Cambridge Environmental Research Consultants

Air quality modelling for Cardiff, 2006 to 2015: methodology and verification report

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1 Introduction

Cambridge Environmental Research Consultants Ltd (CERC) was commissioned by the University of Swansea to carry out air quality modelling across the City of Cardiff for the years 2006 to 2015. This report describes the methodology used to carry out the air quality modelling.

The air quality standards referred to in the model verification are presented in Section 2. The local air quality and model set-up are described in Sections 3 and 4 respectively, and the emissions inventories used in the modelling are described in Section 5. The results of the model verification are presented in Section 6. Contour plots of modelled concentrations are presented in Section 7.

Finally, a description of the ADMS model used in the assessment is given in Appendix A, and detailed model verification results are presented in Appendix B.

2 Air quality standards

Although ozone and $PM_{2.5}$ were also modelled, only NO_2 and PM_{10} were considered in the verification for this assessment. *The Air Quality Strategy for England, Scotland, Wales and Northern Ireland, Working Together for Clean Air*, July 2007, defines Air Quality Objective values for NO_2 and PM_{10}. These objectives are the subject of Statutory Instrument 2000 No. 928, *The Air Quality (England) Regulations 2000*, which came into force on 6th April 2000.

The NO_2 and PM_{10} Air Quality Objectives are presented in Table 2.1.

Table 2.1: Air quality objectives

	Value ($\mu g/m^3$)	Description of standard	Date to be achieved by and maintained thereafter
NO_2	200	Hourly mean not to be exceeded more than 18 times a year (modelled as 99.79th percentile)	31-12-2005
	40	Annual average	31-12-2005
PM_{10}	50	24-hour mean not be exceeded more than 35 times a year (modelled as 90.41st percentile)	31-12-2004
	40	Annual average	31-12-2004

The short-term standards considered are specified in terms of the number of times during a year that a concentration measured over a short period of time is permitted to exceed a specified value. For example, the concentration of NO_2 measured as the average value recorded over a one-hour period is permitted to exceed the concentration of $200\mu g/m^3$ up to 18 times per year. Any more exceedences than this during a one-year period would represent a breach of the objective.

It is convenient to model objectives of this form in terms of the equivalent percentile concentration value. A percentile is the concentration below which lie a specified percentage of concentration measurements. For example, consider the 98th percentile of one-hour concentrations over a year. Taking all of the 8760 one-hour concentration values that occur in a year, the 98th percentile value is the concentration below which 98% of those concentrations lie. Or, in other words, it is the concentration exceeded by 2% (100 – 98) of those hours, that is, 175 hours per year. Taking the NO_2 objective considered above, allowing 18 exceedences per year is equivalent to not exceeding for 8742 hours or for 99.79% of the year. This is therefore equivalent to the 99.79th percentile value.

3 Local air quality

The Local Air Quality Management (LAQM) process, as set out in Part IV of the Environment Act (1995), the Air Quality Strategy for England, Scotland, Wales and Northern Ireland 2007 and the relevant Policy and Technical Guidance documents places an obligation on all local authorities to regularly review and assess air quality in their areas, and to determine whether or not the air quality objectives are likely to be achieved. Where exceedences are considered likely, the local authority must then declare an Air Quality Management Area (AQMA) and prepare an Air Quality Action Plan (AQAP) setting out the measures it intends to put in place in pursuit of the objectives.

Cardiff Council has declared four Air Quality Management Areas (AQMAs) in Cardiff due to elevated annual average NO_2 concentrations:

- The Cardiff City Centre AQMA, covering St. Mary Street and Westgate Street in Cardiff City Centre;
- Stephenson Court AQMA, from NE and NW boundaries of Stephenson Court, NW boundary of Burgess Court, NW and SW boundaries of Four Elms Court, SW corner of Four Elms Court south across Newport road to the junction with Orbit Street, West across Newport Road to the SE corner of Stephenson Court;
- Llandaff AQMA, centred on Cardiff Road through Llandaff village;
- Ely Bridge EQMA, covering a number of residential premises along the A48 (Cowbridge Road West, Western Avenue) and the A4119.

The locations of these AQMAs are given in Figure 3.1.

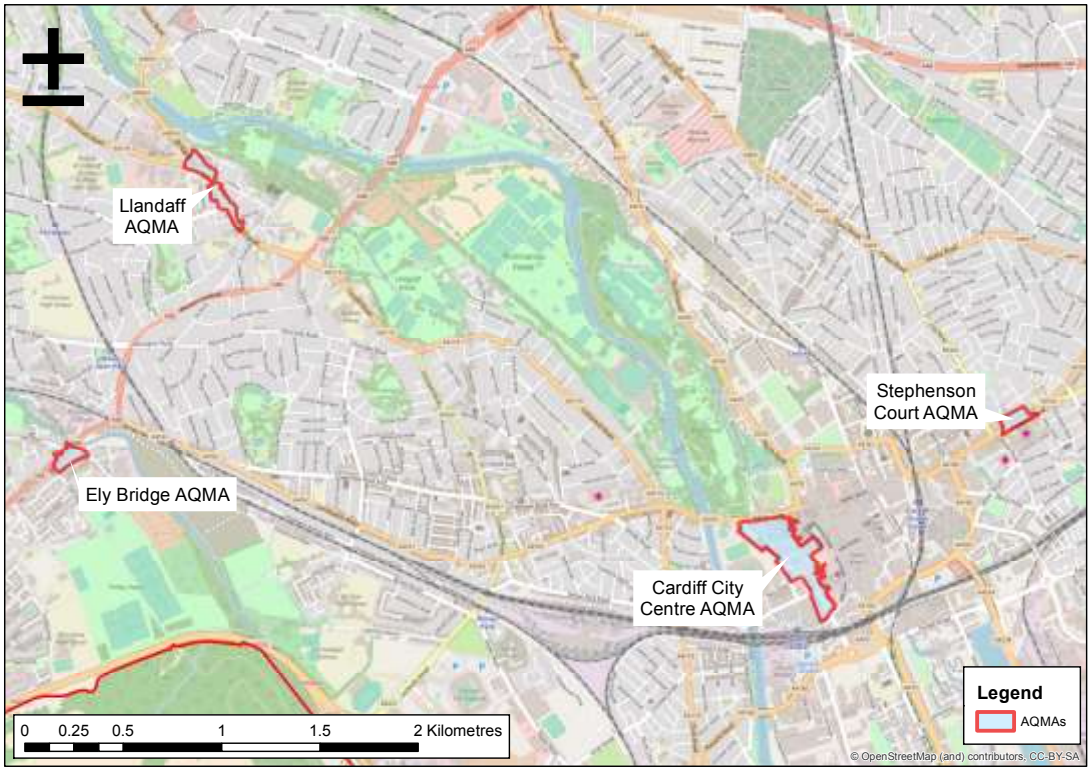


Figure 3.1: AQMAs in Cardiff

The council operates only one automatic monitoring site, at an urban background location, about 1km to the west from the proposed development. Monitoring data from this site for 2011 to 2015 are presented in Table 3.1.

