background values in the urban environment, as well as the rural environment (to a lesser extent), are likely to be elevated by some level of diffuse pollution.

Table 3 Median concentrations in <150mm stream sediment samples **(British Geological Survey, 2001)**

Analyte	Units	Median Value
As	mg/kg	14
Ba	mg/kg	540
Cd	mg/kg	<1
Co	mg/kg	31
Cr	mg/kg	92
Cu	mg/kg	22
Fe_2O_3	wt%	6.8
MnO	wt%	0.18
Mo	mg/kg	1.6
Ni	mg/kg	38
Pb	mg/kg	36
Sb	mg/kg	<1.2
Sn	mg/kg	5
TiO_2	wt%	0.86
U	mg/kg	2.3
V	mg/kg	110
Zn	mg/kg	130

Table 4 Median concentrations of soils from Cardiff (surface and profile)

Analyte	Units	Median (Surface)	Median (Profile)
As	mg/kg	16	15
Ba	mg/kg	454	423
Cd	mg/kg	1	1
Co	mg/kg	21	22
Cr	mg/kg	72	81
Cu	mg/kg	26	23
Fe_2O_3	wt%	5.2	5.5
MnO	wt%	0.15	0.15
Mo	mg/kg	1.1	2.1
Ni	mg/kg	26	28
Pb	mg/kg	76	58
Sb	mg/kg	2	4
Sn	mg/kg	6	5
TiO_2	wt%	0.65	N/A
U	mg/kg	2	2
V	mg/kg	77	83
Zn	mg/kg	121	112

Comparing the above data shows that the regional concentrations are, on the whole, slightly higher than the urban concentrations, this is probably due to the underlying bedrock (e.g. the Coal Measures which are have naturally high levels of certain trace elements such as Ni and V). The only elements showing elevated levels in the urban environment are As, Cu and Pb, which are probably due to anthropogenic sources such as emissions from vehicles and the burning of fossil fuels. It must be remembered that the size fraction of the surface soils (<2mm) differs from that of the profile soils and stream sediments (<150μm) and therefore cannot be compared with any great confidence.

4.2 CHEMICAL VARIATION WITH DEPTH

In a comparison of surface and profile soils, it should again be noted that during sample preparation the two sample types are sieved to different size fractions. The surface soils are sieved to <2 mm whilst the profile soils are sieved to <150 µm. This means that the sieved profile soil has a much larger surface area and will contain more clay particles (which possess the ability to attract and bind many metal elements (Brady and Weil, 1999)) and this may affect the geochemical results.

Based on the median values in Table 4 Fe, V, Cr, Co, Ni Mo and Sb are higher in profile soils probably reflecting size fraction. However, Cd and U are the same in both depths but the levels of these are very close to detection limit and therefore we cannot be confident with the data. Interestingly Ba, Cu, Zn, As, Pb and Sn are higher based on medians in surface soils. These elements probably indicate contamination, reflecting the atmospheric deposition of these metals through sources such as vehicle emissions, industry and the burning of fossil fuels.

There could also be other explanations why the profile soils show elevated levels of some heavy metals. For example, in areas of contamination fresh topsoil could have been brought in for a remediation exercise, resulting in the contaminated soil being buried.

4.3 GEOCHEMICAL DISTRIBUTIONS IN CARDIFF SOILS

There seems to be little correlation between geology and superficial deposits and soil geochemistry. The majority of elevated levels of trace metals can be attributed to anthropogenic sources.

The main area of heavy contamination lies around the dock area and East Moors steel works. Around this area there are elevated levels of Mn, Fe, V, Cr, Ni, Cu, Zn, As, Mo, Pb, Cd and Sb. These are all trace elements that are associated with steel manufacture and the burning of fossil fuels. The docks imported ores for steel making and exported coal, steel and other products, therefore the high levels of trace elements were probably due to spillage of these.

There are very high levels of Co, Ni, Zn, As, Mo, Ni, and Sn around Jubilee Recreation ground at Leckwith and Sevenoaks Park at Grangetown. It was common practise for parks to be landscaped with industrial waste, in Cardiffs case fly ash and waste products from the steel making industry.

There are also levels above the soil guideline values (SGV) by a rather significant amount for Cr, Ni, As, Pb and Cd at the Leckwith Drove allotments. This is probably due to the fact that the allotments share a boundary with the former Leckwith Moors rubbish tip (BBC, 2004). Also there is a possibility that fly ash was spread onto the soil to try and improve it as the elevated trace elements show a characteristic signature.

To the north of the city, to the east of Ton Mawr quarry and to the west of Taffs Well quarry there are exceptionally high levels of Ba. Both of these quarries excavate limestone. One of the main minerals found within the limestone at these sites is Baryte, which would explain the large Ba anomaly in this area.

There is a TiO_2 anomaly around Trowbridge to the east of Cardiff and south towards Rumney Great Wharf. There are also high levels of V and Fe in this area, which is indicative of an Ilmenite signature and could be contained within the blown sands.

Another area in Cardiff with elevated levels of trace elements is Butetown, which was constructed on reclaimed land.

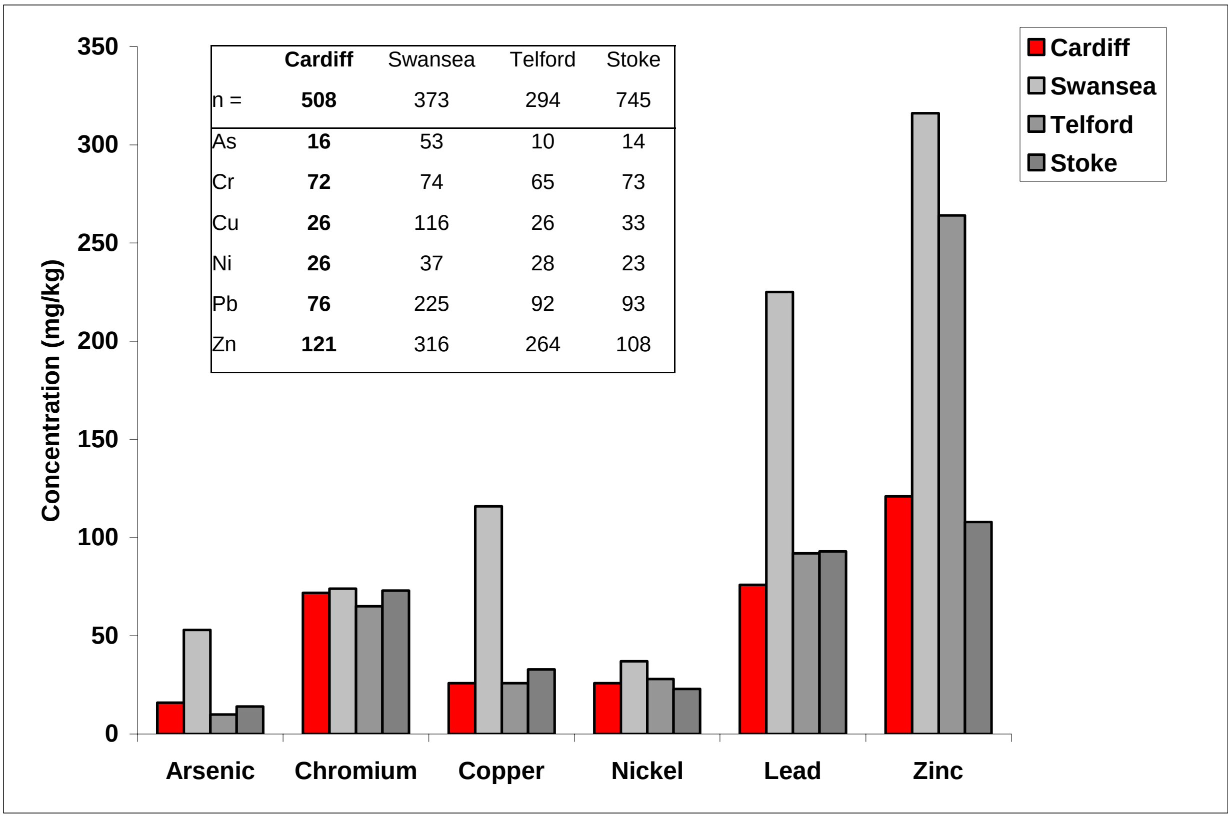
Higher levels of elements such as Pb, Zn and Ba can be related to the road traffic network around the city. Pb used to be an additive in petrol and was deposited from vehicle emissions; Zn is used in tyre manufacture and could be enriched due to the use of road vehicles and organo-metallic compounds containing Ba are added to diesel fuel to reduce black smoke emissions from diesel engines (Health Canada, 2005).

The geochemistry of Cardiff soils has been examined in more detail by Kelleher (1999) and Cave et al. (2003).

Taking into account the regional trends, the levels of heavy metals within the Cardiff urban area are not particularly elevated, although lead and copper are slightly higher than the regional levels suggest (see Table 3 and Table 4).

4.4 SOIL GEOCHEMISTRY OF CARDIFF IN RELATION TO OTHER WELSH ATLAS URBAN AREAS

Six elements that may be affected by anthropogenic contamination in urban areas (As, Cr, Cu, Ni, Pb, and Zn) from Cardiff surface soils are presented in the context of three other urban areas from the Welsh atlas region in Figure 6. On the basis of median values, concentrations of elements such as As, Ni and Cr in Cardiff compare with those of Telford and Stoke, but are considerably lower than Swansea that has a history of heavy metal smelting.



	Cardiff	Swansea	Telford	Stoke
n =	**508**	373	294	745
As	**16**	53	10	14
Cr	**72**	74	65	73
Cu	**26**	116	26	33
Ni	**26**	37	28	23
Pb	**76**	225	92	93
Zn	**121**	316	264	108

Figure 6 Comparisons of surface soil As, Cr, Cu, Ni, Pb and Zn median values between cities within the Welsh atlas area

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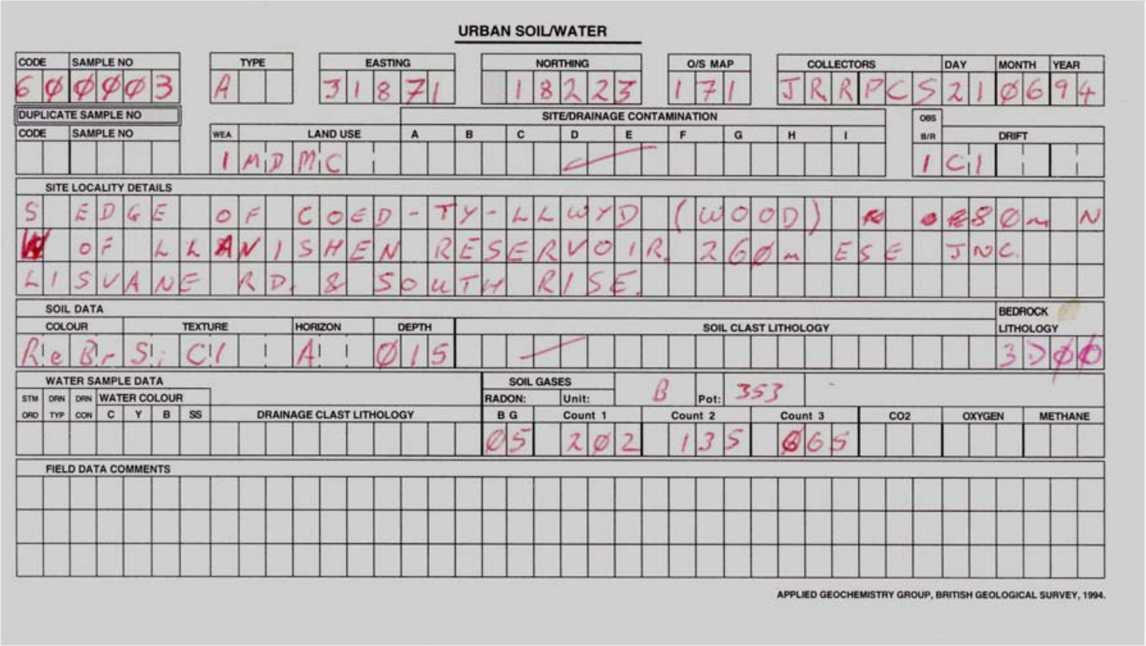
Appendix A: Examples of urban surface and profile field cards from Cardiff.



URBAN SOIL/WATER

CODE: 60
SAMPLE NO: 0003
TYPE: A
EASTING: 31871
NORTHING: 18223
O/S MAP: 171
COLLECTORS: JRRPCS
DAY: 21
MONTH: 06
YEAR: 94

DUPLICATE SAMPLE NO
CODE:
SAMPLE NO:

WEA: 1
LAND USE: MD MC
SITE/DRAINAGE CONTAMINATION: A B C D E F G H I
OBS B/R: 1
DRIFT: C1

SITE LOCALITY DETAILS
S EDGE OF COED-TY-LLWYD (WOOD) 80m N W OF LLANISHEN RESERVOIR. 260m ESE JNC. LISVANE RD. & SOUTH RISE.

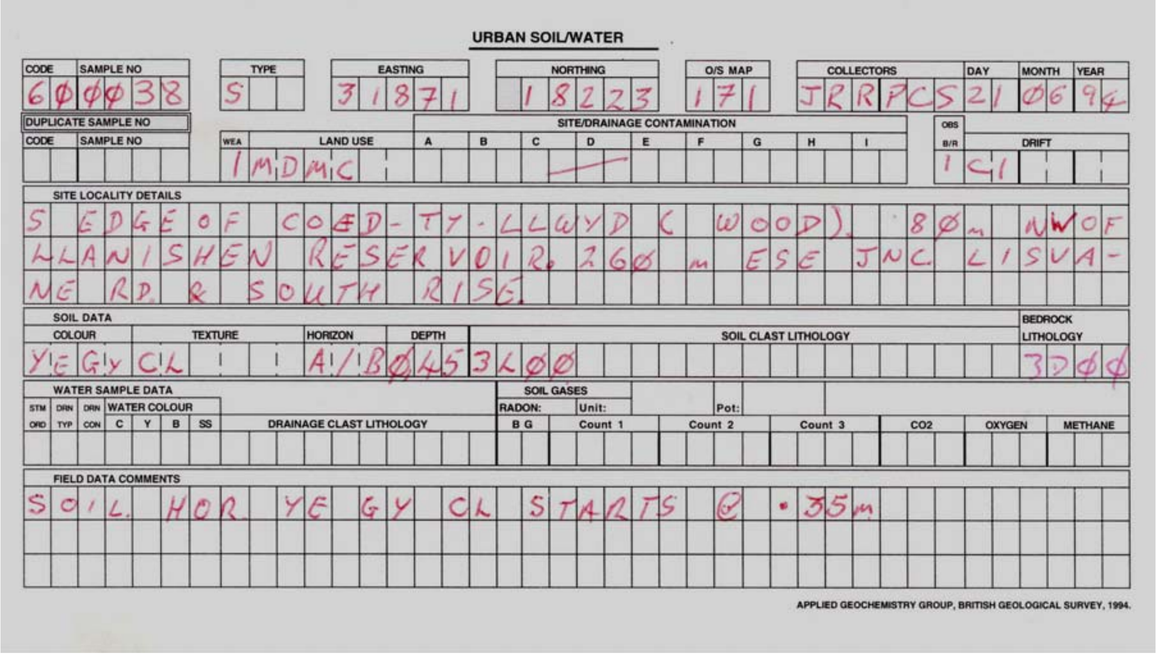
SOIL DATA
COLOUR: ReBr
TEXTURE: SiCl
HORIZON: A
DEPTH: 015
SOIL CLAST LITHOLOGY:
BEDROCK LITHOLOGY: 3D00

WATER SAMPLE DATA
STM ORD:
DRN TYP:
DRN CON:
WATER COLOUR C Y B SS:
DRAINAGE CLAST LITHOLOGY:

SOIL GASES
RADON: Unit: B
Pot: 353
B G: 05
Count 1: 202
Count 2: 135
Count 3: 065
CO2:
OXYGEN:
METHANE:

FIELD DATA COMMENTS

APPLIED GEOCHEMISTRY GROUP, BRITISH GEOLOGICAL SURVEY, 1994.



URBAN SOIL/WATER

CODE: 60
SAMPLE NO: 0038
TYPE: S
EASTING: 31871
NORTHING: 18223
O/S MAP: 171
COLLECTORS: JRRPCS
DAY: 21
MONTH: 06
YEAR: 94

DUPLICATE SAMPLE NO
CODE:
SAMPLE NO:

WEA: 1
LAND USE: MD MC
SITE/DRAINAGE CONTAMINATION: A B C D E F G H I
OBS B/R: 1
DRIFT: C1

SITE LOCALITY DETAILS
S EDGE OF COED-TY-LLWYD (WOOD). 80m NW OF LLANISHEN RESERVOIR. 260 m ESE JNC. LISVA-NE RD. & SOUTH RISE.

SOIL DATA
COLOUR: YeGy
TEXTURE: CL
HORIZON: A/B
DEPTH: 045
SOIL CLAST LITHOLOGY: 3L00
BEDROCK LITHOLOGY: 3D00

WATER SAMPLE DATA
STM ORD:
DRN TYP:
DRN CON:
WATER COLOUR C Y B SS:
DRAINAGE CLAST LITHOLOGY:

SOIL GASES
RADON: Unit:
Pot:
B G:
Count 1:
Count 2:
Count 3:
CO2:
OXYGEN:
METHANE:

FIELD DATA COMMENTS
SOIL HOR. YE GY CL STARTS @ .35m

APPLIED GEOCHEMISTRY GROUP, BRITISH GEOLOGICAL SURVEY, 1994.

Appendix B: Percentile calculations for Cardiff soils

*surface soils in yellow.