Table 3.1: Automatic monitoring data in Cardiff

Site ID	Site Type	Pollutant	Statistic	Value 2011	2012	2013	2014	2015
Cardiff Centre AURN	Urban Centre	NO_2	Annual Mean, µg/m³	27	27	26	25	27
			Number of hourly means > 200µg/m³	0	0	5	0	0
		PM_{10}	Annual Mean, µg/m³	22	18	19	16	16
			Number of daily means > 50µg/m³	3	5	3	4	5

The council also operates 73 diffusion tube locations in the borough. Table 3.2 presents the monitored annual average concentrations for 2011 to 2015. Data were taken from Cardiff Council's 2016 Progress Report, and are bias-adjusted.

Table 3.2: Diffusion tube monitoring data in Cardiff

Site ID	Site name	Site type	x	y	z	Relevant exposure	Monitored NO_2 concentration, µg/m³				
							2011	2012	2013	2014	2015
16	Ninian Park Road	Roadside	317040	176060	1.5	Y (0.05m)	32.1	30.9	31.3	32.4	27.9
33	Mitre Place	Kerbside	315248	178165	3	N (20m)	55.0	49.8	49.6	51.2	46.9
44	City Road	Kerbside	319086	177097	3	Y (2m)	39.2	34.8	33.2	29.7	27.1
45	Mackintosh Place	Kerbside	318722	177788	3.5	N (3m)	36.8	36.8	36.8	37.8	32.1
47	Ely Bridge	Kerbside	314457	176738	2.5	N (2m)	53.0	51.1	48.0	47.1	41.4
49	Penarth Road	Roadside	317760	175310	1.5	Y (0.05m)	31.9	27.9	32.1	32.6	29.4
56	Birchgrove Village	Roadside	316816	180005	2.5	N (10m)	31.5	33.9	35.4	35.8	29.6
58	Westgate Street	Kerbside	317937	176400	2.5	N (5m)	54.9	49.5	52.4	51.2	48.3
73	Green Street	Kerbside	317607	176434	2.5	N (2m)	28.0	25.6	24.9	26.8	22.1
74	Station Terrace	Kerbside	318772	176544	2.5	N (50m)	48.0	50.1	47.8	47.3	41.6
81	Stevenson Court	Roadside	319387	176980	2	Y (0.05m)	40.6	40.6	37.2	36.4	35.3
82	104 Birchgrove Road	Roadside	316518	179683	2	Y (0.05m)	28.2	28.5	32.1	27.6	23.8
85	497 Cowbridge Road West	Roadside	312129	175084	1.5	Y (0.05m)	28.2	27.3	26.7	27.2	22.4
86	19 Fairoak Road	Roadside	318452	178805	1.5	Y 0.10m)	39.9	40.3	38.8	38.9	34.9
96	Manor Way Junction	Roadside	316601	179653	1.5	Y (0.05m)	34.5	35.4	35.5	34.4	31.1
97	Newport Road (premises)	Roadside	319955	177546	1.5	Y (0.05m)	35.4	37.8	34.5	33.6	30.5
98	Western Avenue (premises)	Roadside	314805	177345	1.5	Y (0.05m)	29.1	26.9	28.3	29.8	25.4
99	Cardiff Road Llandaff	Roadside	315275	178117	1.5	Y (0.05m)	39.8	34.5	38.9	39.6	29.8
100	188 Cardiff Road	Roadside	316226	177305	1.5	Y (0.10m)	34.8	33.7	32.6	31.8	28.9
101	Cardiff Centre AURN					Y (0.10m)	26.7	25.8	26.5	24.4	20.3
102	Cardiff Centre AURN	Urban Centre	318416	176525	3	Y (0.10m)	28.0	26.1	26.9	24.2	21.1
103	Cardiff Centre AURN					Y (0.10m)	27.4	25.8	26.2	24.4	20.7
106	30 Caerphilly Road	Roadside	316851	179520	1.5	Y (0.05m)	34.0	35.7	34.8	34.9	29.4
107	Lynx Hotel	Roadside	320356	177618	1.5	Y (0.05m)	36.4	37.6	34.6	34.8	30.7
111	98 Leckwith Road	Roadside	316444	175866	1.5	Y (0.05m)	24.5	23.7	25.2	24.7	21.3
112	17 Sloper Road	Roadside	316613	175910	1.5	Y (0.05m)	30.2	30.6	30.7	28.8	27.1