Percentile	TiO$_2$ wt%	MnO wt %	MnO wt %	Fe$_2$O$_3$ wt %	Fe$_2$O$_3$ wt %	V mg/kg	V mg/kg	Cr mg/kg	Cr mg/kg	Co mg/kg	Co mg/kg	Ba mg/kg	Ba mg/kg	Ni mg/kg	Ni mg/kg	Cu mg/kg	Cu mg/kg
99	0.974	0.639	0.658	16.17	16.07	158	203	259	228	70	90	2805	4169	167	154	529	480
95	0.895	0.320	0.330	7.64	8.26	128	135	125	126	38	38	1185	1284	60	67	132	154
90	0.798	0.260	0.263	6.89	7.04	111	116	107	109	31	31	909	1021	45	46	80	85
75	0.704	0.193	0.197	5.90	6.01	89	94	84	90	25	26	625	631	34	37	42	39
50	0.645	0.151	0.151	5.20	5.45	77	83	72	81	21	22	454	423	26	28	26	23
25	0.585	0.119	0.111	4.64	4.99	71	77	65	74	18	20	372	341	20	24	20	18
15	0.538	0.103	0.087	4.40	4.68	68	75	62	71	17	19	337	308	18	22	18	16
10	0.503	0.085	0.074	4.18	4.42	66	73	58	69	17	18	327	297	17	21	17	14
5	0.458	0.070	0.049	3.88	3.96	63	71	53	64	14	17	304	268	15	19	15	13
Max	1.086	1.398	0.958	42.59	60.89	469	664	2426	1374	100	162	17566	29561	476	582	2046	6167
Min	0.148	0.021	0.009	1.78	1.87	43	38	1	3	1	1	198	70	9	12	10	7
Mean	0.648	0.174	0.168	5.62	5.88	84	91	90	91	23	25	605	668	32	36	53	61
Median	0.645	0.151	0.151	5.20	5.45	77	83	72	81	21	22	454	423	26	28	26	23

Percentile	Zn mg/kg	Zn mg/kg	As mg/kg	As mg/kg	Mo mg/kg	Mo mg/kg	Pb mg/kg	Pb mg/kg	U mg/kg	U mg/kg	Cd mg/kg	Cd mg/kg	Sn mg/kg	Sn mg/kg	Sb mg/kg	Sb mg/kg
99	1511	1951	53	68	10.0	35.7	1382	1700	3	4	5	3	195	348	24	41
95	586	585	32	36	3.6	9.4	743	650	2	3	2	2	60	68	8	9
90	363	314	27	26	2.5	5.3	400	327	2	3	2	1	32	36	5	7
75	183	171	20	18	1.6	3.3	147	124	2	2	1	1	12	11	2	5
50	121	112	16	15	1.1	2.1	76	58	2	2	1	1	6	5	2	4
25	94	88	13	12	0.8	1.5	54	34	1	2	1	1	4	4	1	3
15	84	77	12	11	0.6	1.1	45	28	1	2	1	1	4	3	1	3
10	80	71	11	10	0.5	0.9	43	25	1	2	1	1	4	3	1	3
5	72	61	10	9	0.3	0.7	38	21	1	1	1	1	3	3	1	3
Max	23238	27811	150	242	75.9	208.6	7575	16669	4	6	82	37	334	3148	153	333
Min	41	26	6	1	0.2	0.2	14	6	0	0	1	1	2	2	1	2
Mean	274	263	18	18	1.7	3.8	194	205	2	2	1	1	16	27	3	6
Median	121	112	16	15	1.1	2.1	76	58	2	2	1	1	6	5	2	4

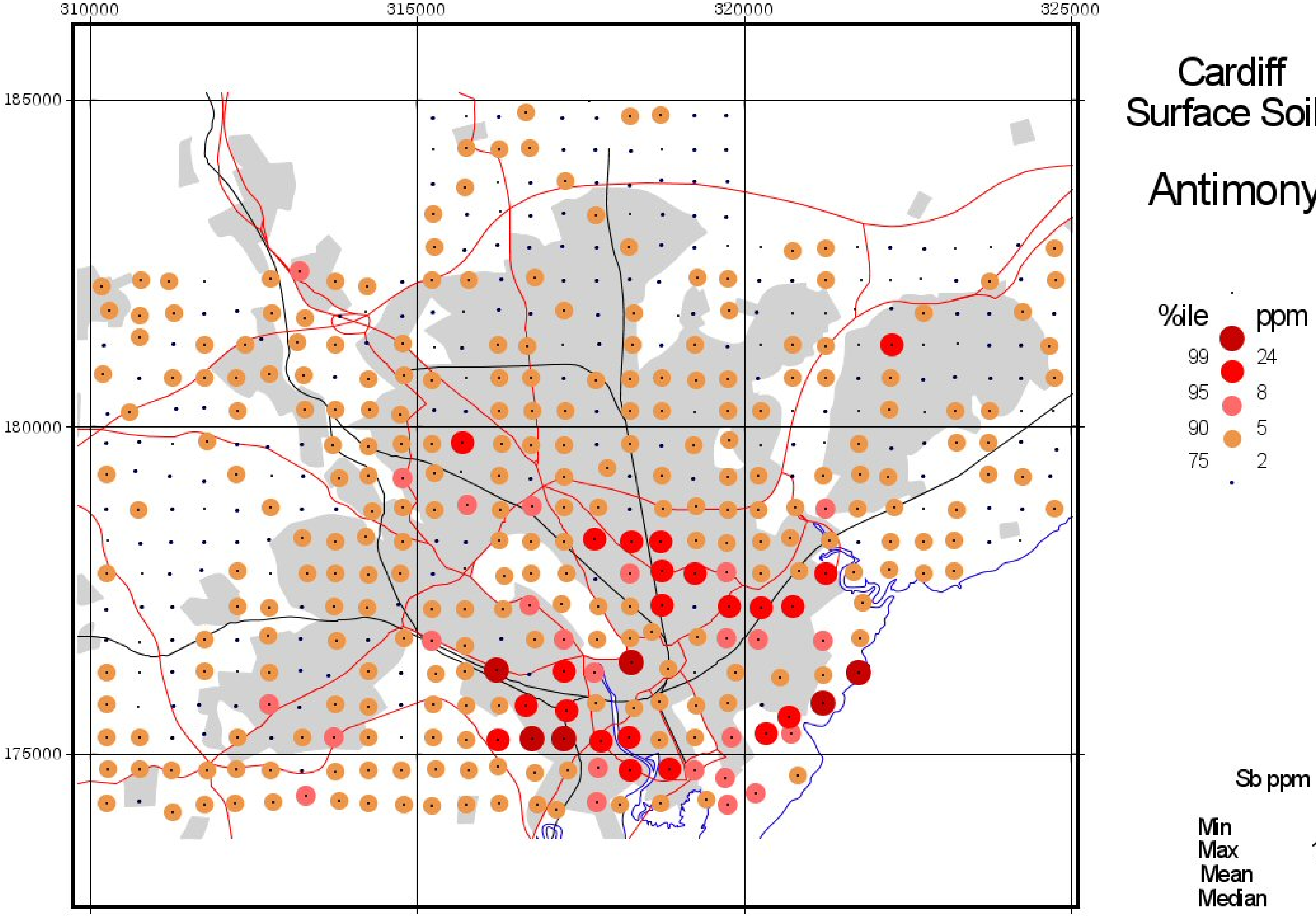
Appendix C: Graduated symbol geochemical maps for Cardiff surface and profile soils

Antimony
Arsenic
Barium
Cadmium
Chromium
Cobalt
Copper
Iron
Lead
Manganese
Molybdenum
Nickel
Tin
Titanium
Uranium
Vanadium
Zinc

Note ppm = mg/kg on all maps

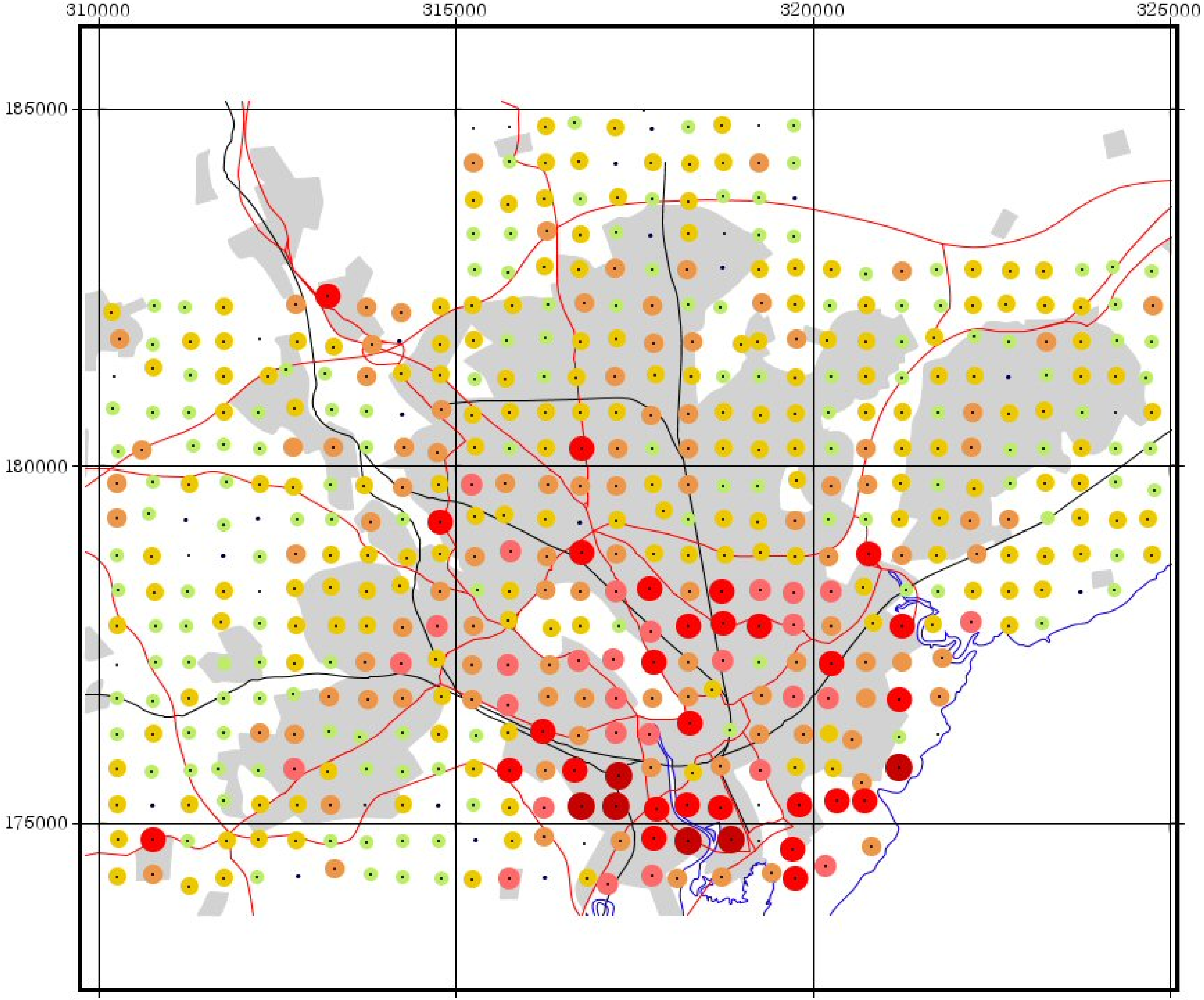
Cardiff
Surface Soils

Antimony



Sb ppm

Min	1
Max	153
Mean	3
Median	2



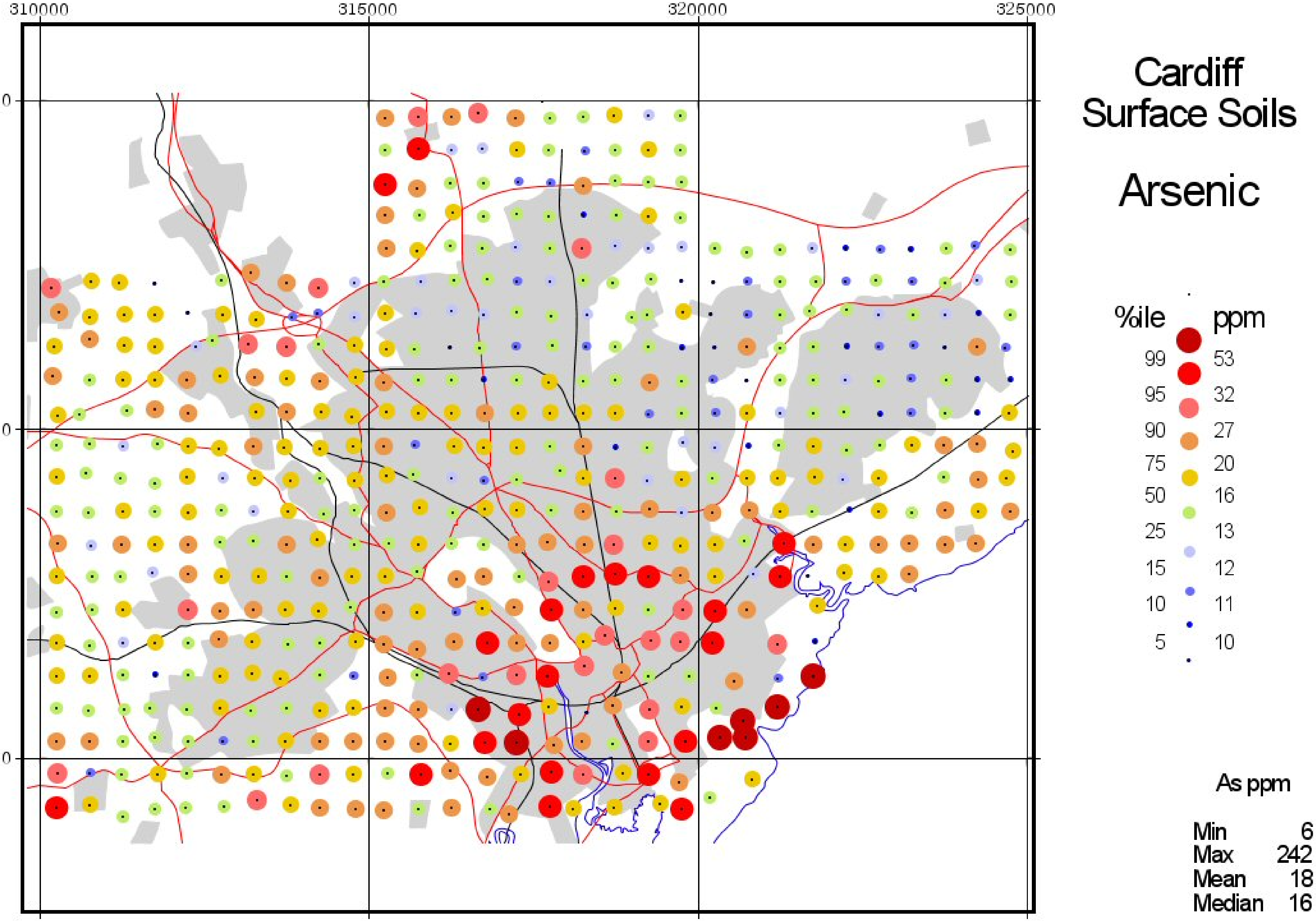
Cardiff
Profile Soils

Antimony

%ile	ppm
99	41
95	9
90	7
75	5
50	4
25	3

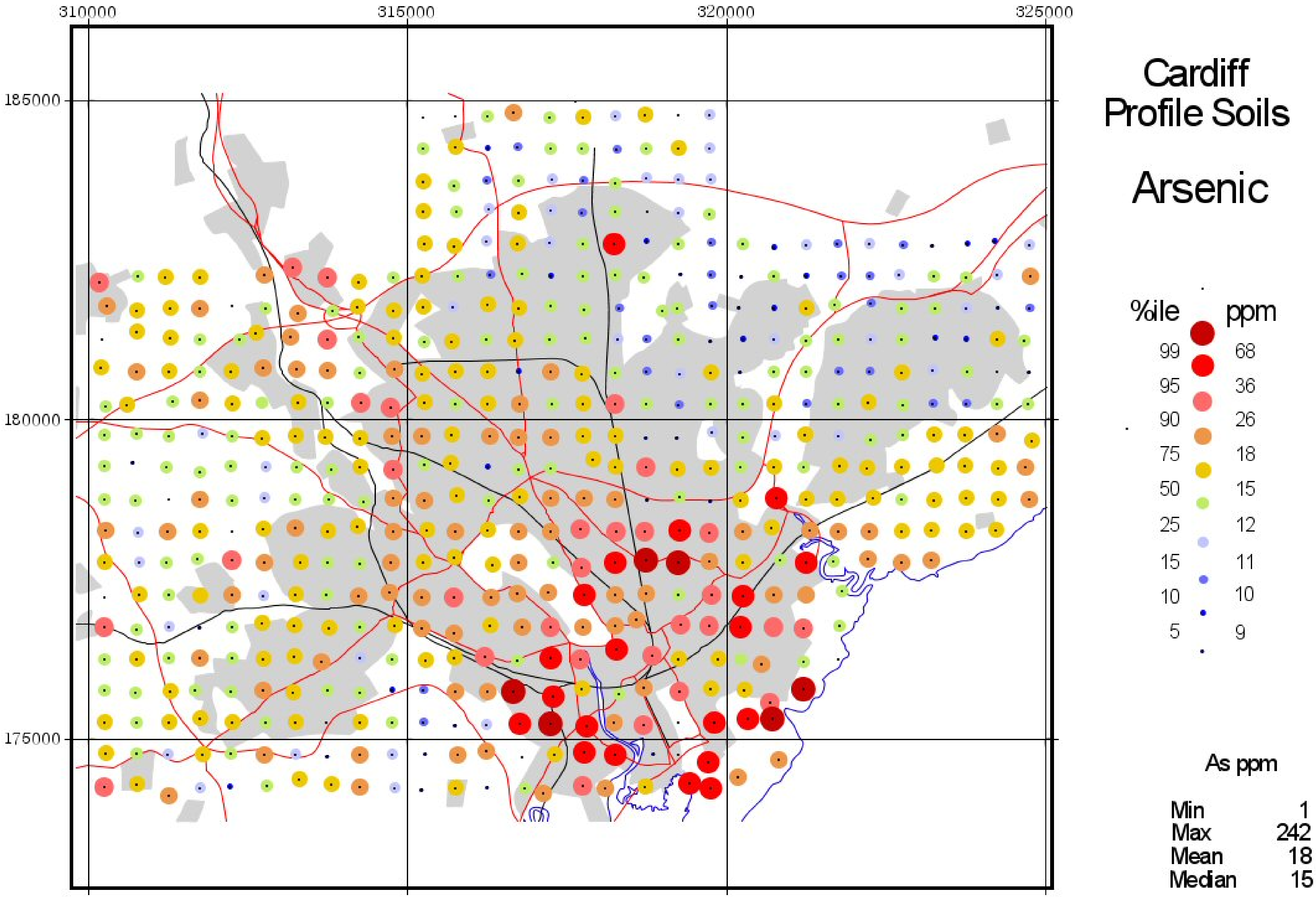
Sb ppm

Min	2
Max	333
Mean	6
Median	4


Cardiff
Surface Soils
Arsenic
310000
315000
320000
325000
185000
180000
175000
%ile
ppm
99
53
95
32
90
27
75
20
50
16
25
13
15
12
10
11
5
10
As ppm
Min 6
Max 242
Mean 18
Median 16

Cardiff Profile Soils

Arsenic

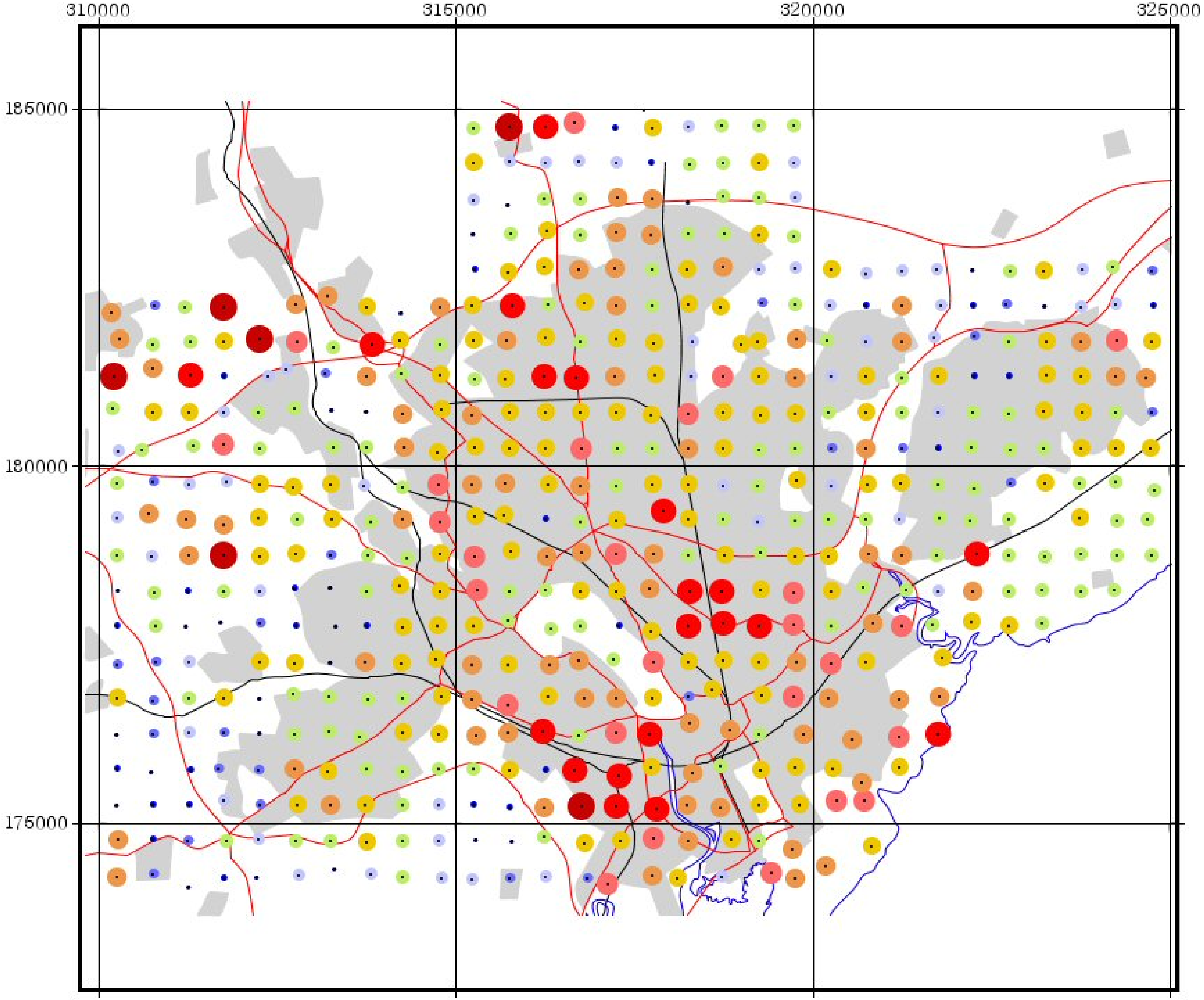


As ppm

Min	1
Max	242
Mean	18
Median	15

Cardiff
Surface Soils

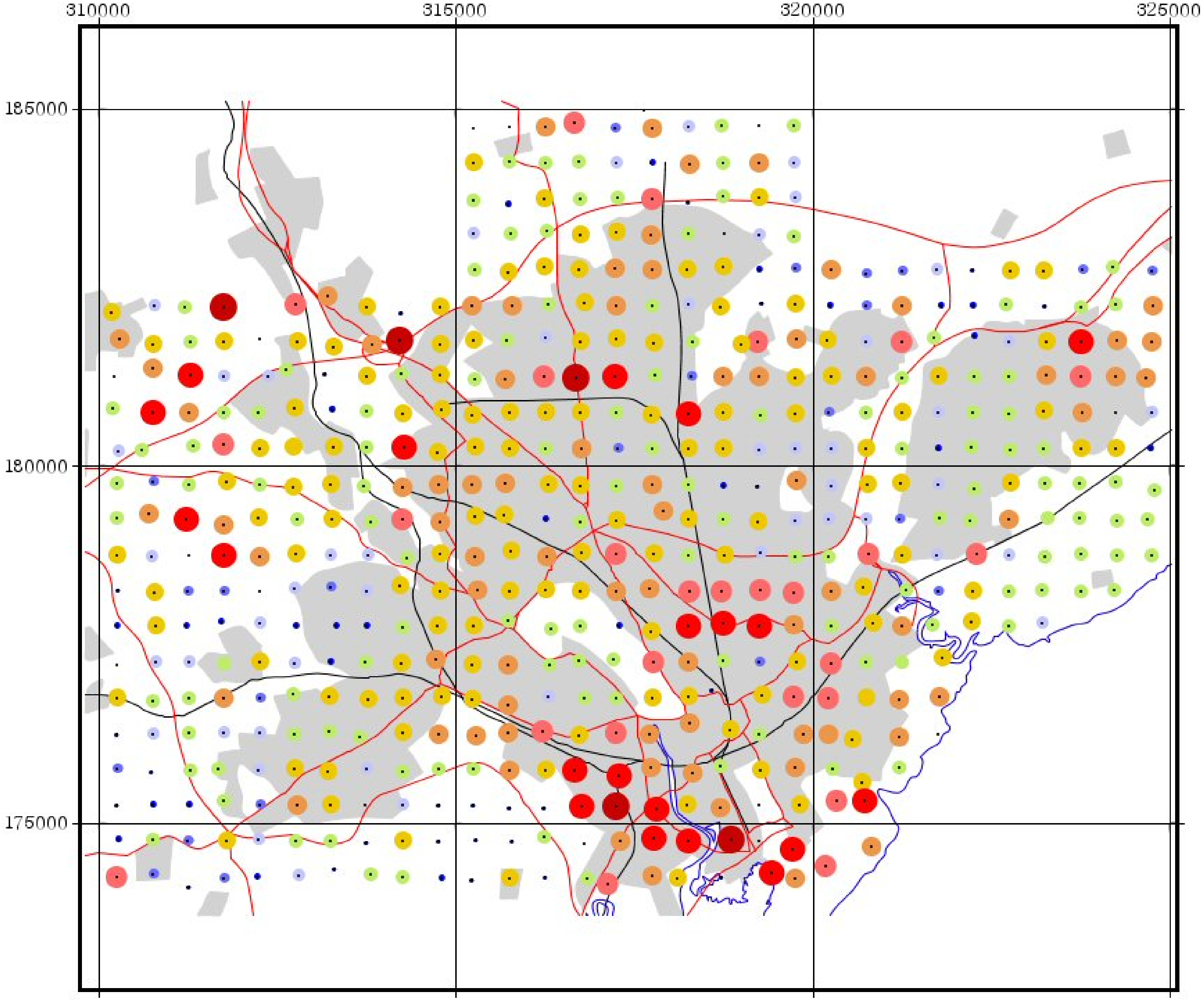
Barium



%ile	ppm
	●
99	2805
95	1185
90	909
75	625
50	454
25	372
15	337
10	327
5	304

Ba ppm

Min	198
Max	17566
Mean	605
Median	454



Cardiff Profile Soils

Barium

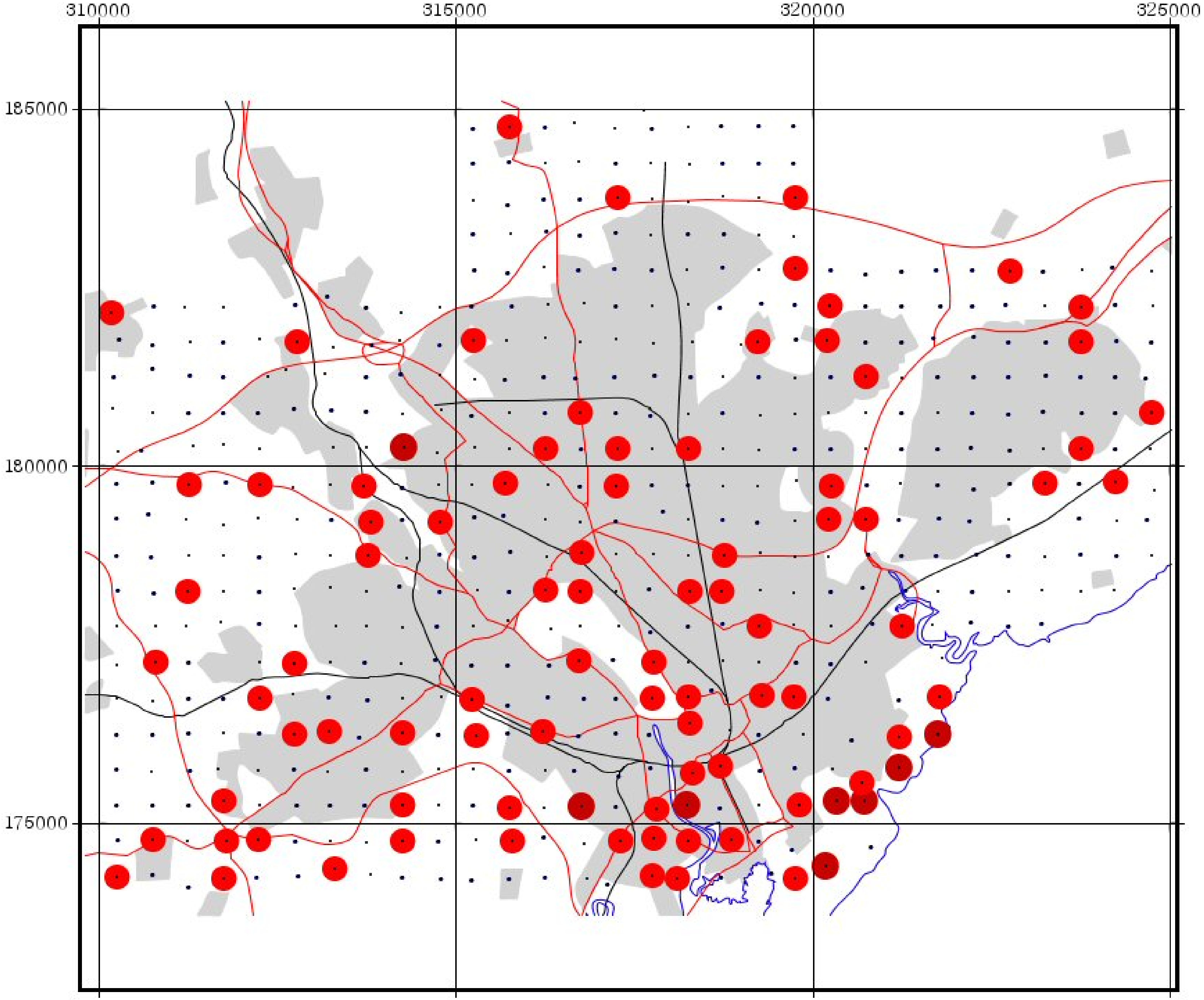
%ile	ppm
99	4169
95	1284
90	1021
75	631
50	423
25	341
15	308
10	297
5	268