115	21 Llandaff Road	Roadside	316604	176641	1.5	Y (0.05m)	38.7	37.7	35.5	36.3	32.5
117	25 Cowbridge Road West	Roadside	314458	176735	2	Y (0.05m)	46.5	42.6	44.9	42.3	39.5
119	Havelock Street	Kerbside	318184	176086	2	N	40.2	33.7	33.2	32.0	27.7
124	287 Cowbridge Road East	Roadside	316586	176535	1.5	Y (0.05m)	27.0	25.5	26.1	26.3	22.5
126	Westgate Street Flats	Roadside	317946	176387	1.5	Y (0.10m)	45.4	39.9	44.0	41.2	36.0
128	117 Tudor Street	Roadside	317540	175979	1.5	Y (0.05m)	36.7	35.1	34.7	36.5	29.6
129	Stephenson Court 2	Roadside	319349	176963	1.2	Y (3m)	36.2	34.9	32.8	32.0	31.5
130	Burgess Court	Roadside	319326	176949	2	Y (0.05m)	44.4	41.5	39.0	38.9	35.2
131	Dragon Court	Roadside	319292	176932	1.75	Y (0.05m)	47.3	47.9	43.9	41.2	39.5
133	St Mark's Avenue	Roadside	317019	179078	2	N (21m)	39.5	39.3	37.8	37.5	31.9
134	Sandringham Hotel	Roadside	318261	176229	2	N (3m)	45.1	37.2	33.4	34.5	32.1
139	Lower Cathedral Road	Kerbside	317540	176410	2	Y (3m)	34.3	34.3	34.1	35.5	29.4
140	Clare Street	Kerbside	317600	176047	2	Y (6m)	42.5	41.7	42.2	42.9	36.3
141	Fairoak Road 2	Roadside	318438	178742	2	N (5m)	40.0	47.6	37.7	37.0	32.3
142	Pure Rugby	Kerbside	318326	176086	2	N (>25m)	48.7	47.6	46.3	44.9	41.8
143	Windsor House	Roadside	318009	176337	1.5	Y (0.10m)	43.8	41.5	42.1	42.1	38.2
144	Marlborough House	Roadside	318046	176307	1.5	Y (0.10m)	42.9	39.5	39.0	38.2	37.2
145	Tudor Street Flats	Roadside	317904	175921	1.5	Y (0.05m)	34.6	33.8	34.5	32.6	29.9
146	Neville Street	Roadside	317508	176275	2	Y (0.05m)	29.4	29.5	30.9	29.7	26.6
147	211 Penarth Road	Roadside	317636	175161	1.5	Y (0.10m)	31.1	31.0	32.0	31.3	27.7
148	161 Clare Road	Roadside	317695	175389	1.5	Y (0.05)	29.0	27.8	29.3	29.1	27.5
149	10 Corporation Road	Roadside	317764	175174	1.5	Y (0.05)	34.1	33.0	34.5	33.2	33.6
152	James Street	Roadside	319003	174596	1.5	Y (0.10m)	32.8	32.5	31.0	29.7	27.6
153	Roundabout	Roadside	319491	176183	1.5	Y (0.10m)	35.0	36.2	33.0	33.2	29.0
156	2a/4 Colum Road	Roadside	317997	177412	1.5	Y (0.10m)	33.4	32.6	34.9	31.4	25.9
157	47 Birchgrove Road	Roadside	316605	179703	1.5	Y (0.10m)	33.1	31.6	29.0	29.7	27.2
158	64/66 Cathays Terrace	Roadside	318093	177716	1.5	Y (0.05m)	31.5	28.8	30.2	29.1	25.5
159	IMO façade replacement	Roadside	320709	177918	1.5	Y (0.10m)	38.7	39.9	38.8	39.2	34.0
160	High Street Zizzi	Urban Centre	318131	176407	2	Y (0.10m)	32.6	31.4	30.3	28.3	27.0
161	52 Bridge Road	Roadside	315230	178205	1.5	Y (0.05m)	-	43.0	39.1	37.2	32.3
162	58 Cardiff Road	Roadside	315533	177809	1.5	Y (0.05m)	-	28.5	27.6	27.6	24.5
163	118 Cardiff Road	Roadside	315738	177723	1.5	Y (0.05m)	-	27.5	25.4	28.2	23.2
164	725 Newport Road	Roadside	321405	179345	1.5	Y (0.05m)	-	-	25.4	23.9	20.3
165	6 Heol Tyrrell	Roadside	315918	176221	1.5	Y (0.05m)	-	-	19.4	17.4	15.1
166	163 Lansdowne Road	Roadside	315950	176424	1.5	Y (0.05m)	-	-	34.9	36.6	32.1
167	359 Lansdowne Road	Roadside	315326	176714	1.5	Y (0.05m)	-	-	31.7	31.5	28.3
168	570 Cowbridge Road East	Roadside	314856	176929	1.5	Y (0.05m)	-	-	27.9	27.7	24.3
169	43 Clos Hector	Background	321586	177414	1.5	Y (0.05m)	-	-	18.0	18.1	16.3
170	11 Pengam Green	Roadside	320973	177721	1.5	Y (0.05m)	-	-	22.1	21.9	19.1
171	23 Tweedsmuir Road	Roadside	320750	177053	1.5	Y (0.05m)	-	-	22.5	20.8	18.1
172	Ocean Way 1	Roadside	320544	175613	2	N (>650m)	-	-	49.5	47.8	44.5
173	Ocean Way 2	Roadside	320395	175623	2	N (>650m)	-	-	33.7	33.3	28.4
174	76 North Road	Kerbside	317508	177868	1.5	Y (0.1m)	-	-	-	33.9	28.7
175	Northgate House	Kerbside	318217	176545	2	N (9.4m)	-	-	-	46.8	42.0
176	Castle Arcade	Roadside	318079	176457	2	N (3.8m)	-	-	-	55.0	53.1
177	Angel Hotel	Roadside	317944	176438	2	Y (0.1m)	-	-	-	51.8	48.1
178	Park Street/Westgate Street	Kerbside	318235	176140	2	N (2.5m)	-	-	-	51.6	54.3

Figure 3.2 presents the locations of the diffusion tubes.

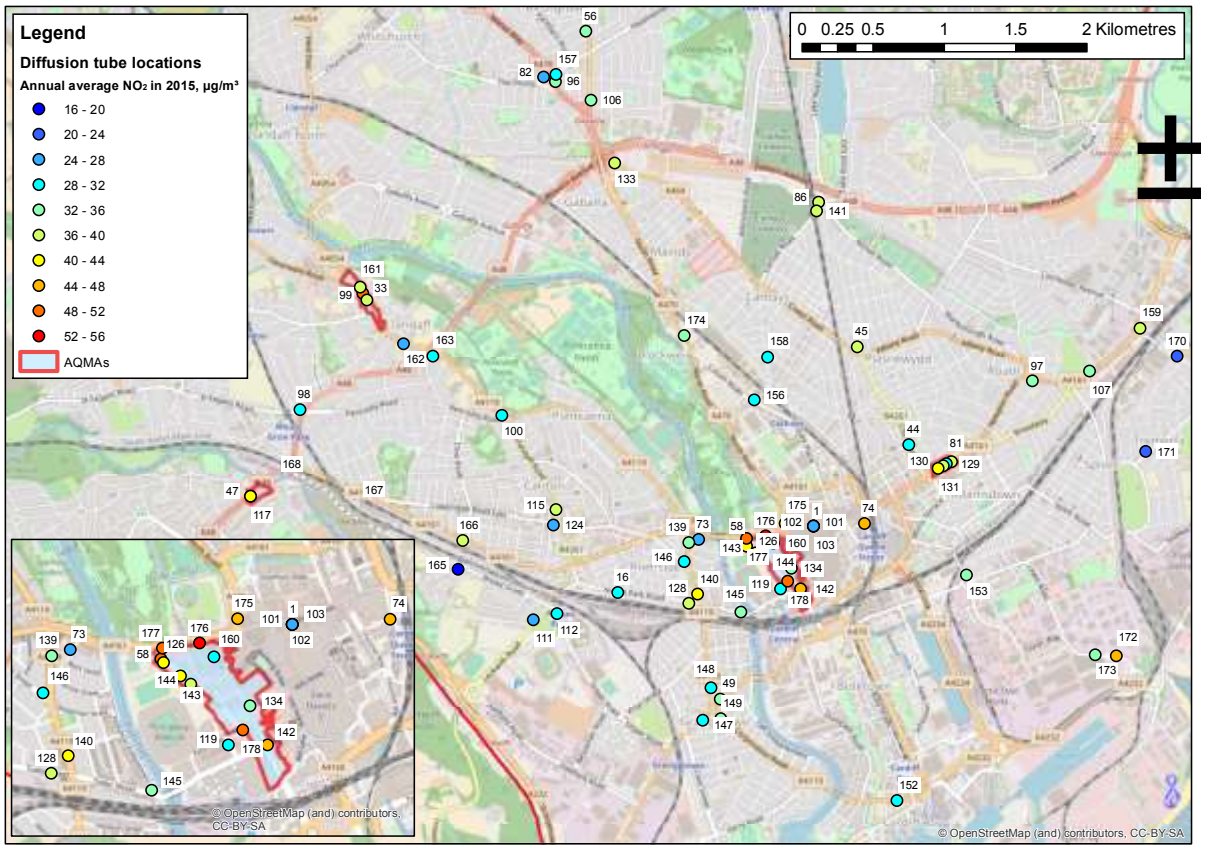


Figure 3.2: Diffusion tube location, with measured 2015 annual average NO_2 concentrations, µg/m³

4 Air quality modelling

Modelling was carried out using the ADMS-Urban model (version 4.1.0). The model uses the detailed emissions data described in Section 5, together with a range of other input data, to calculate the dispersion of pollutants.

Concentrations were output at all residential and school locations across Cardiff for the ten years 2006 to 2015. Minimum, maximum and mean concentrations were calculated for three periods per day:

1. School (9am – 3pm)
2. After school (3pm – 5pm)
3. Home (5pm – 9am)

These concentrations were provided to other members of the project team for further processing. In addition, contour plots of annual average concentrations of each modelled pollutant for each year were generated across Cardiff.

This section summarises the various data and assumptions used in the modelling.

4.1 Surface roughness

A length scale parameter called the surface roughness length is used in the model to characterise the study area in terms of the effects it will have on wind speed and turbulence, which are key factors in the modelling. A value of 0.75 metres was used in the modelling to represent the built-up nature of the area.

The difference in land use at Cardiff airport (Rhoose) compared to the study area was taken into account by entering a different surface roughness for the meteorological site. See Section 4.3 for further details.

4.2 Monin-Obukhov length

In urban and suburban areas a significant amount of heat is emitted by buildings and traffic, which warms the air within and above a city. This is known as the urban heat island and its effect is to prevent the atmosphere from becoming very stable. In general, the larger the urban area the more heat is generated and the stronger the effect becomes.

In the ADMS-Urban model, the stability of the atmosphere is represented by the Monin-Obukhov parameter, which has the dimension of length. In very stable conditions it has a positive value of between 2 metres and 20 metres. In near neutral conditions its magnitude is very large, and it has either a positive or negative value depending on whether the surface is being heated or cooled by the air above it. In very convective conditions it is negative with a magnitude of typically less than 20 metres.

The effect of the urban heat island is that, in stable conditions, the Monin-Obukhov length will never fall below some minimum value; the larger the city, the larger the minimum value. A value of 30 metres was used in the modelling.

4.3 Meteorological data

The ADMS meteorological pre-processor, written by the Met Office, uses the data provided to calculate the parameters required by the program. Data for 2015 from the BADC St. Athan site was used. Table 4.1 presents a summary of the meteorological data used in the modelling. Figure 4.1 shows a wind rose for the St. Athan meteorological station, showing the frequency of occurrence of wind from different directions for a number of wind speed ranges.

The difference in land use at the meteorological site compared to the study area was taken into account by entering a different surface roughness for the meteorological site. The surface roughness for St. Athan was set to 0.1 metre, compared to 1 metre for Cardiff.

Table 4.1: Summary of meteorological data used in the modelling

Year	Percentage used	Wind Speed (m/s)			Temperature (° C)			Cloud Cover (oktas)		
		Min	Max	Av	Min	Max	Av	Min	Max	Av
2006	98.4%	0	16.5	5.0	-3.6	30.7	11.3	0	8	5.3
2007	99.4%	0	19.5	4.9	-3.6	25.1	11.2	0	8	5.1
2008	98.5%	0	16.5	5.2	-3.1	26.8	10.6	0	8	5.2
2009	97.7%	0	17.0	4.7	-5.3	26.5	10.6	0	8	5.2
2010	98.4%	0	17.5	4.2	-8.4	24.9	9.6	0	8	4.8
2011	98.6%	0	17.0	5.0	-5.8	25.8	11.4	0	8	5.3
2012	99.7%	0	17.5	4.9	-6.3	26.5	10.5	0	8	5.4
2013	99.7%	0	17.5	4.9	-3	28.7	10.4	0	8	5.1
2014	96.3%	0	19.0	4.7	-2.3	27.3	11.7	0	8	5.0
2015	97.5%	0	17.5	5.2	-2.7	27.1	11.1	0	8	5.1