Ba ppm

Min	70
Max	29561
Mean	668
Median	423

Cardiff Surface Soils

Cadmium

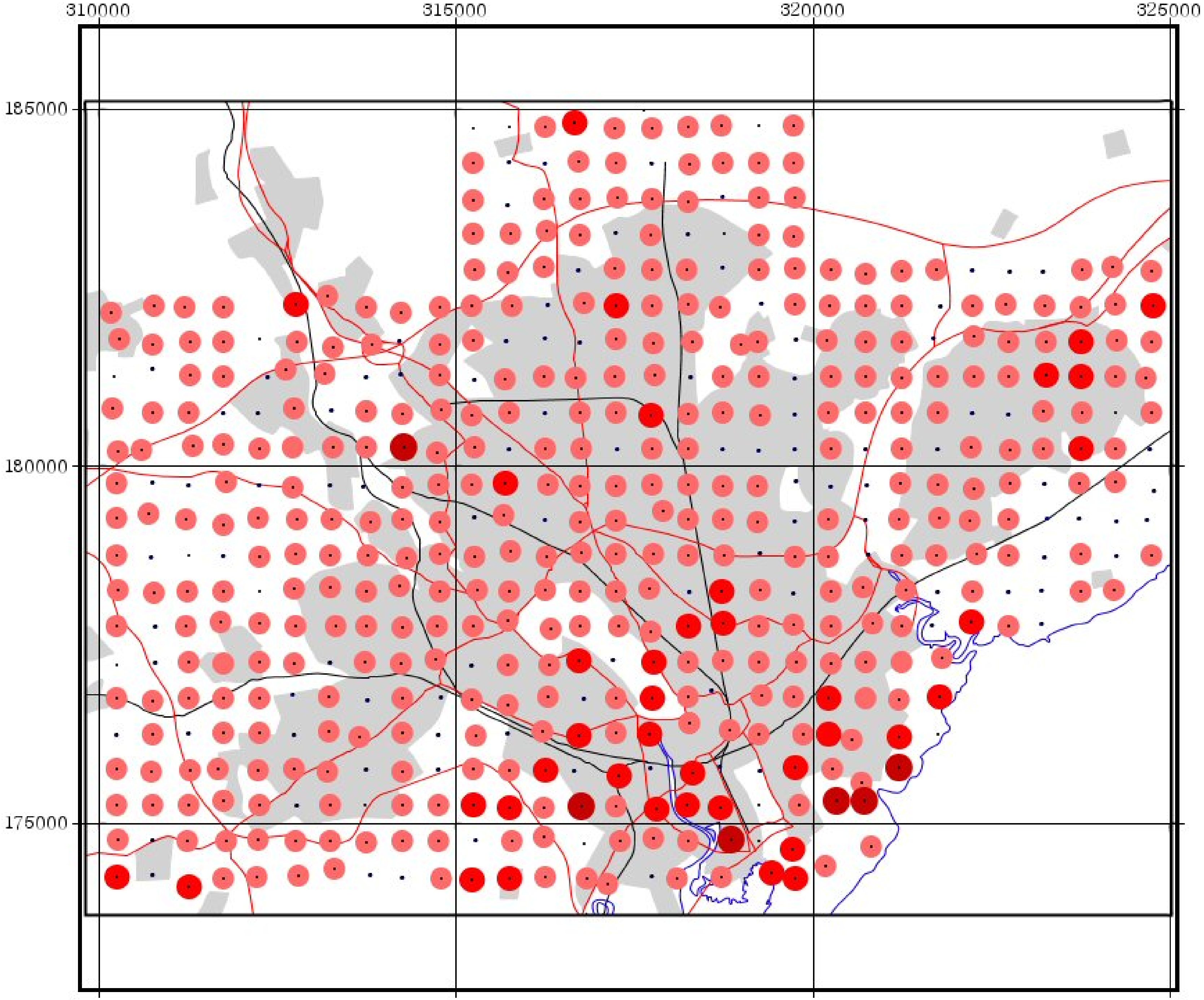


Cd ppm

Min	1
Max	82
Mean	1
Median	1

Cardiff
Profile Soils

Cadmium

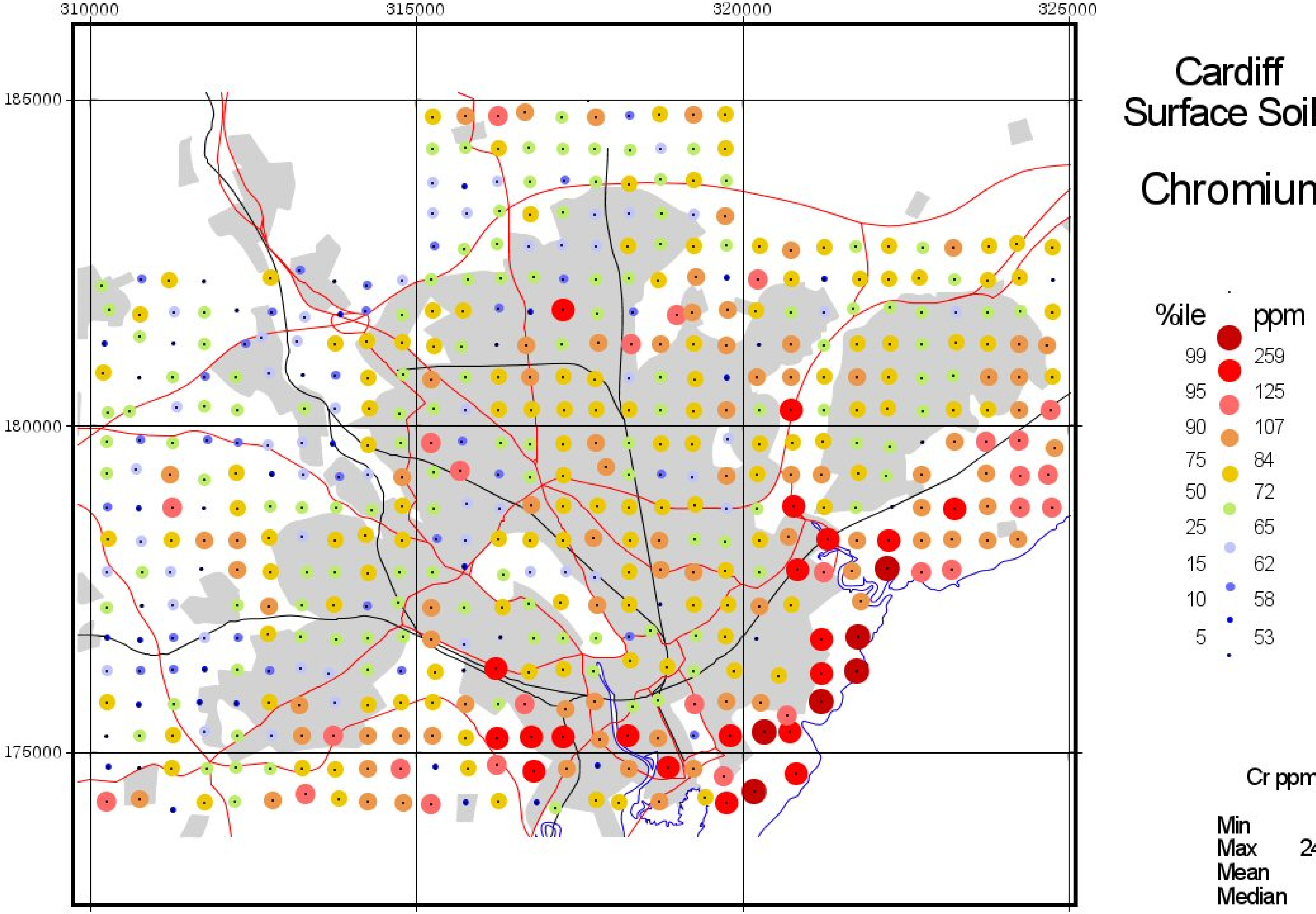


%ile	ppm
99	3
95	2
90	1

Cd ppm	
Min	1
Max	37
Mean	1
Median	1

Cardiff
Surface Soils

Chromium

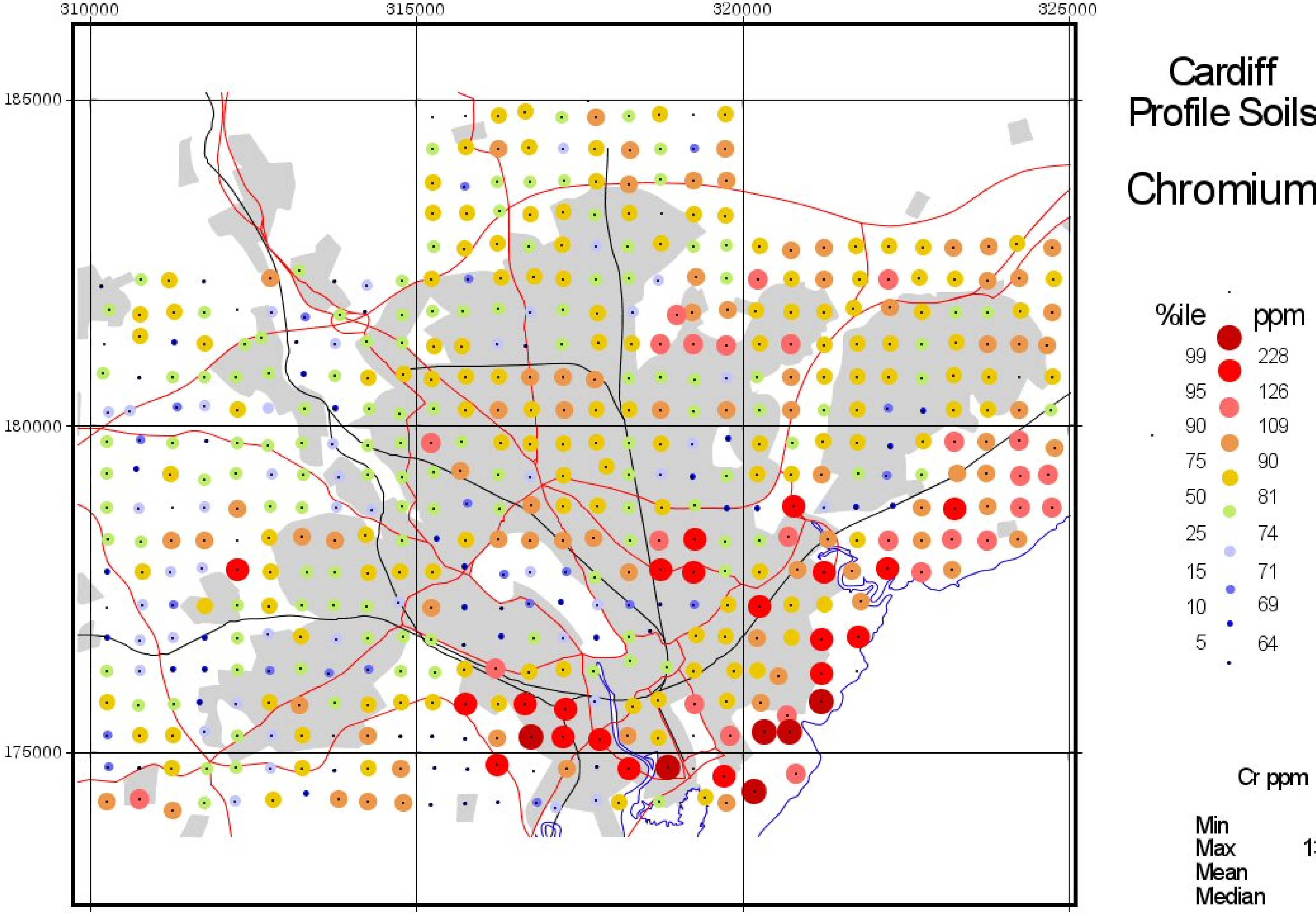


Cr ppm

Min	1
Max	2426
Mean	90
Median	72

Cardiff Profile Soils

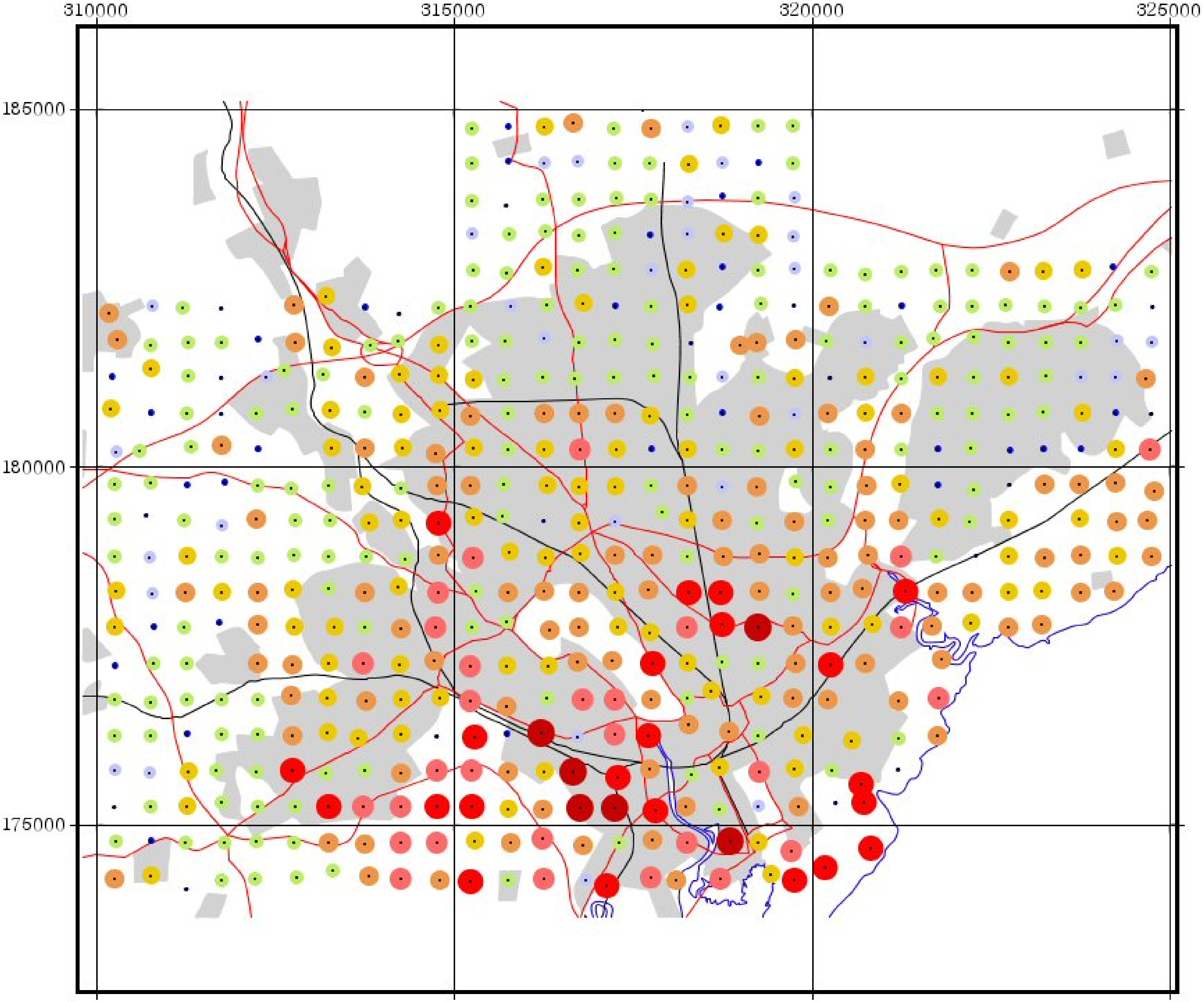
Chromium



Cr ppm	
Min	3
Max	1374
Mean	91
Median	81

Cardiff
Surface Soils

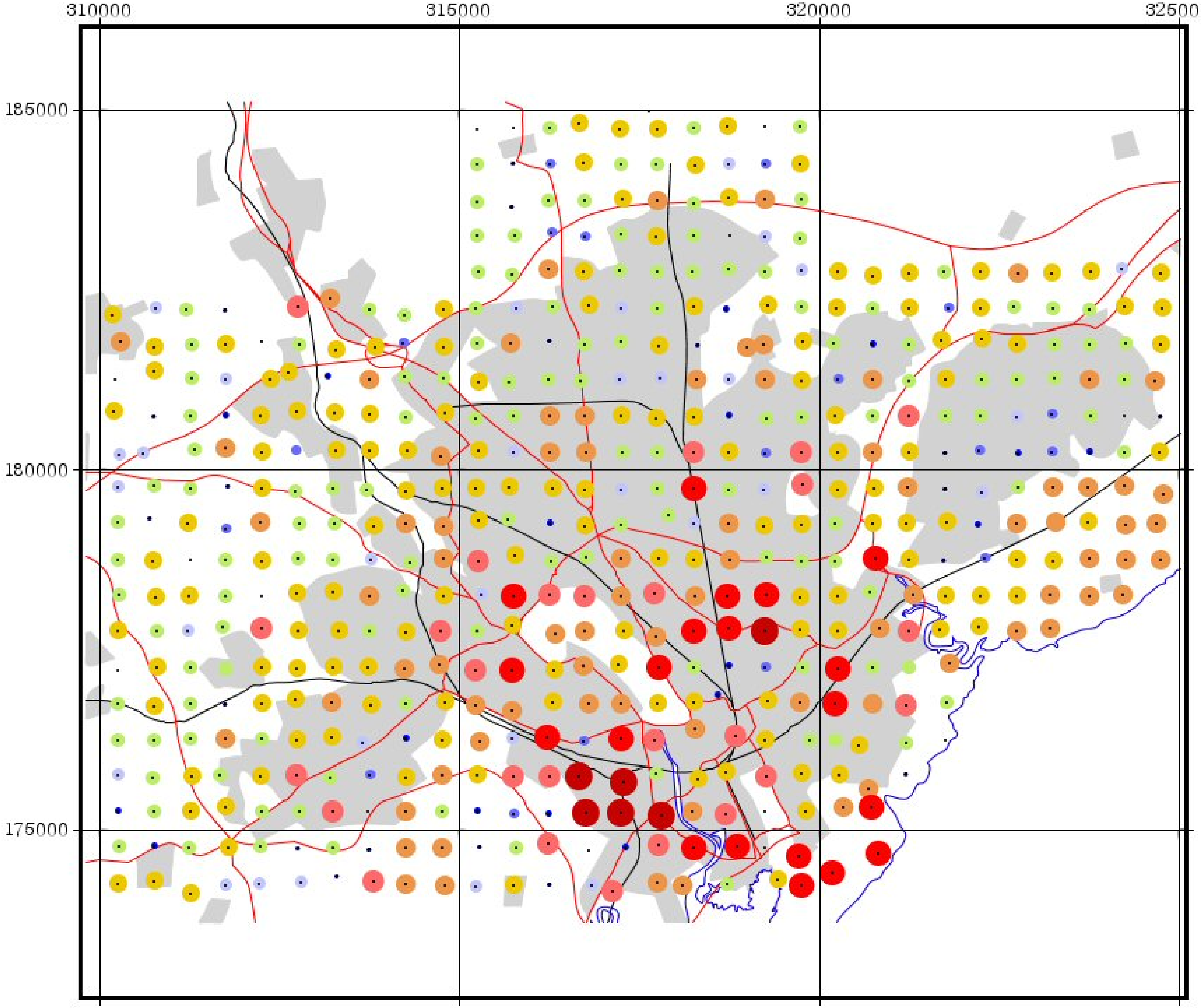
Cobalt



Co ppm	
Min	1
Max	100
Mean	23
Median	21

Cardiff
Profile Soils

Cobalt



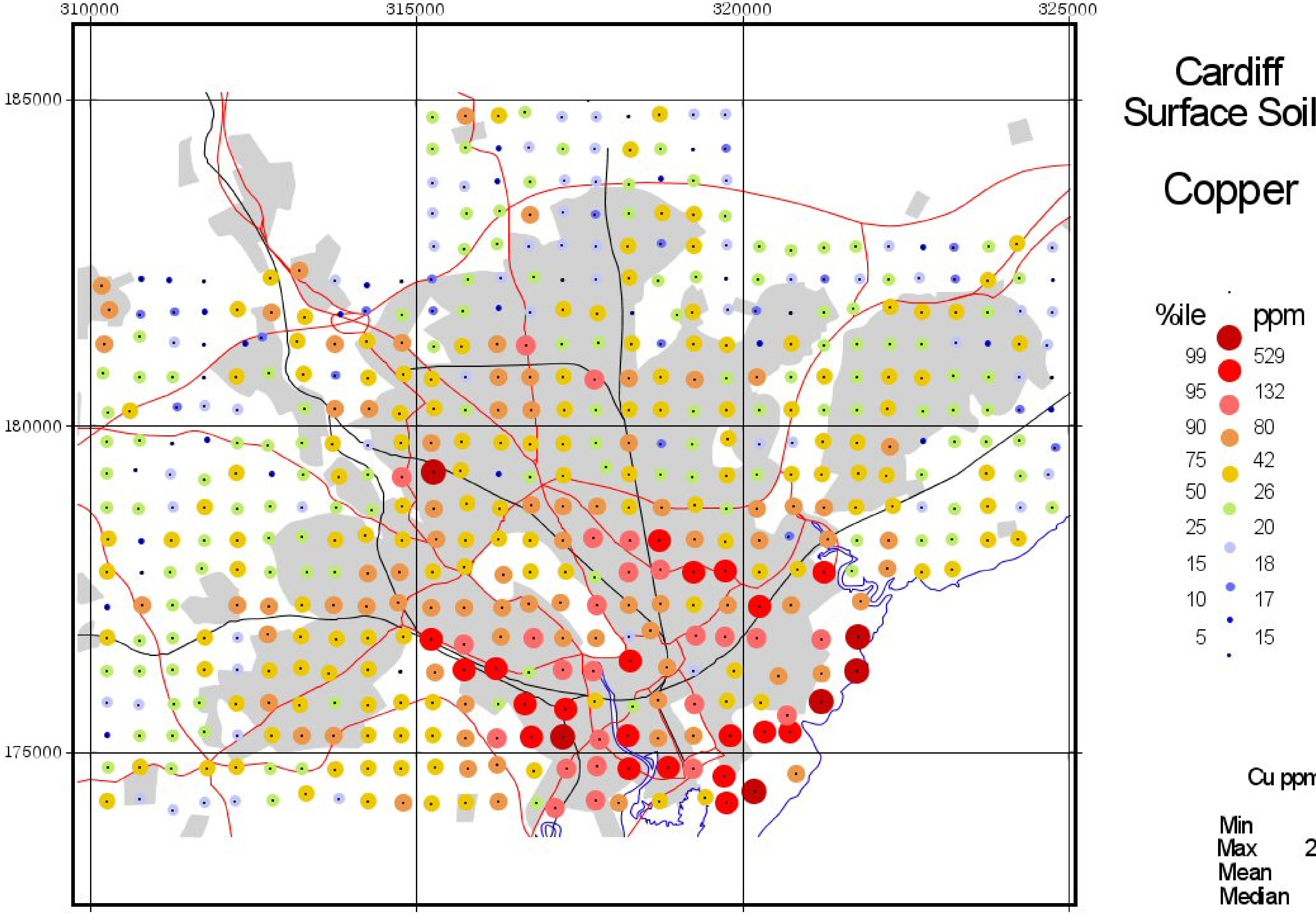
%ile	ppm
99	90
95	38
90	31
75	26
50	22
25	20
15	19
10	18
5	17

Co ppm

Min	1
Max	162
Mean	25
Median	22

Cardiff
Surface Soils

Copper

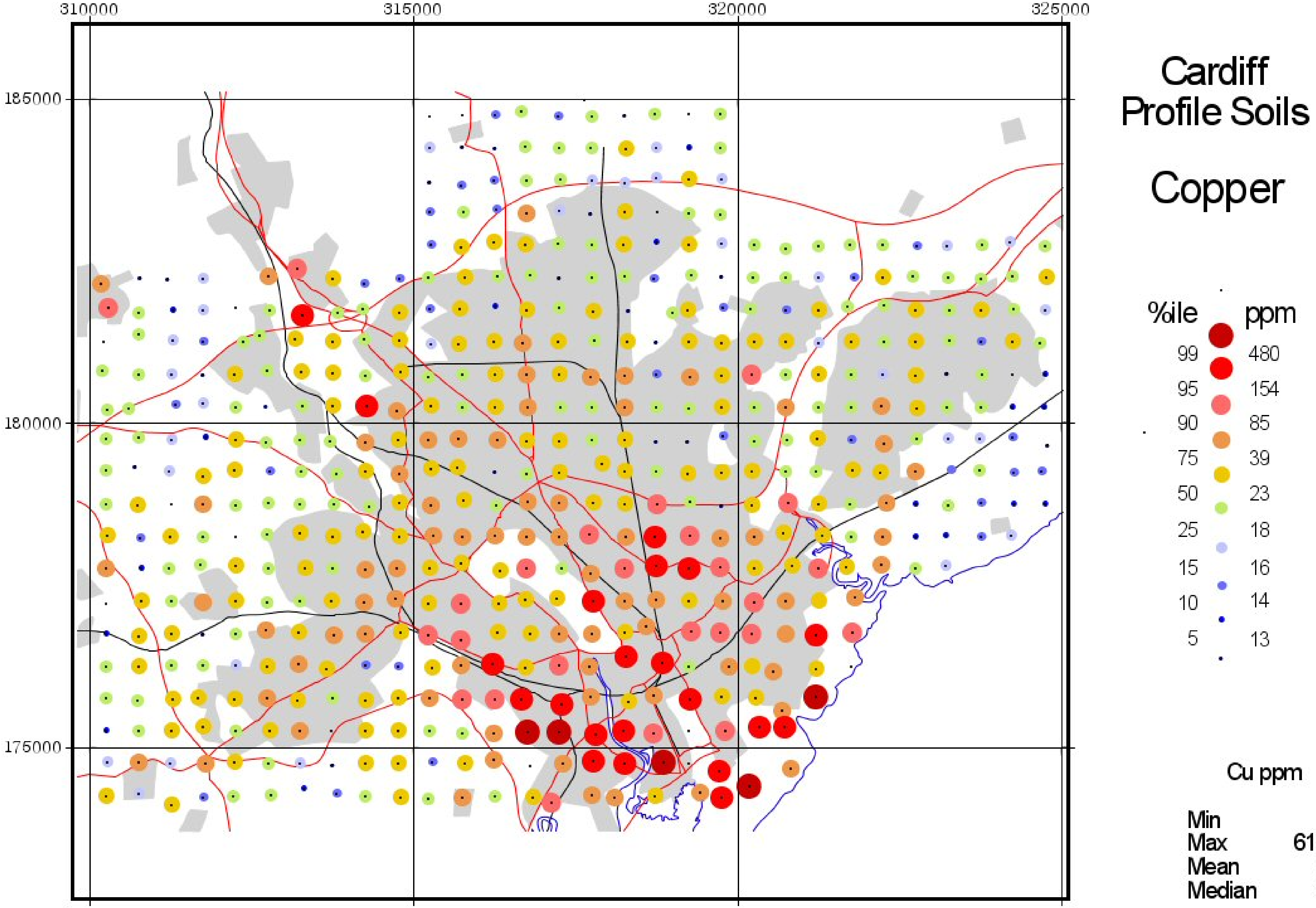


Cu ppm

Min	10
Max	2046
Mean	53
Median	26

Cardiff
Profile Soils

Copper

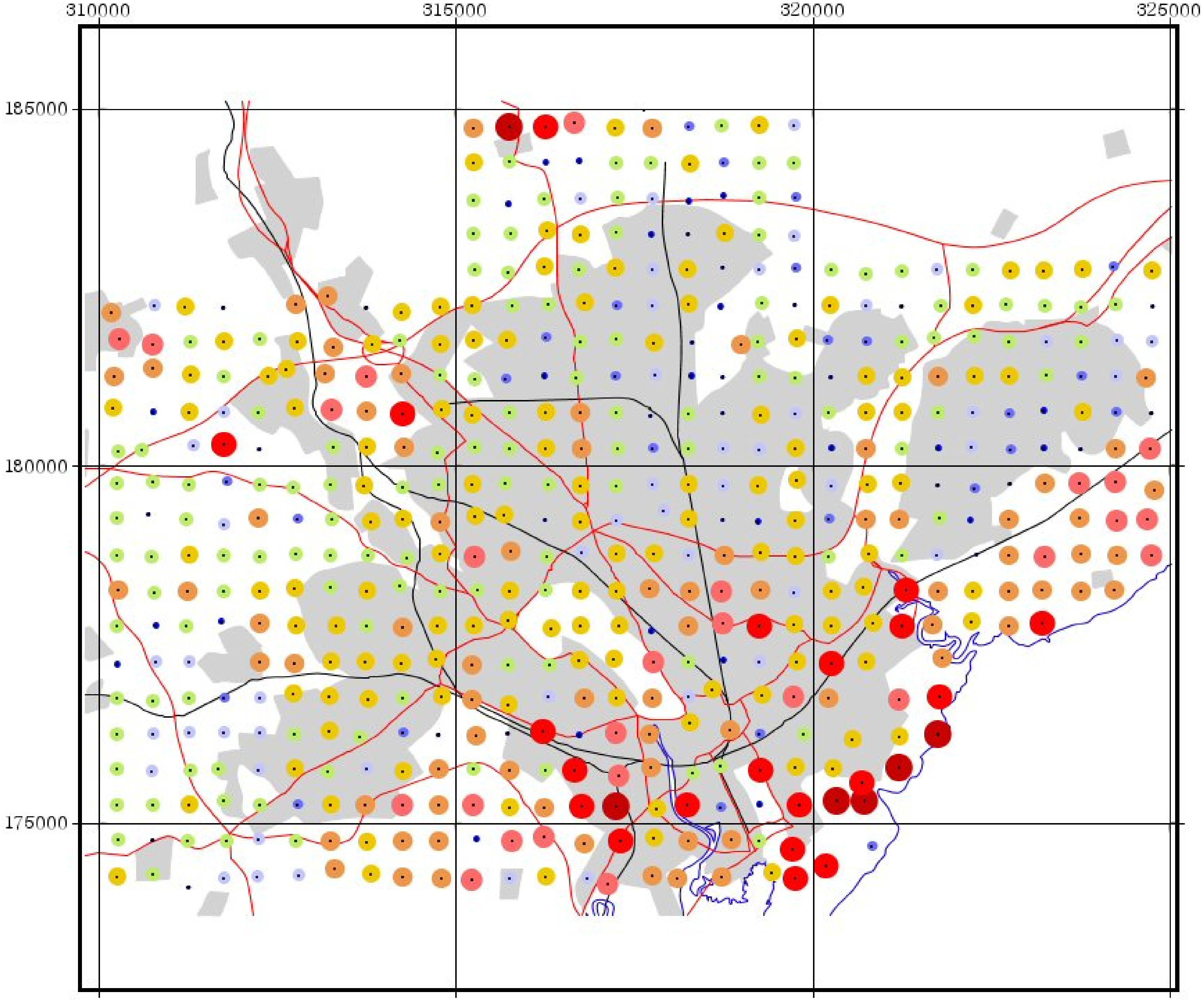


Cu ppm

Min	7
Max	6167
Mean	61
Median	23

Cardiff
Surface Soils

Iron

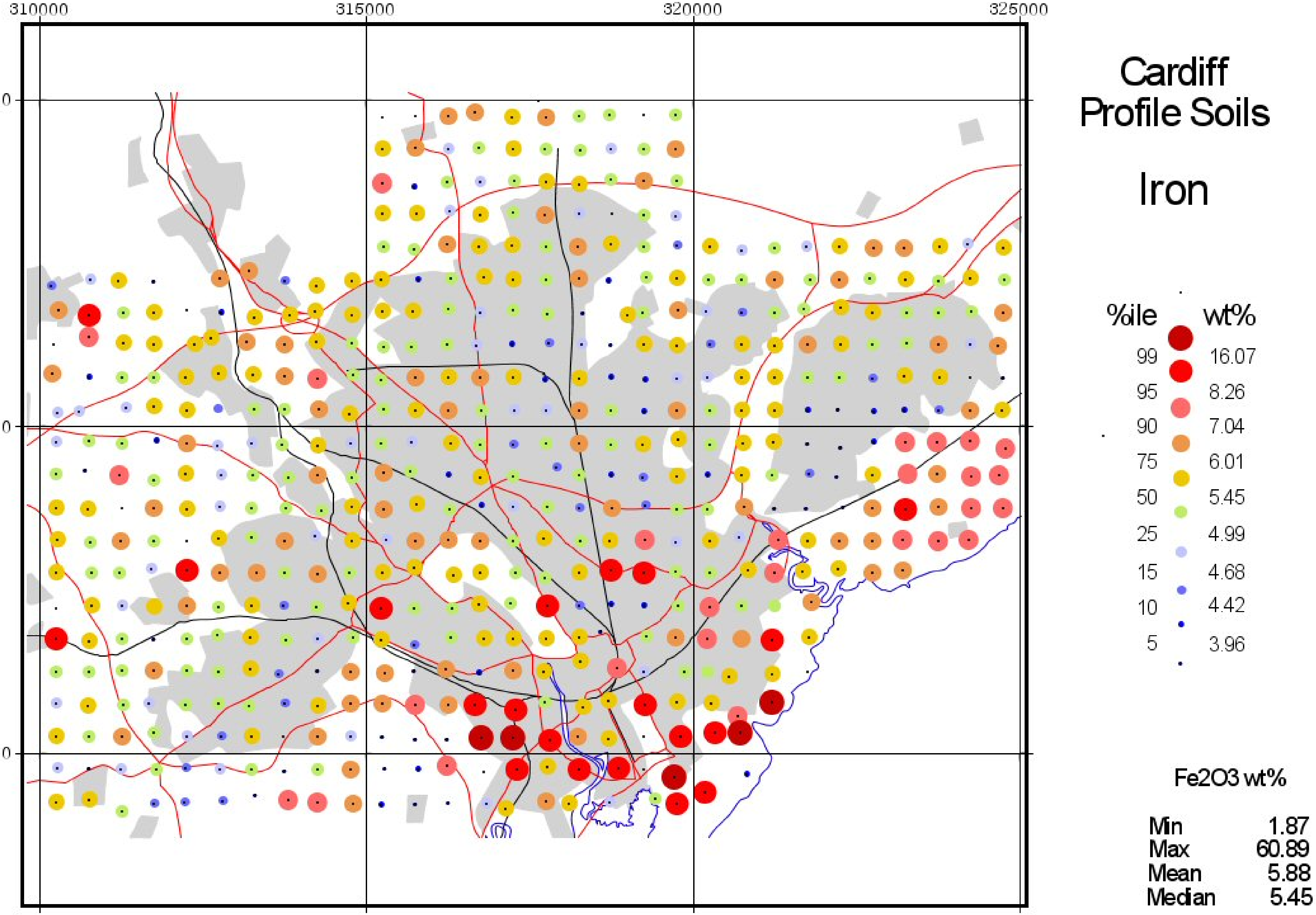


Fe2O3 Wt%

Min	1.78
Max	42.59
Mean	5.62
Median	5.20

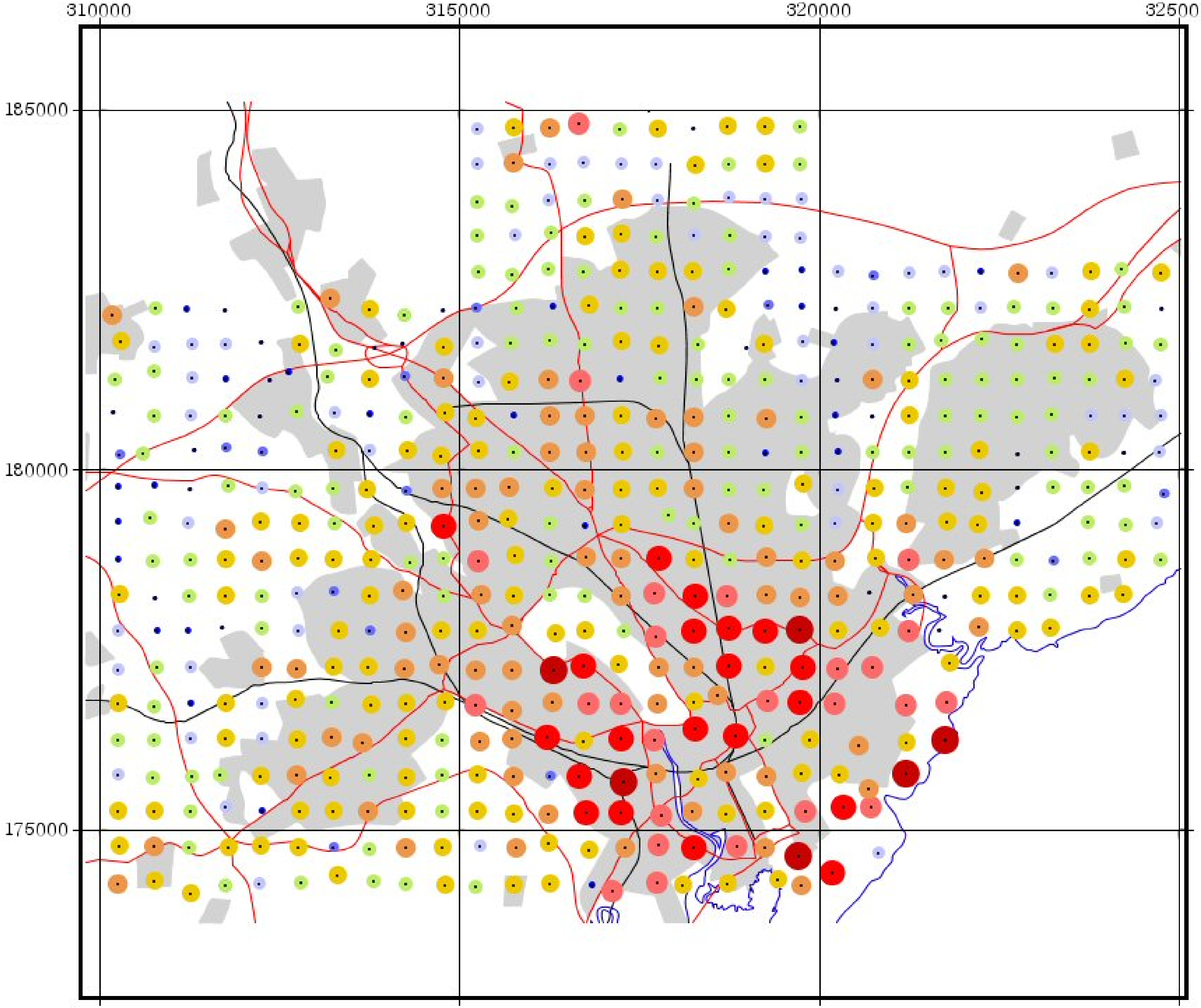
Cardiff Profile Soils

Iron



Fe2O3 wt%

Min	1.87
Max	60.89
Mean	5.88
Median	5.45



Cardiff Surface Soils

Lead

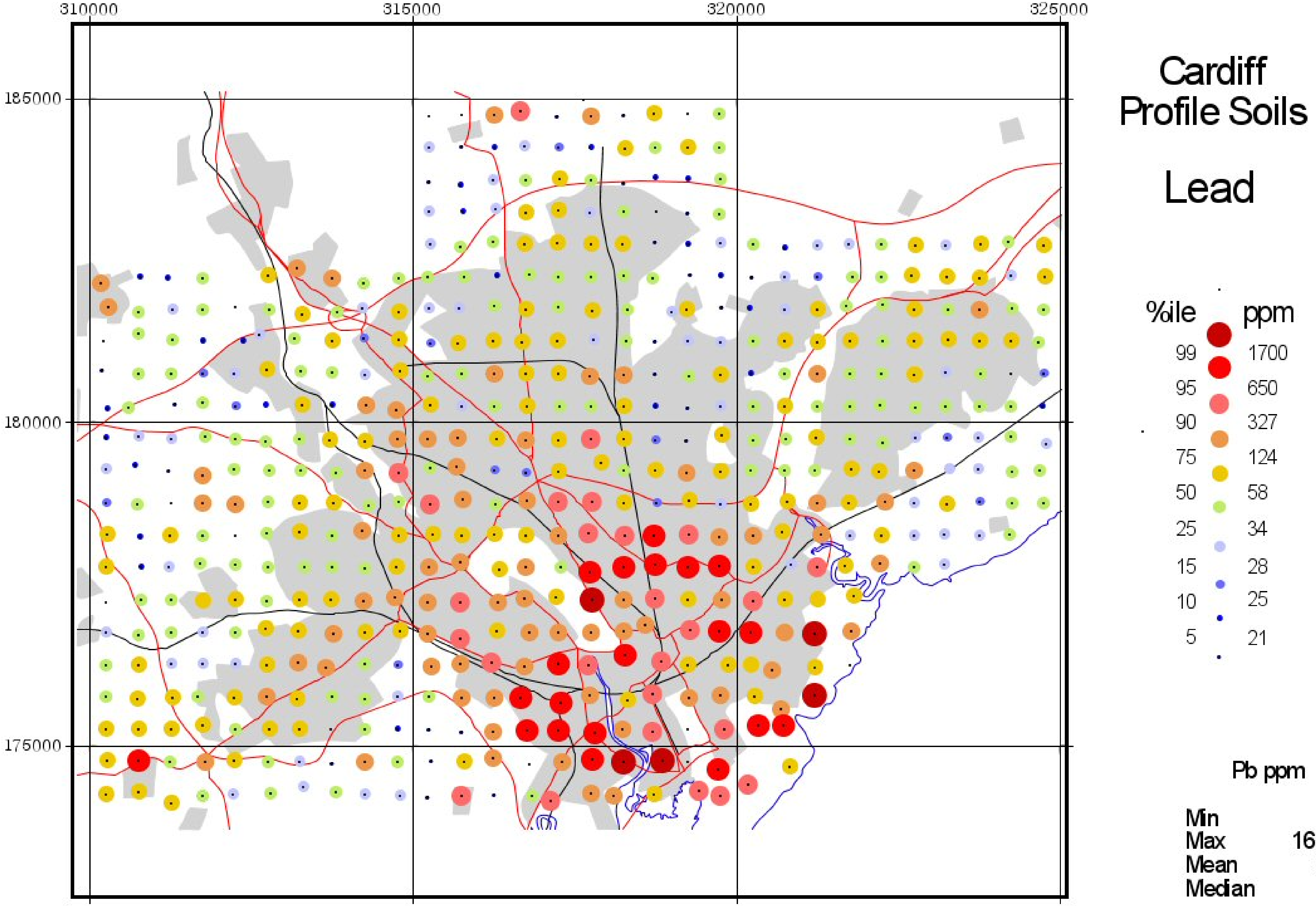
%ile	ppm
99	1382
95	743
90	400
75	147
50	76
25	54
15	45
10	43
5	38