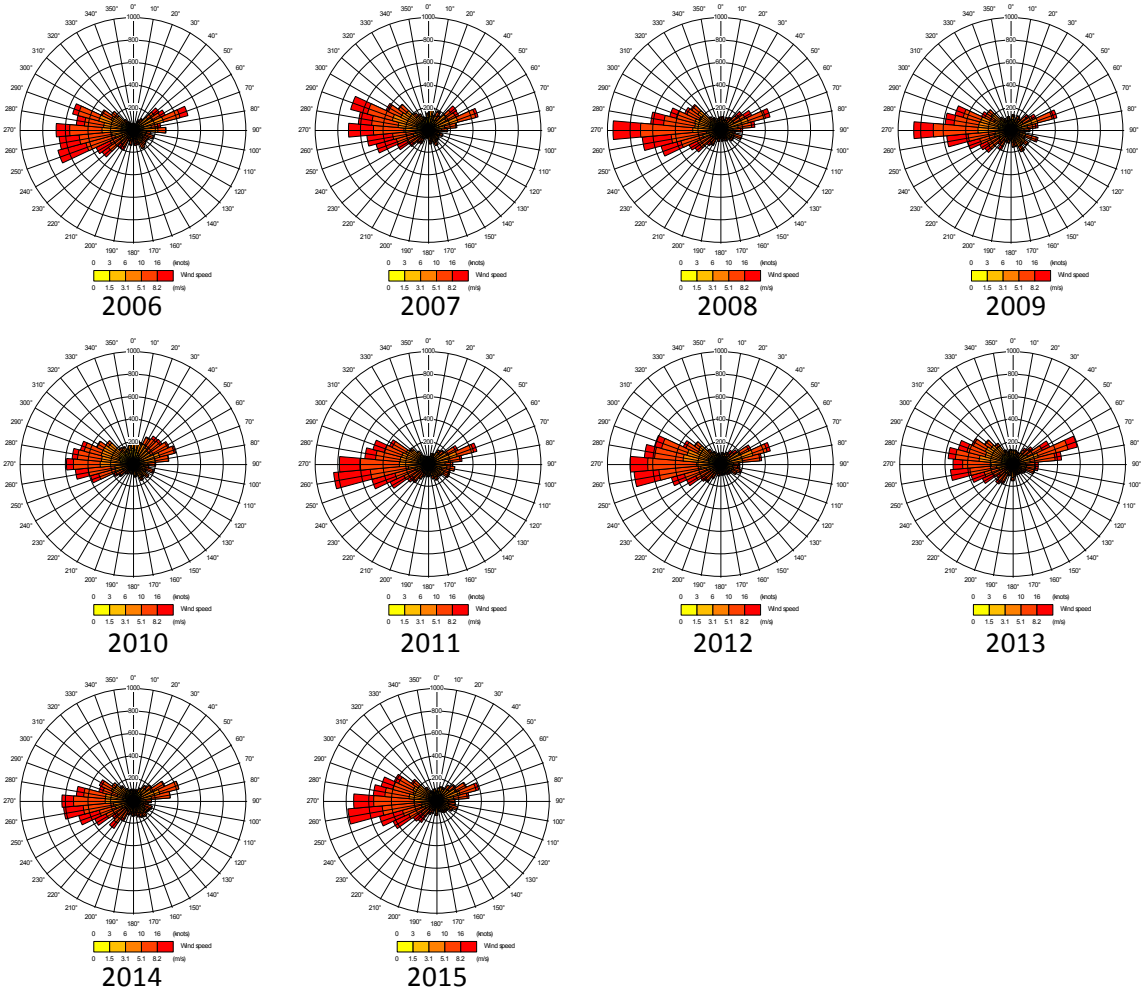


Figure 4.1: Wind roses for Rhoose, 2006-2015

4.4 Background data

Nitrogen dioxide (NO_2) results from direct emissions from combustion sources together with chemical reactions in the atmosphere involving NO_2, nitric oxide (NO) and ozone (O_3). The combination of NO and NO_2 is referred to as nitrogen oxides (NO_x).

The chemical reactions taking place in the atmosphere were taken into account in the modelling using the Generic Reaction Set (GRS) of equations. These use hourly average background concentrations of NO_x, NO_2 and O_3, together with meteorological and modelled emissions data to calculate the NO_2 concentration at a given point.

Background concentrations of all pollutants measured at sites operated by the National Assembly for Wales and other members of the Welsh Air Quality Forum were downloaded from the Welsh Air Quality Data and Statistics Database[1].

Hourly background data were taken from the Narberth automatic monitoring site, a rural site located approximately 100km to the west of the proposed development. In addition, data for NO_x, NO_2 and O_3 were taken from the Aston Hill monitoring site. The two sites are approximately equidistant from Cardiff. However, as Narberth is upwind of the prevailing wind, this site was used preferentially. In 2007 and 2008 data capture at the Narberth site fell below an acceptable threshold; therefore NO_x, NO_2 and O_3 data from the Aston Hill site was used.

The locations of the two sites are shown in Figure 4.2.

Figure 4.2: Rural background monitoring sites relative to Cardiff

[1] www.welshairquality.co.uk

Using raw data from the Narbeth monitoring site would lead to an underestimation in background concentrations outside Cardiff, as there is an extensive urban area between this site and Cardiff. In order to correct the measured concentrations, hourly background concentrations were scaled by the difference in the Defra background maps[2] between the square containing Narbeth and a location on the western edge of Cardiff. The resulting annual average background concentrations are presented in Table 4.2 and Figure 4.3.

Table 4.2: Background concentrations for modelled years (µg/m³)

Year	NO_x	NO_2	O_3	PM_{10}	$PM_{2.5}$	SO_2
2006	16.6	12.3	60.3	17.6	11.5	2.8
2007	15.6	13.0	64.1	18.2	11.9	2.1
2008	15.7	13.1	64.1	16.0	10.5	3.3
2009	9.9	7.0	59.6	11.7	7.7	2.7
2010	14.5	10.2	54.5	8.1	5.3	2.6
2011	11.5	8.8	57.3	10.8	7.1	2.1
2012	12.9	9.2	57.1	10.9	7.1	1.4
2013	11.1	8.0	62.2	15.8	10.3	1.7
2014	9.5	6.7	60.3	13.5	8.8	1.6
2015	8.1	5.7	61.2	11.3	7.4	0.9

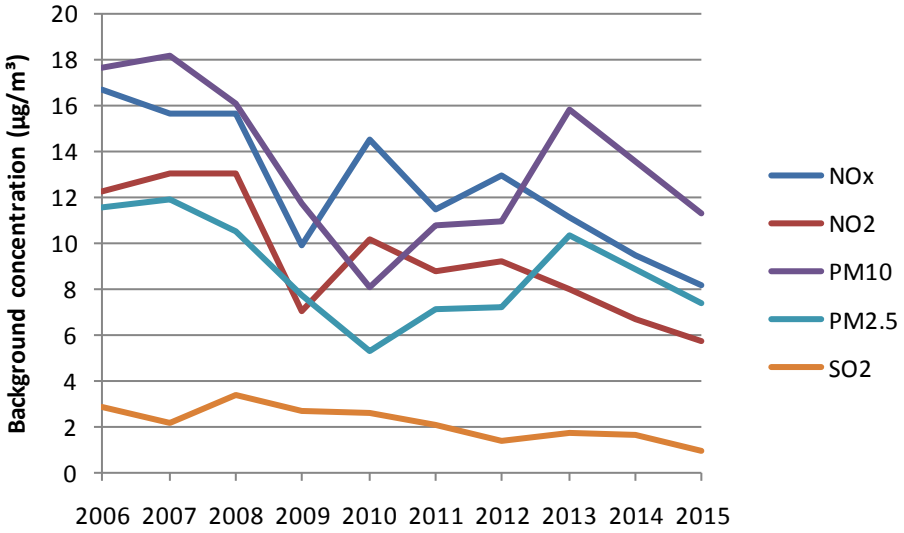


Figure 4.3: Background concentrations for modelled years (µg/m³)

As $PM_{2.5}$ data were not available from the Narberth site, concentrations were calculated from the PM_{10} concentrations based on the ratio in the background maps. Note that in 2010 and 2011, data capture for PM_{10} at the Narbeth site was low; in the absence of other data, the average diurnal profile for each month was used to fill the gaps; this may account for the low PM_{10} concentrations recorded in these years.

[2] https://laqm.defra.gov.uk/review-and-assessment/tools/background-maps.html

5 Emission inventories

For each modelled year, an emission inventory containing all the emissions across the borough was compiled using EMIT, the emissions inventory toolkit developed by CERC. Details of the emission calculations and source geometries are given below.

5.1 Traffic data

5.1.1 Road geometries

The *OS Open Roads* dataset published by Ordnance Survey[3] was used to model the road network. All road sources were treated as a single source per link, representing both directions of traffic, except at roundabouts; the source width parameters used are presented in Table 5.1.

Table 5.1: Modelled road widths for all years

Road category	Road type	Width (m)
Motorway	Dual carriageway	15
A Road	Dual carriageway	15
	Single carriageway	12
	Roundabout	10
	Slip Road	7
B Road	Single carriageway	7

Road geometries were simplified using the Douglas-Peucker algorithm with a tolerance of 1m in order to optimise model run times.

Street canyon geometry data was calculated on a link-by-link basis using the ADMS-Urban street canyon parameter calculation tool using OS Mastermap building footprint and height data as inputs. The advanced canyon module considers canyon asymmetry and porosity in addition to building location and average canyon height in order to represent the effects of street canyons on pollutant concentrations more accurately, both within canyons, and at urban background locations.

[3] https://www.ordnancesurvey.co.uk/business-and-government/products/os-open-roads.html

5.1.2 Emission factors

Traffic emissions of NO_x, NO_2, PM_{10}, and VOCs were calculated from traffic flows using EMIT. In EMIT, emissions of traffic sources are calculated using emission factors based on 'Euro' vehicle emissions categories. In EMIT, a 'route type' consists of a set of specific traffic fleet composition data and an accompanying set of emission factors. National projections, represented by the 'NAEI 2014 Urban Wales' route type, were used for the relevant years.

The NAEI 2014 emission factors include speed-emissions data for NO_x based on the COPERT 4 version 10 tool, including primary NO_2 emission factors for each vehicle type resulting in accurate road-by-road NO_x and NO_2 emission rates. Note that there is large uncertainty surrounding the current emissions estimates of NO_x from all vehicle types, in particular diesel vehicles, in these factors; refer to for example an AQEG report from 2007[4] and a Defra report from 2011[5]. In order to address this discrepancy, the NO_x emission factors were modified based on recently published Remote Sensing Data (RSD)[6] for vehicle NO_x emissions. Scaling factors were applied to each vehicle category and Euro standard.

Concentrations of PM_{10} and $PM_{2.5}$ at roadside locations are affected by brake, tyre and road-wear, and concentrations of PM_{10} are also affected by resuspension. These non-exhaust road traffic emissions were calculated in EMIT 3.4 on a road-by-road basis using the traffic flows and speeds described in Sections 6.1.2 and 6.1.3. Brake, tyre and road-wear emissions were calculated using emission factors in the 2009 EMEP/EEA emissions inventory guidebook[7], and scaled using empirically-derived factors used in the London Atmospheric Emissions Inventory (LAEI) 2013. Resuspension emission factors were taken from a report produced by TRL Limited on behalf of Defra[8].

5.1.3 Traffic flows

For all major roads in the area, yearly traffic flow data published by the DfT was used. These data were supplemented by automatic and manual traffic count data from a series of traffic surveys carried out by Cardiff City Council where available.

At junctions, traffic was calculated by assuming that traffic was evenly split between the different forks of the road. The roads included explicitly in the emissions inventory are shown in Figure 5.1.

[4] Trends in primary nitrogen dioxide in the UK
[5] Trends in NOx and NO2 emissions and ambient measurements in the UK
[6] Carslaw, D and Rhys-Tyler, G 2013: New insights from comprehensive on-road measurements of NO_x, NO_2 and NH_3 from vehicle emission remote sensing in London, UK. *Atmos. Env.* **81** pp 339–347.
[7] EMEP/EEA air pollutant emissions inventory guidebook – 2009 Technical report no. 9/2009 http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009
[8] Road vehicle non-exhaust particulate matter: final report on emission modelling, TRL Limited Project Report PPR110 http://uk-air.defra.gov.uk/reports/cat15/0706061624_Report2__Emission_modelling.PDF

In EMIT, traffic flows can be input in either 3 vehicle categories, or 11 vehicle categories. The DfT traffic counts use the 11 vehicle categories, while the Cardiff City Council traffic counts included varying levels of detail. The measured datasets were processed in order to generate a single set of traffic flows for each link with traffic split into the 11 vehicle categories; where the measured traffic count data did not include this level of detail, the average vehicle split in the DfT traffic counts was used to calculate the missing categories.

For large roundabouts where no link data were available, link traffic flows were calculated by assuming that traffic flowing into the roundabout from each link flowed out of the roundabout in proportion to the total traffic flow on each link.

For roads where traffic was taken from manual traffic counts, speed data from these counts was used in the modelling. For roads using traffic flows from the DfT, national average traffic flow speeds, also published by the DfT[9], were used. Average free flowing traffic speeds are provided for roads split by speed limit, road type and vehicle category. The average speed for all vehicle types was used.