Pb ppm

Min	14
Max	7575
Mean	194
Median	76

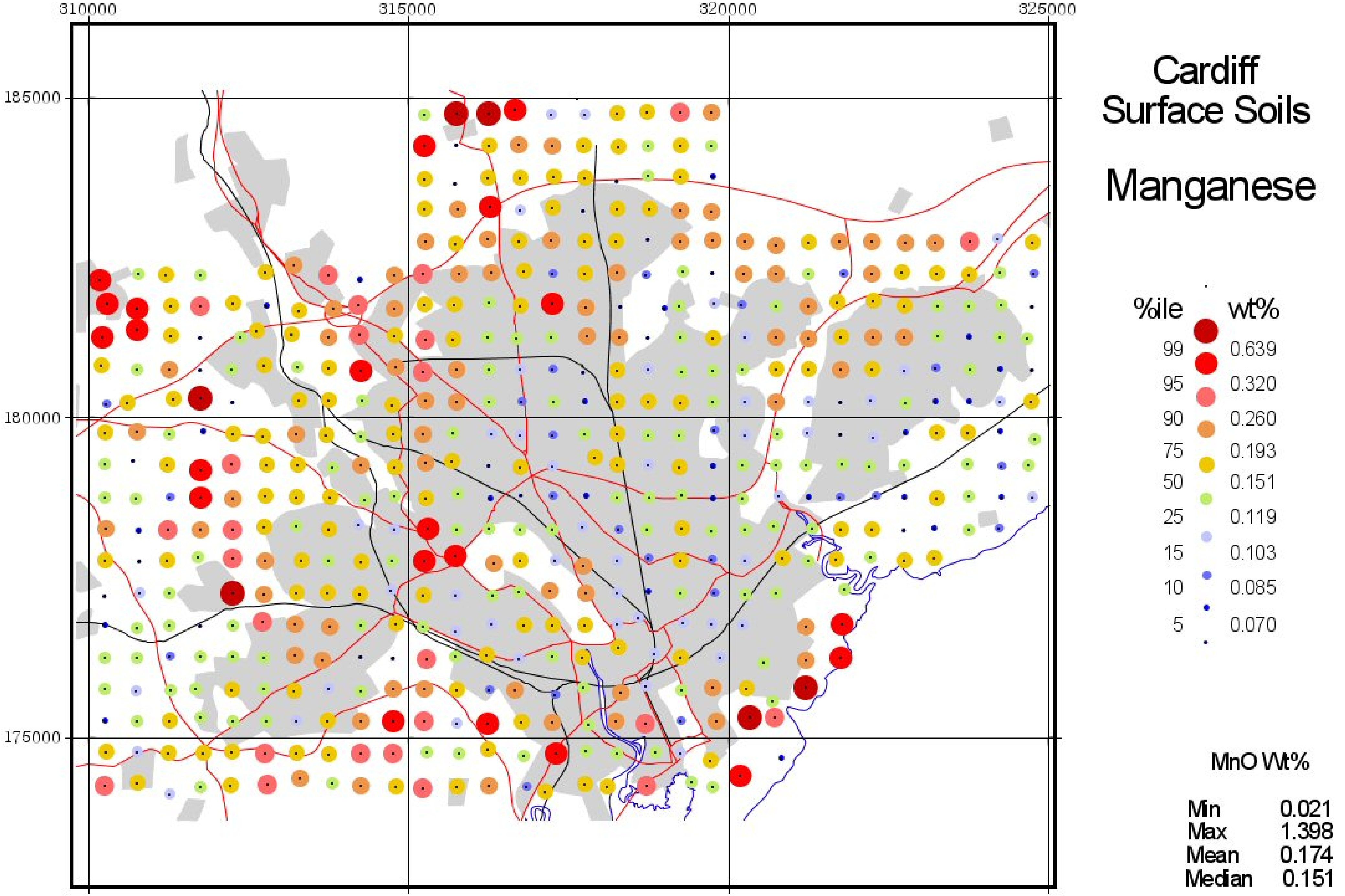
Cardiff
Profile Soils

Lead

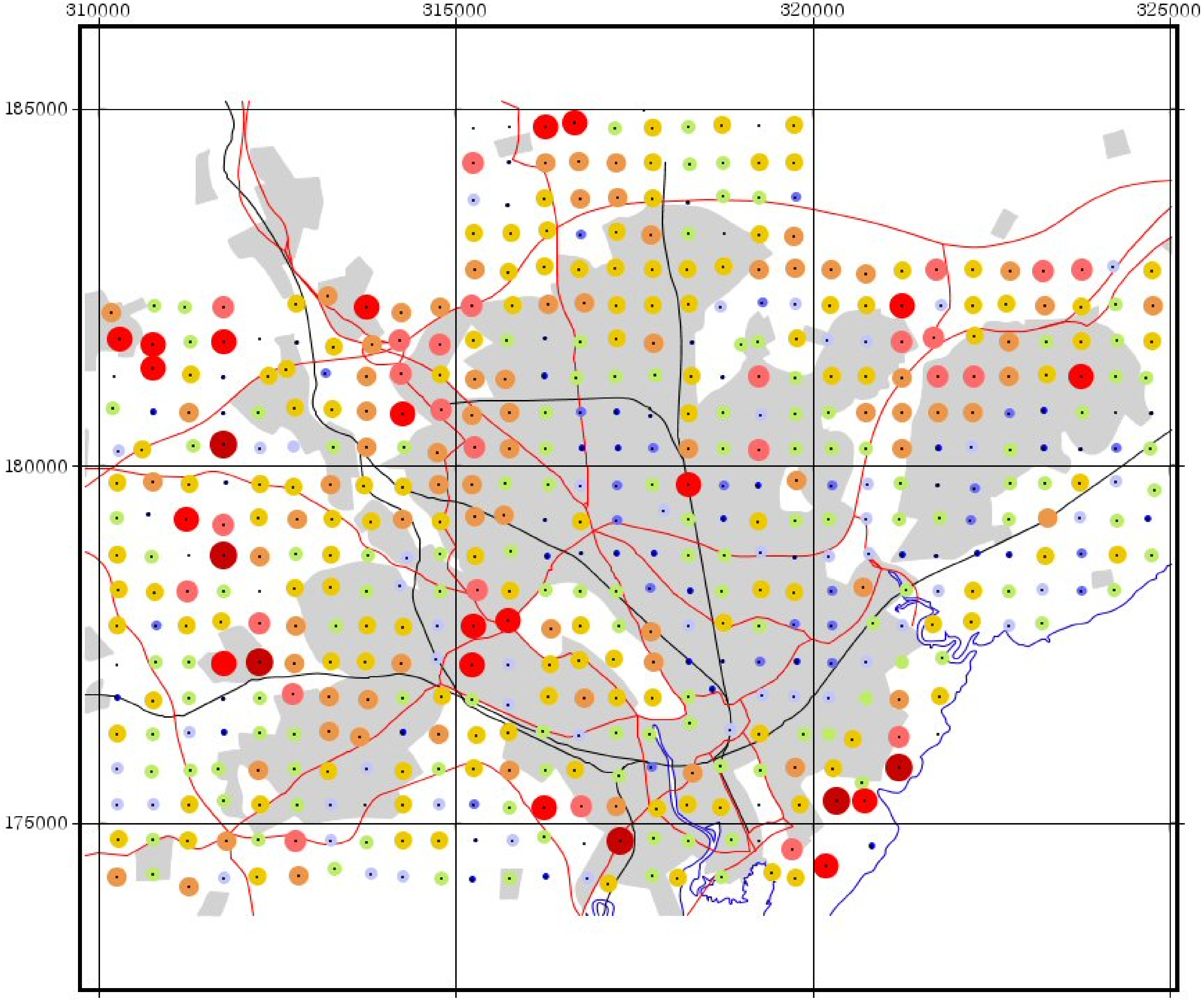


Pb ppm

Min	6
Max	16669
Mean	205
Median	58



MnO Wt%	
Min	0.021
Max	1.398
Mean	0.174
Median	0.151



Cardiff Profile Soils

Manganese

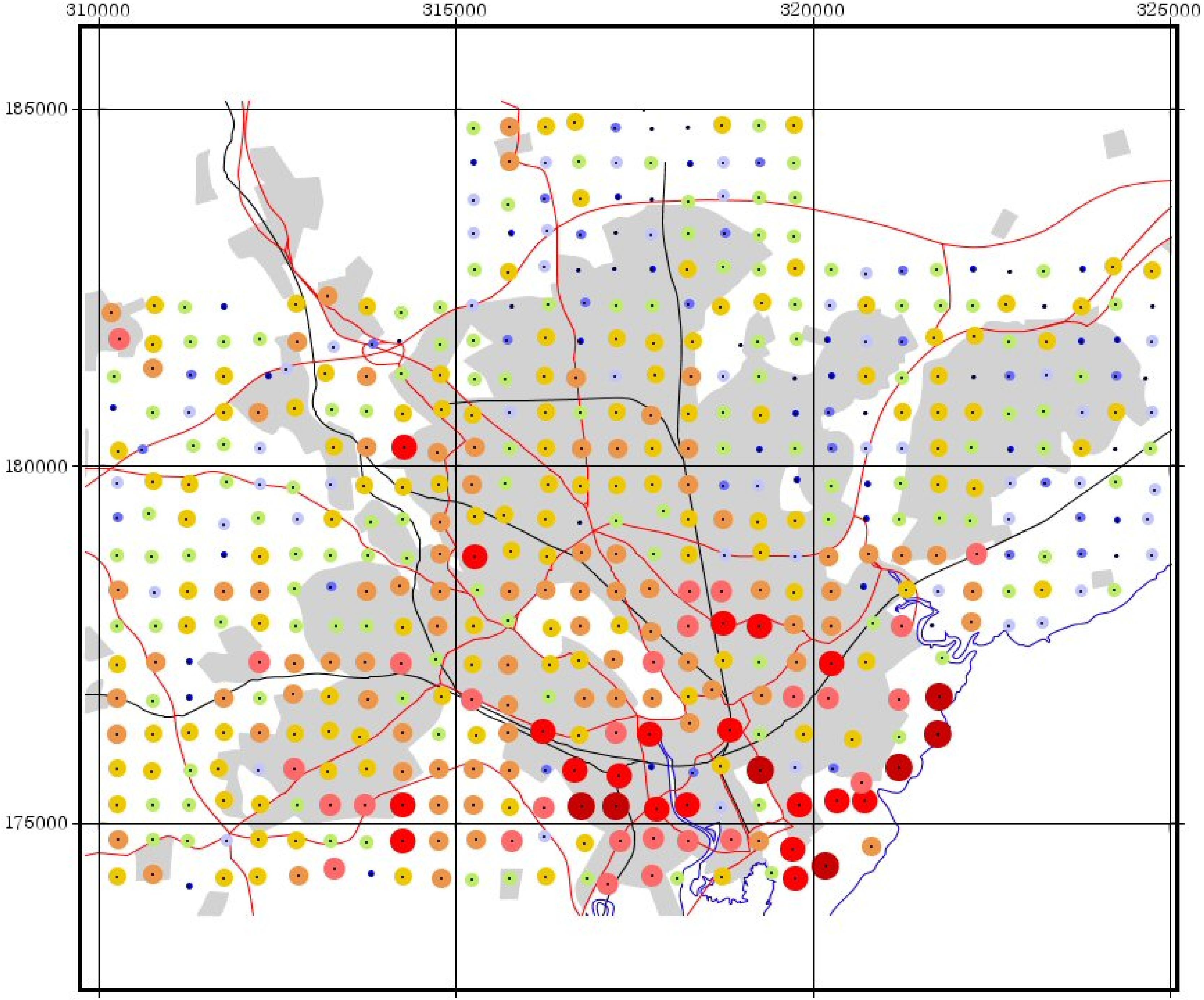
%ile	wt%
99	0.658
95	0.330
90	0.263
75	0.197
50	0.151
25	0.111
15	0.087
10	0.074
5	0.049

MnO wt%

Min	0.009
Max	0.958
Mean	0.168
Median	0.151

Cardiff Surface Soils

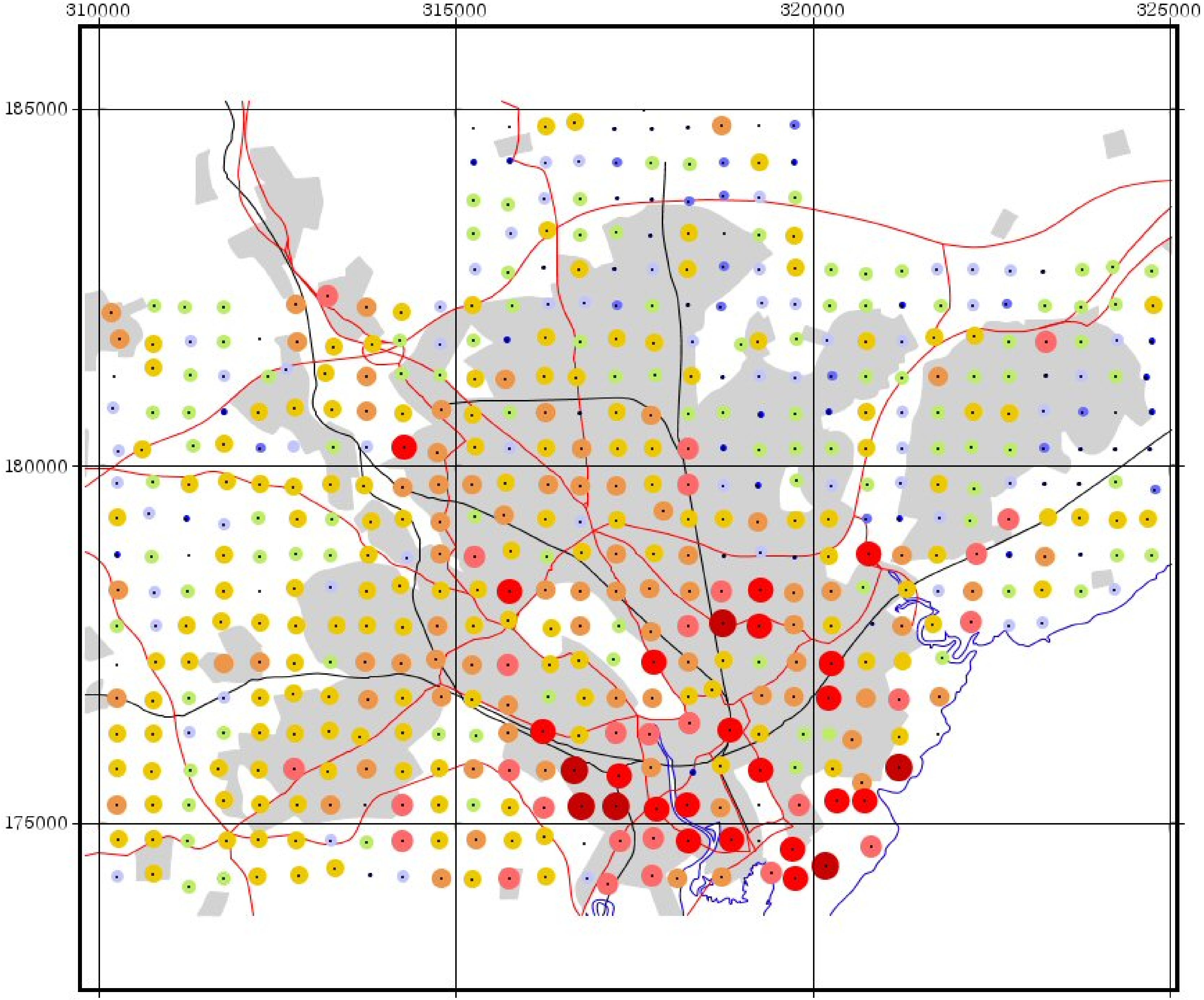
Molybdenum



%ile	ppm
99	10.0
95	3.6
90	2.5
75	1.6
50	1.1
25	0.8
15	0.6
10	0.5
5	0.3

Mo ppm

Min	0.2
Max	75.9
Mean	1.7
Median	1.1



Cardiff
Profile Soils

Molybdenum

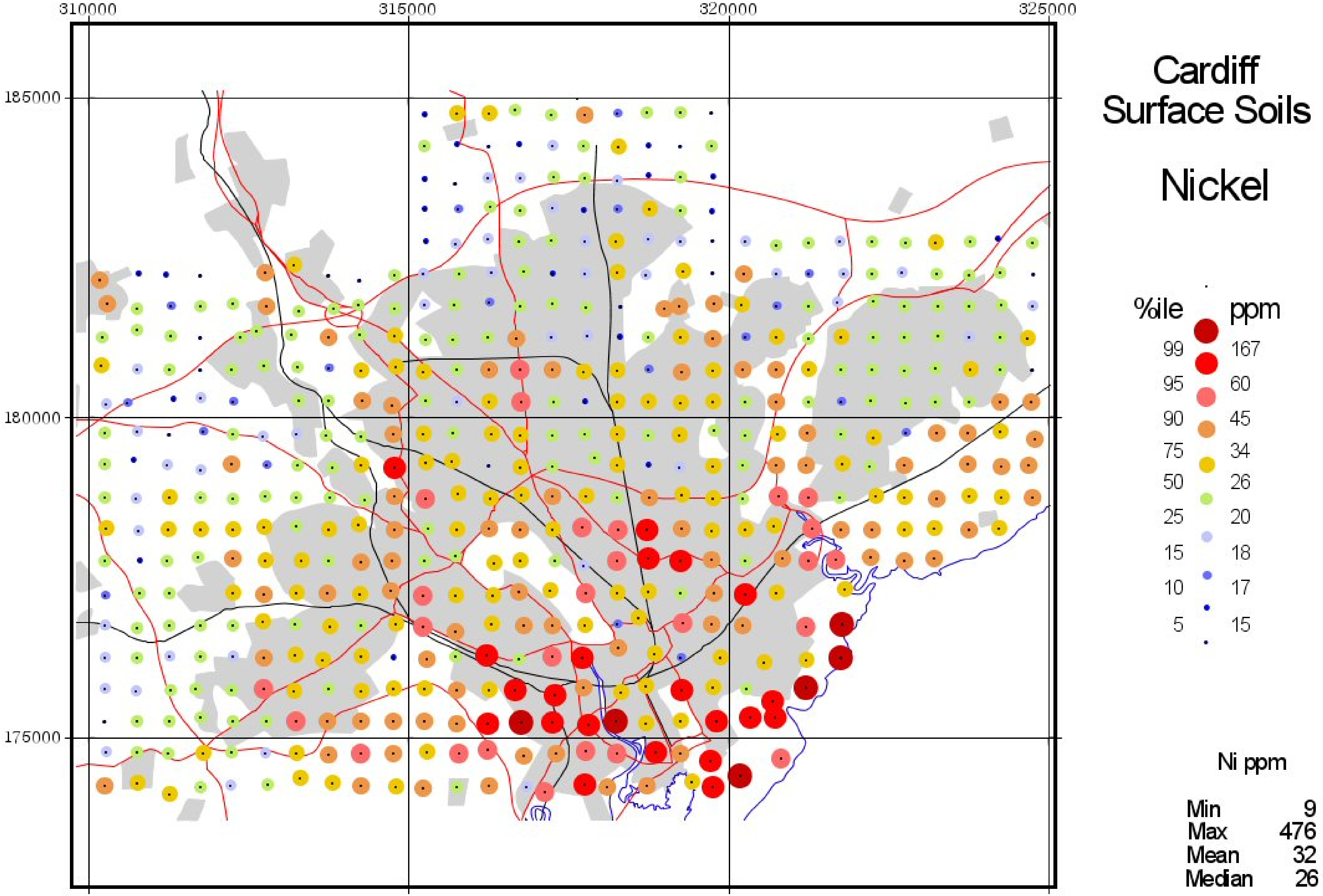
%ile		ppm
	●	
99		35.7
	●	
95		9.4
	●	
90		5.3
	●	
75		3.3
	●	
50		2.1
	●	
25		1.5
	●	
15		1.1
	●	
10		0.9
	●	
5		0.7
	●	

Mo ppm

Min	0.2
Max	208.6
Mean	3.8
Median	2.1

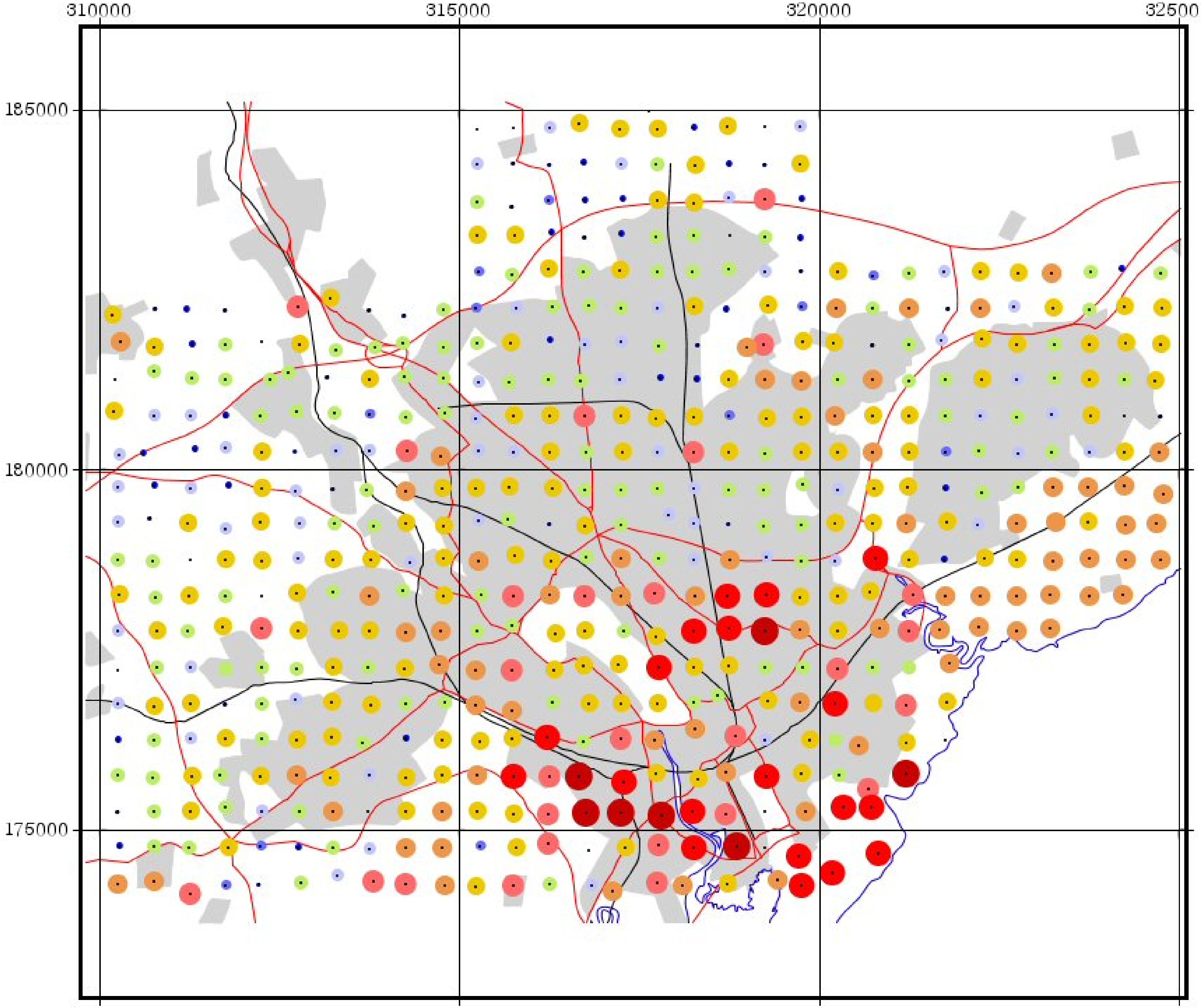
Cardiff Surface Soils

Nickel



Cardiff
Profile Soils

Nickel



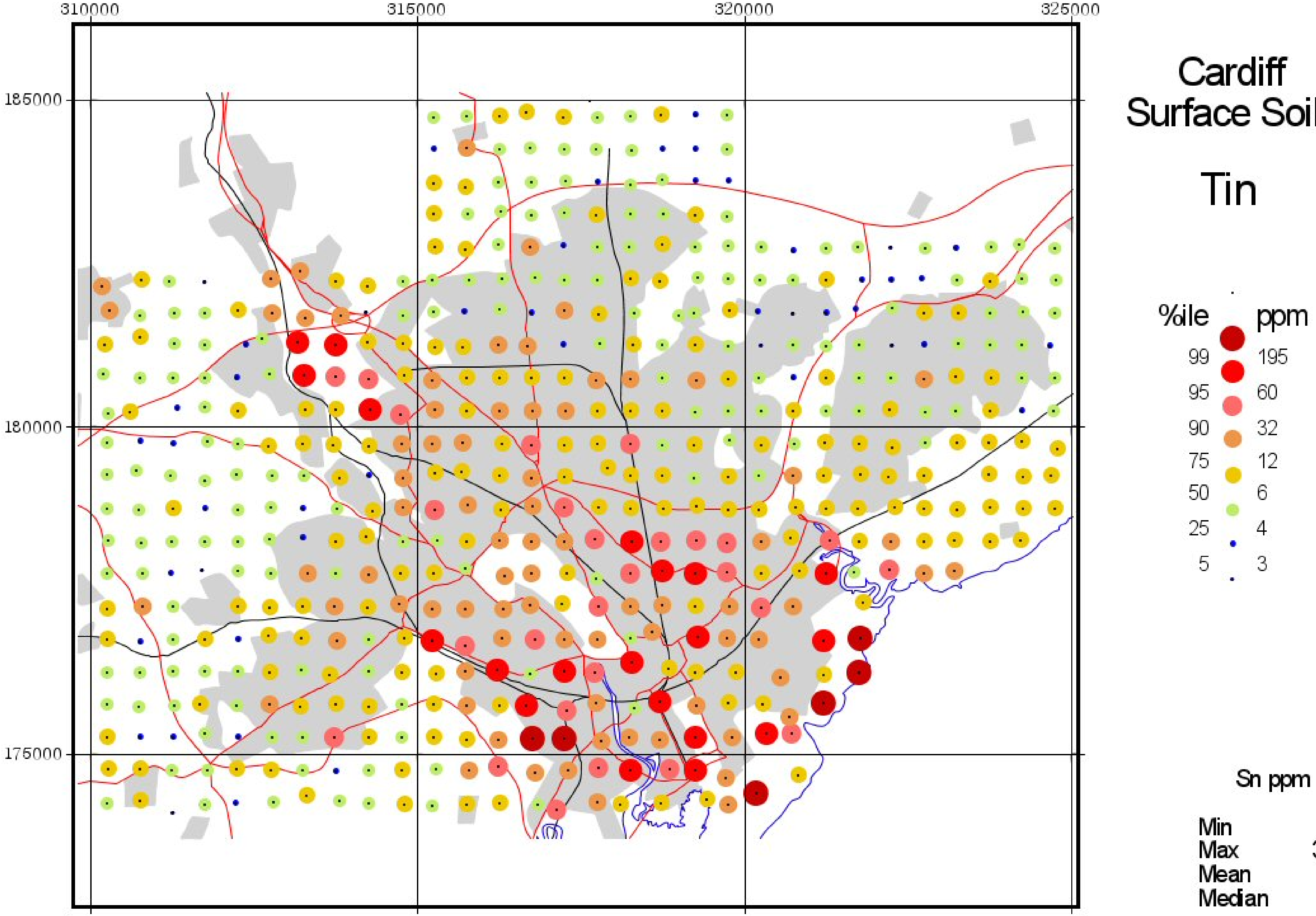
%ile	ppm
99	154
95	67
90	46
75	37
50	28
25	24
15	22
10	21
5	19