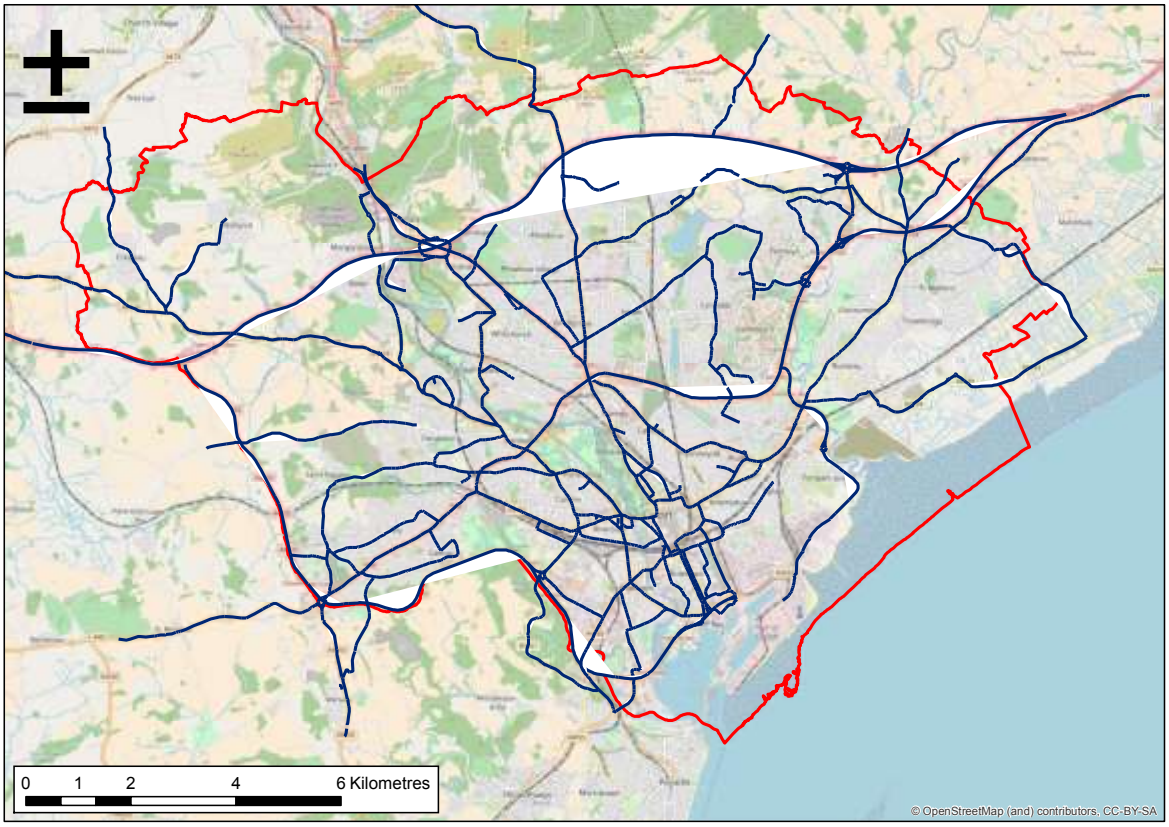


Figure 5.1: Major roads modelled for all years

[9] https://www.gov.uk/government/publications/free-flow-vehicle-speeds-in-great-britain-2012

5.1.4 Speed

No speed data were available on a link-by-link basis for this study. Therefore, average free-flowing traffic speeds categorised by road type published by the DfT[10] were used. Speeds are provided by road type and vehicle type; the average speed for all vehicle types was used. Traffic speeds within 75m of junctions and on roundabout links were reduced to 20km/h in order to represent slowing traffic and queuing.

5.1.5 Minor Roads

Total traffic volume by local authority is published by StatsWales[11]. The total explicitly modelled road traffic volume across the borough, generated as described in Section 5.1.3, was subtracted from the total traffic volume across the borough, and the remaining traffic volume apportioned across a 1km grid over the borough using road density data as the distribution key. Emissions were calculated using a minor road traffic speed of 37 km/h. Figure 5.2 shows the minor roads NO_x emissions calculated for 2014 for illustrative purposes. These emissions were modelled as a 1-km passive grid source in ADMS-Urban.