Ni ppm

Min	12
Max	582
Mean	36
Median	28

Cardiff Surface Soils

Tin

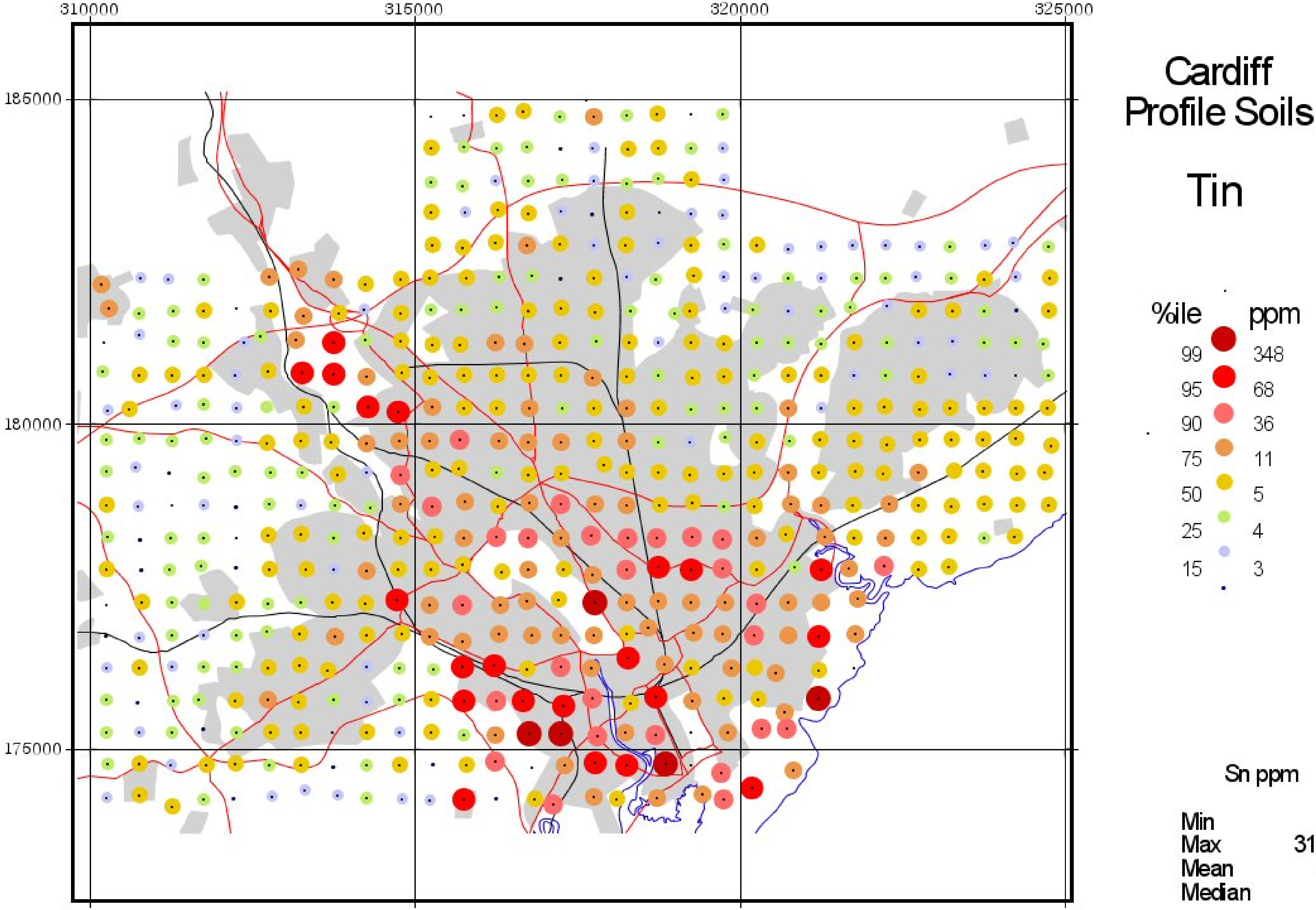


Sn ppm

Min	2
Max	334
Mean	16
Median	6

Cardiff Profile Soils

Tin

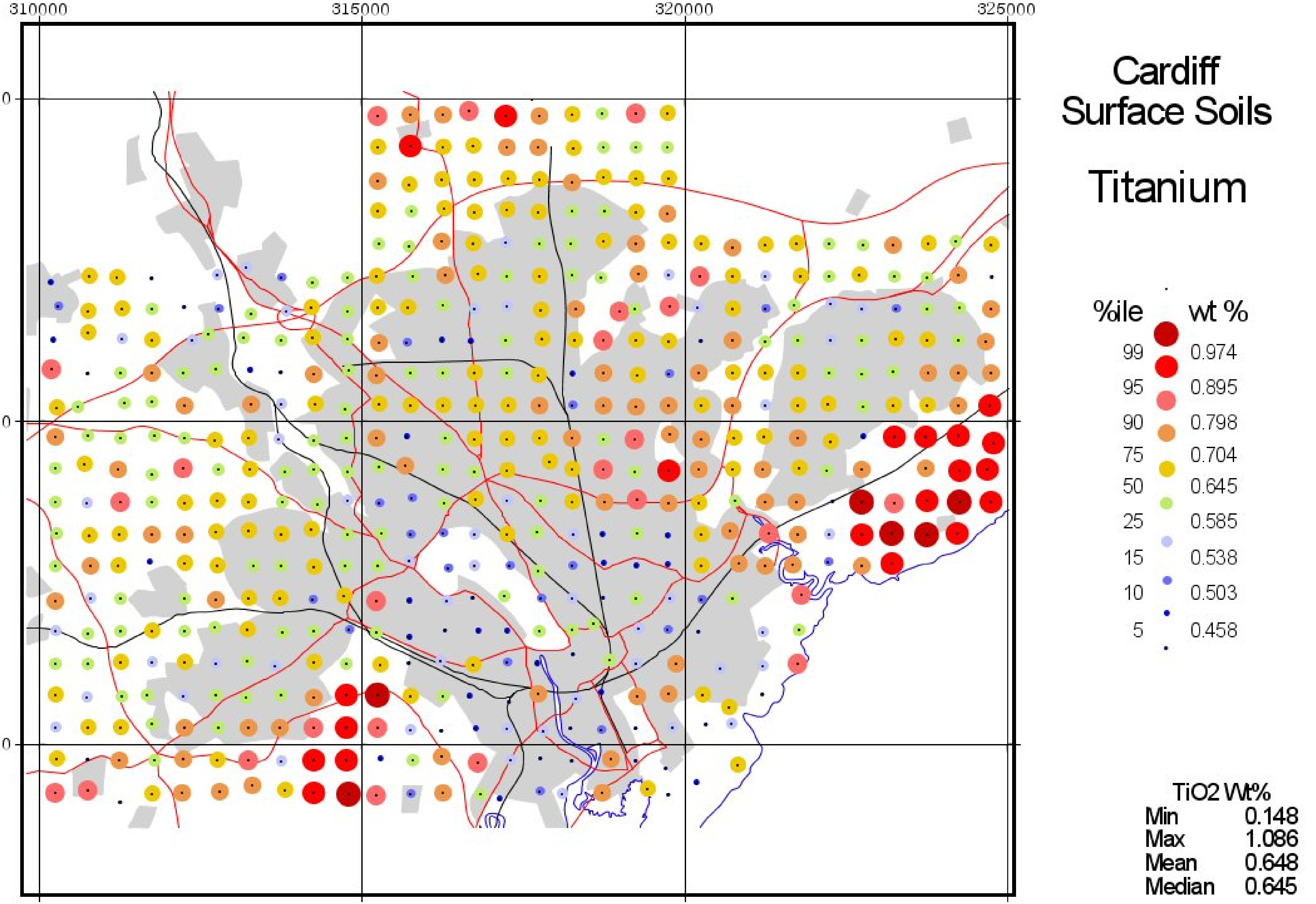


Sn ppm

Min	2
Max	3148
Mean	27
Median	5

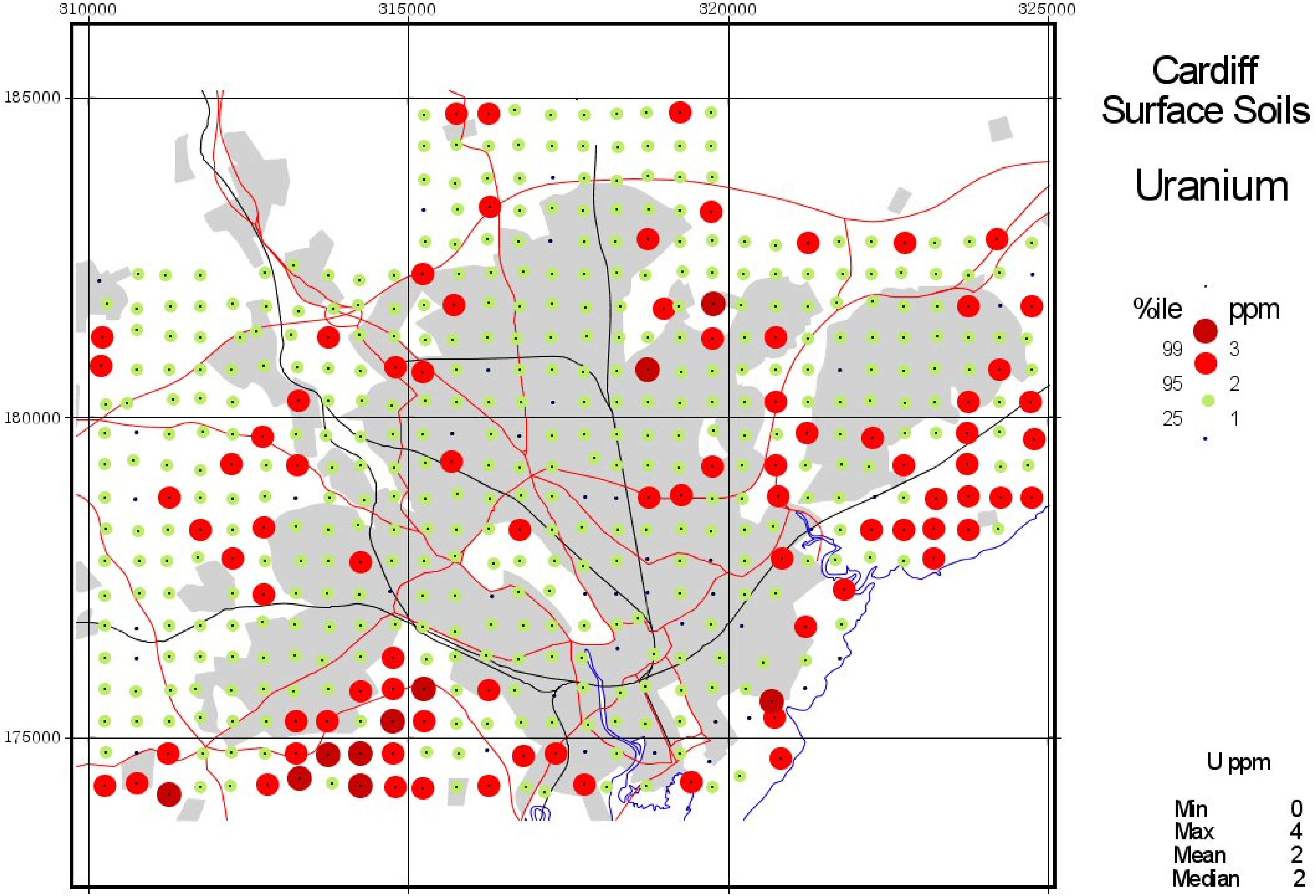
Cardiff Surface Soils

Titanium



TiO2 Wt%	
Min	0.148
Max	1.086
Mean	0.648
Median	0.645

No Profile Soil Data for TiO2

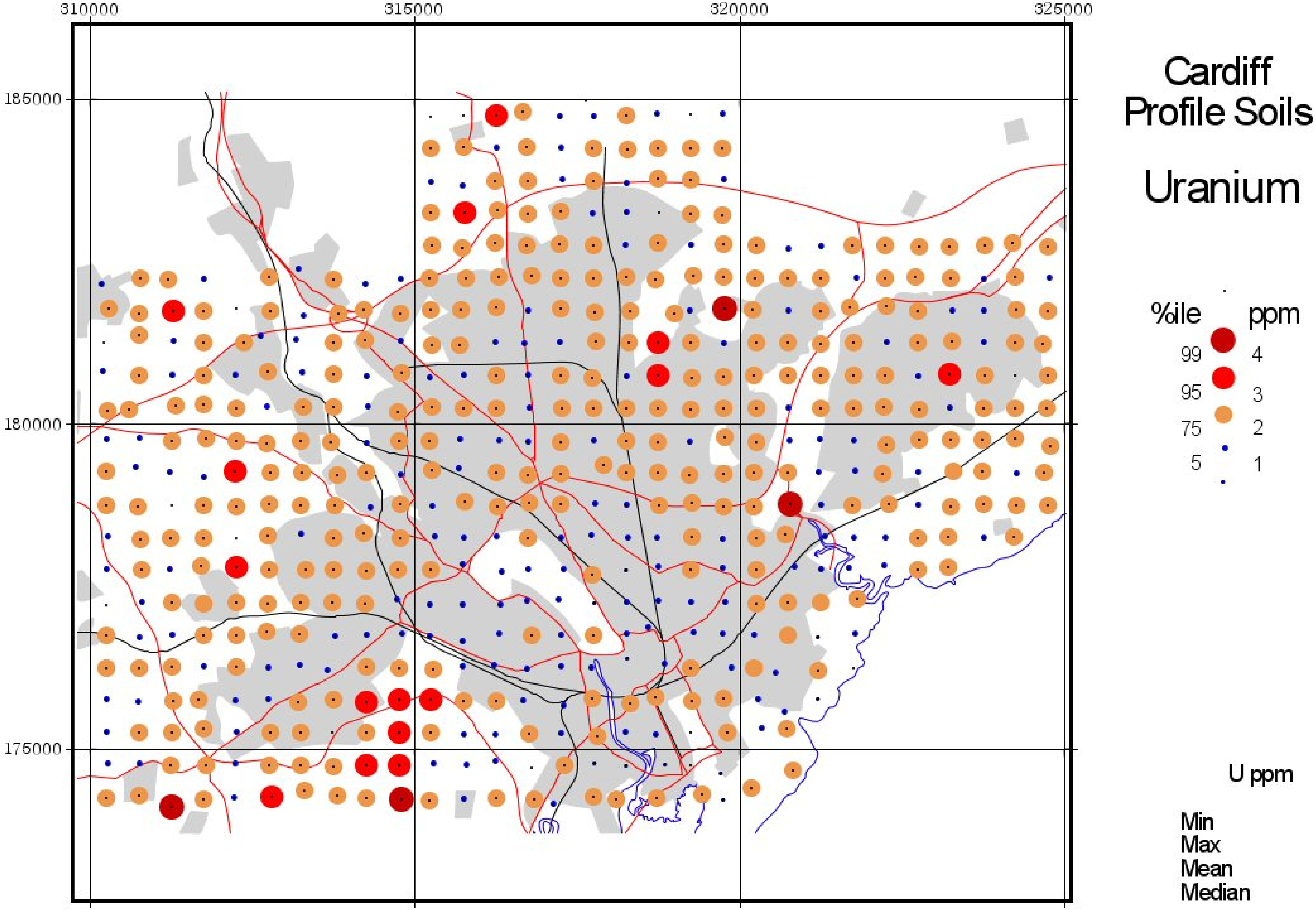


Cardiff Surface Soils

Uranium

U ppm

Min	0
Max	4
Mean	2
Median	2

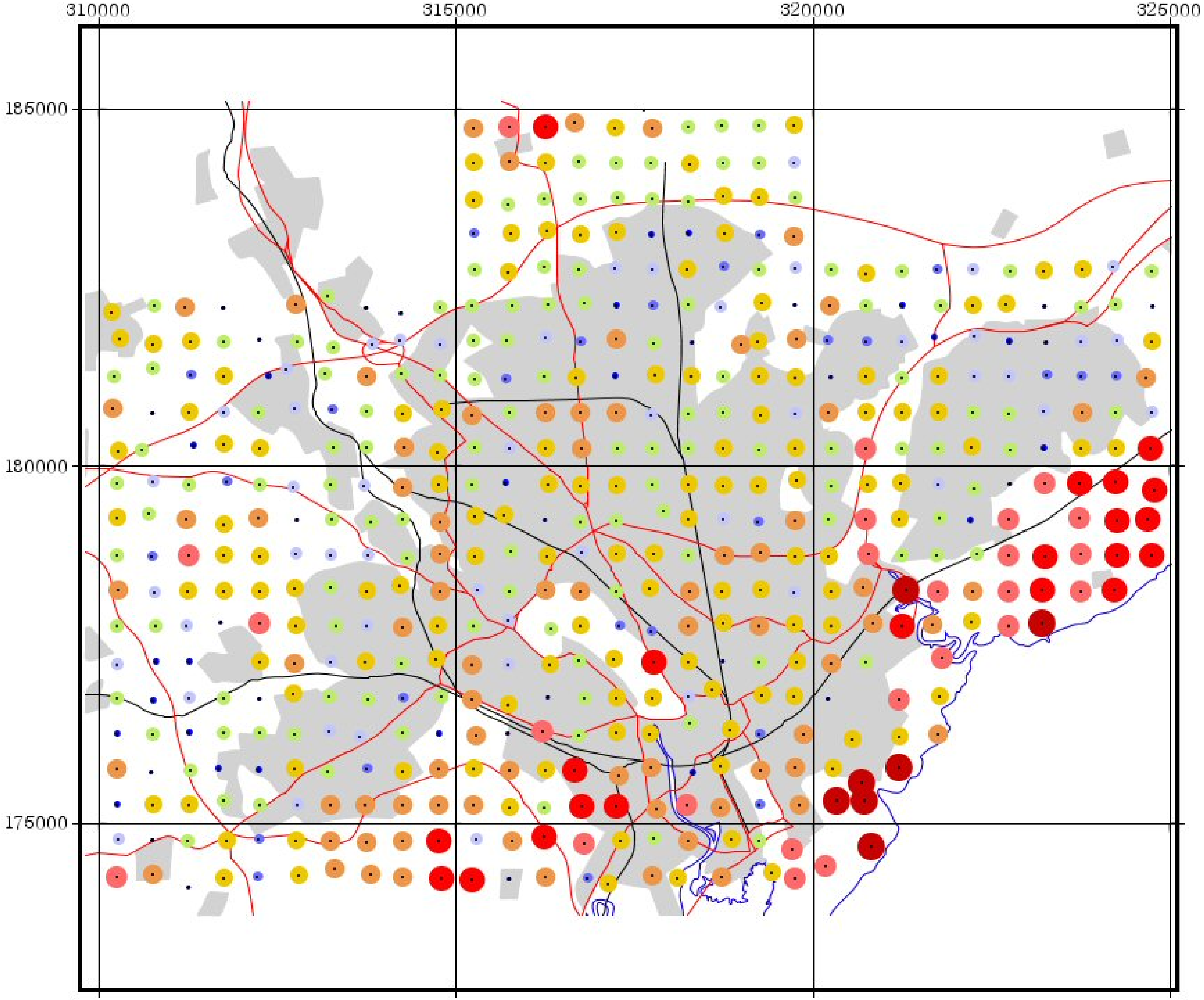


Cardiff
Profile Soils

Uranium

U ppm

Min	6
Max	0
Mean	2
Median	2



Cardiff
Surface Soils

Vanadium

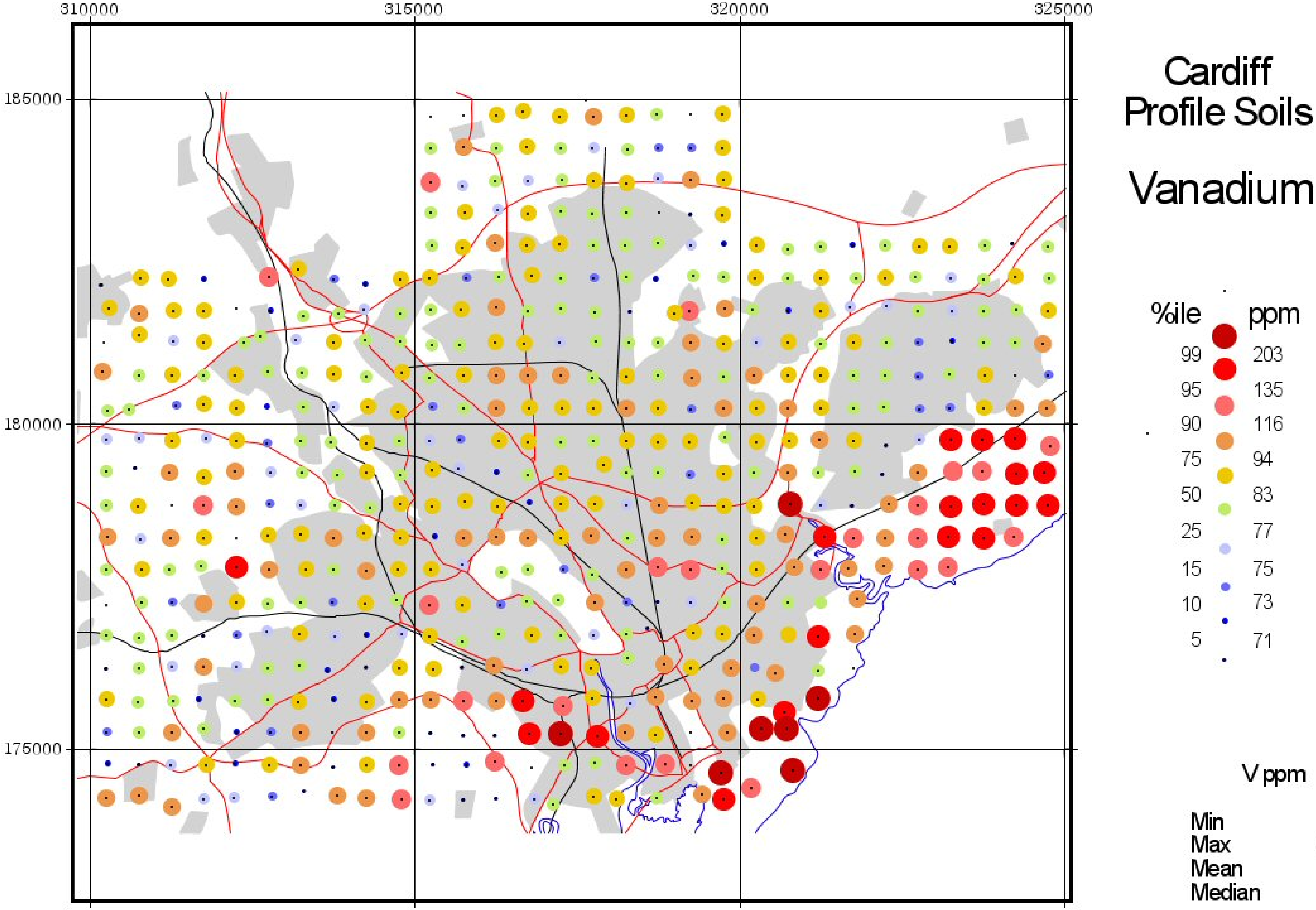
%ile	ppm
99	158
95	128
90	111
75	89
50	77
25	71
15	68
10	66
5	63

V ppm

Min	43
Max	469
Mean	84
Median	77

Cardiff
Profile Soils

Vanadium

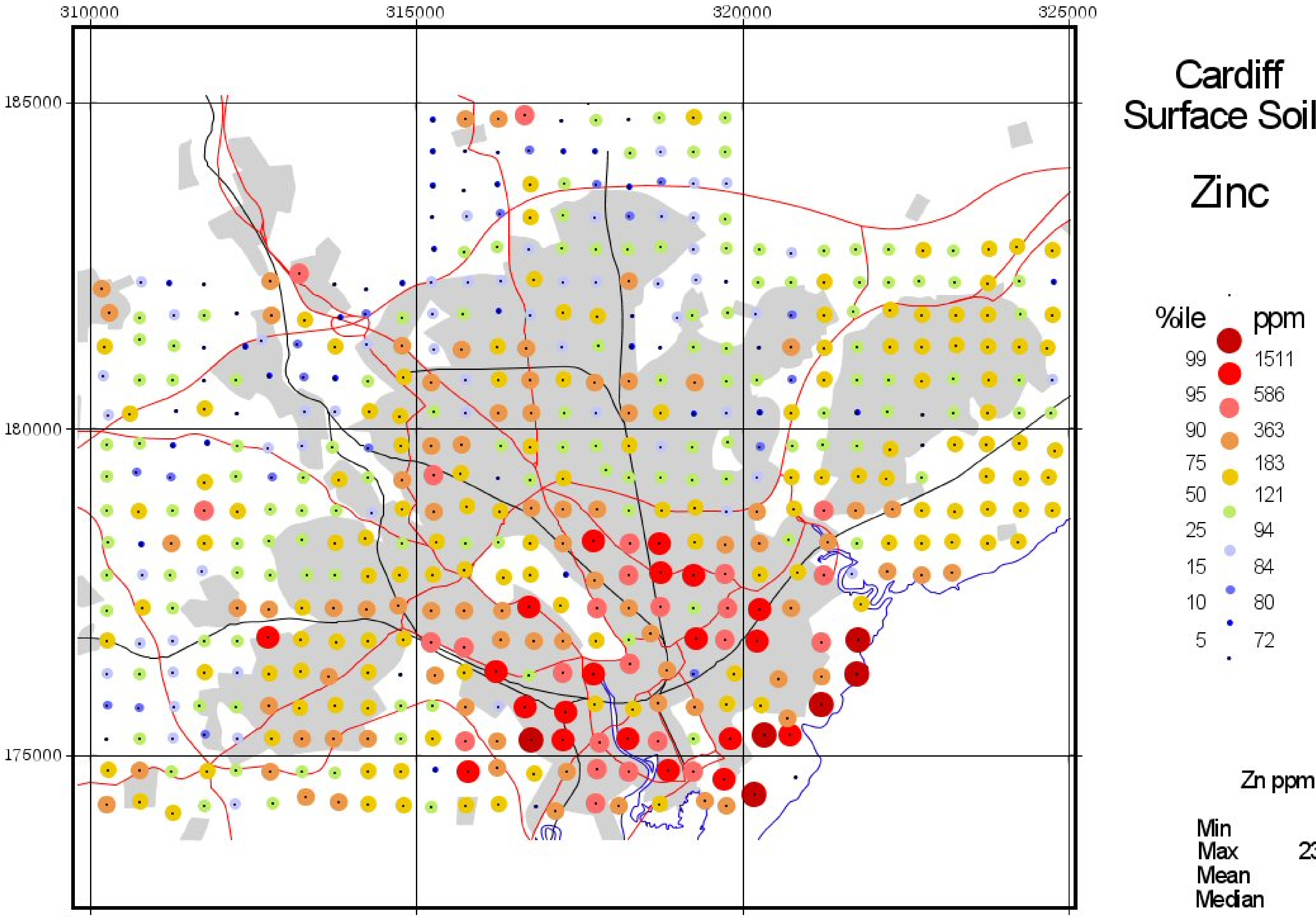


V ppm

Min	38
Max	664
Mean	91
Median	83

Cardiff Surface Soils

Zinc

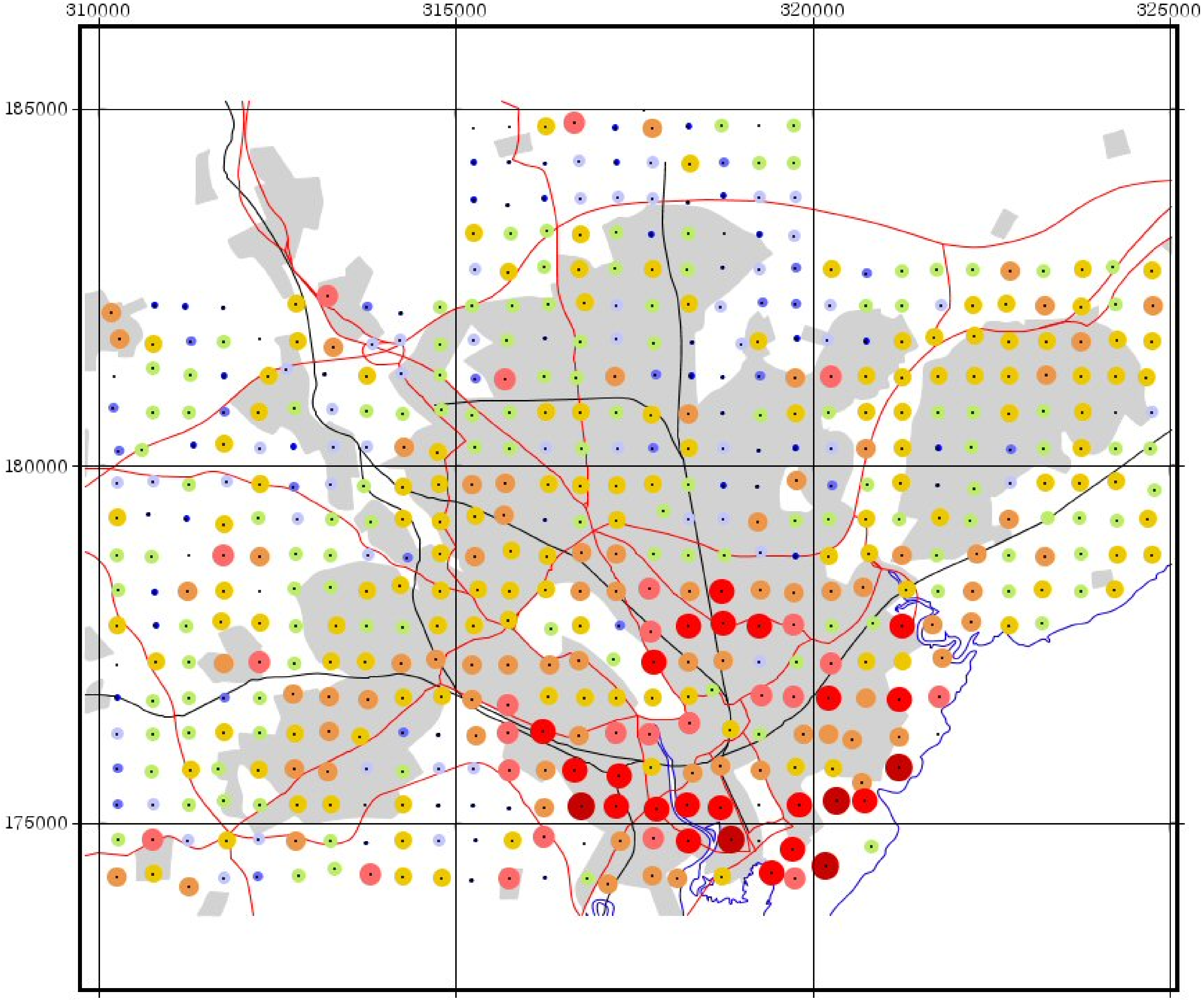


Zn ppm

Min	41
Max	23238
Mean	274
Median	121

Cardiff Profile Soils

Zinc



%ile	ppm
99	1951
95	585
90	314
75	171
50	112
25	88
15	77
10	71
5	61

Zn ppm

Min	26
Max	27811
Mean	263
Median	112