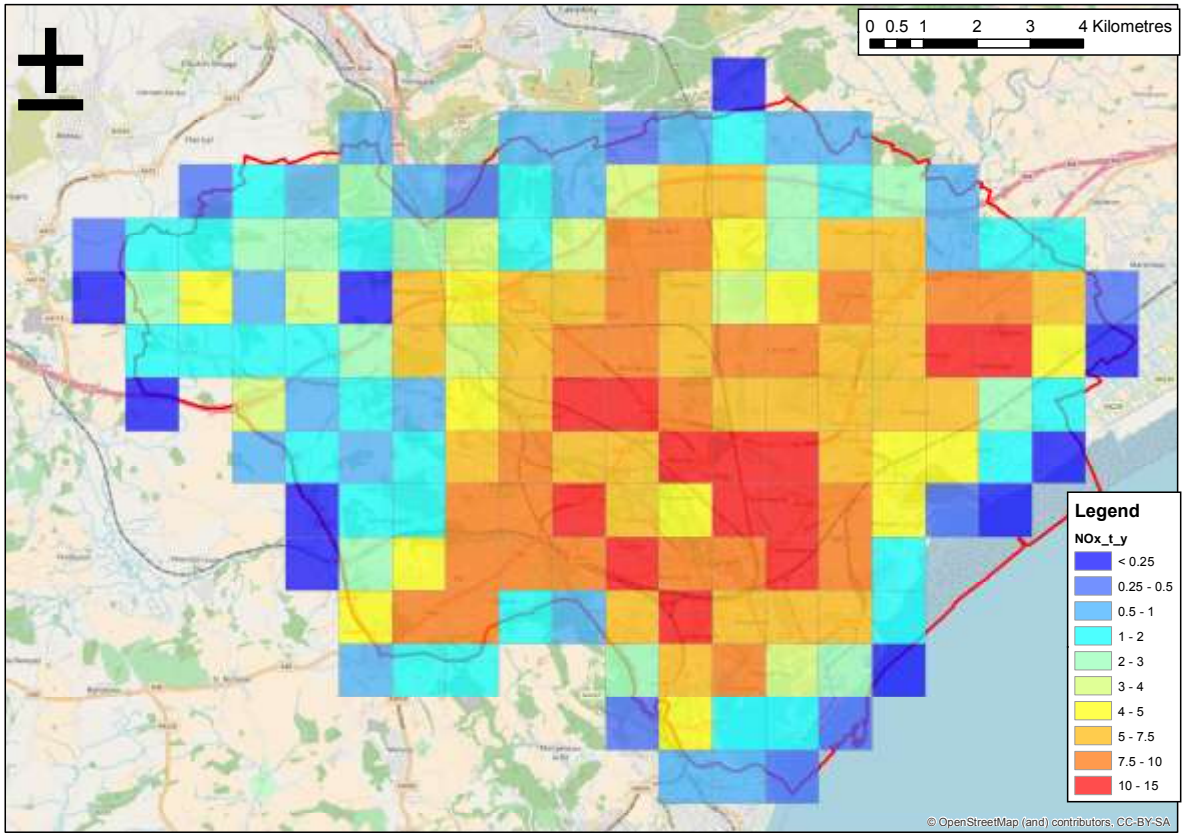


Figure 5.2: Minor roads NOx emissions, tonnes per year, 2014

[10] https://www.gov.uk/government/statistics/free-flow-vehicle-speeds-in-great-britain-2015
[11] https://statswales.gov.wales/Catalogue/Transport/Roads/Road-Traffic/volumeofroadtraffic-by-localauthority-year

5.1.6 Time-varying emissions profiles

The variation of traffic flow during the day was taken into account by applying a set of diurnal profiles to the road emissions. National average diurnal profiles, published by the DfT, were used.[12] These profiles are shown in Figure 5.3. These profiles were applied to all major roads in the modelling area and grid sources, representing emissions of minor roads, and other emissions, aggregated on 1-km square basis, described in Section 6.2.

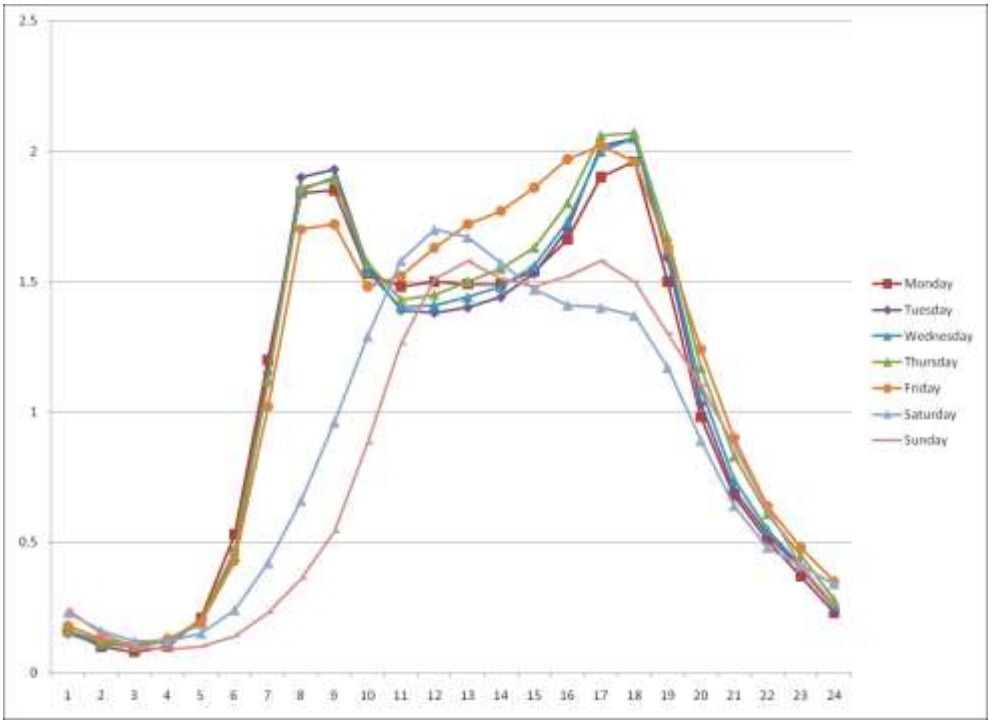


Figure 5.3: Diurnal profiles used for roads and grid sources

5.2 Non-traffic emissions

5.2.1 Industrial sources

Emissions from industrial sources were modelled as point sources in ADMS-Urban, using height data derived estimated from aerial imagery, and average exit parameters adapted from the London Atmospheric Emissions Inventory (LAEI).

5.2.2 Other emissions

All non-traffic sources across Cardiff were represented as an aggregated 1km grid source in ADMS-Urban, using emissions from the National Atmospheric Emissions Inventory (NAEI) for the relevant years. Note that the most recent available year at the time of modelling was 2014; no projection was carried out for 2015, as emissions from non-road sources are likely to be fairly consistent between the two years.

[12] https://www.gov.uk/government/statistical-data-sets/tra03-motor-vehicle-flow

6 Model verification

The first stage of a modelling study is to model a current case in order to verify that the input data and model set-up are appropriate for the area by comparing measured and modelled concentrations for local monitoring locations. The monitor locations used for this purpose are described in Section 3. Note that diffusion tubes for which the nearest major road source were not modelled were not included in the verification; it is considered that the remaining coverage of sites provides a sufficiently robust verification methodology.

Table 6.1 presents modelled and monitored concentrations for NO_2 and PM_{10} at the Cardiff Centre automatic monitoring site for the years 2013 to 2015. Although the model underpredicts exceedences of the 50µg/m³ objective for PM_{10}, the annual average results match well, and the measured exceedences are well below the objective.

Table 6.1: Model verification results at the Cardiff City Centre automatic monitor

Pollutant and statistic	Measured			Modelled		
	2013	2014	2015	2013	2014	2015
NO_2 annual average (µg/m^3)	27.0	26.7	26.0	23.2	27.0	20.9
Exceedences of the 200µg/m^3 objective for hourly average NO_2	5	0	0	0	0	0
PM_{10} annual average (µg/m^3)	19	16	16	18	18	15
Exceedences of the 50µg/m^3 objective for 24-hourly average PM_{10}	3	4	5	4	1	1

Figures 6.1 to 6.5 present monitored and modelled annual average NO_2 concentrations at the diffusion tube monitoring sites and at the Cardiff Centre automatic monitor for the years 2011 to 2015. The modelled annual average NO_2 concentrations show good agreement with monitored concentrations across all sites for all years. Full verification results are presented in Appendix B.

The verification indicates that the model set-up and emissions are suitable for the situation considered and lends confidence to the predictions of future concentrations.

Figure 6.1: Measured and modelled annual average NO_2 concentrations, 2011

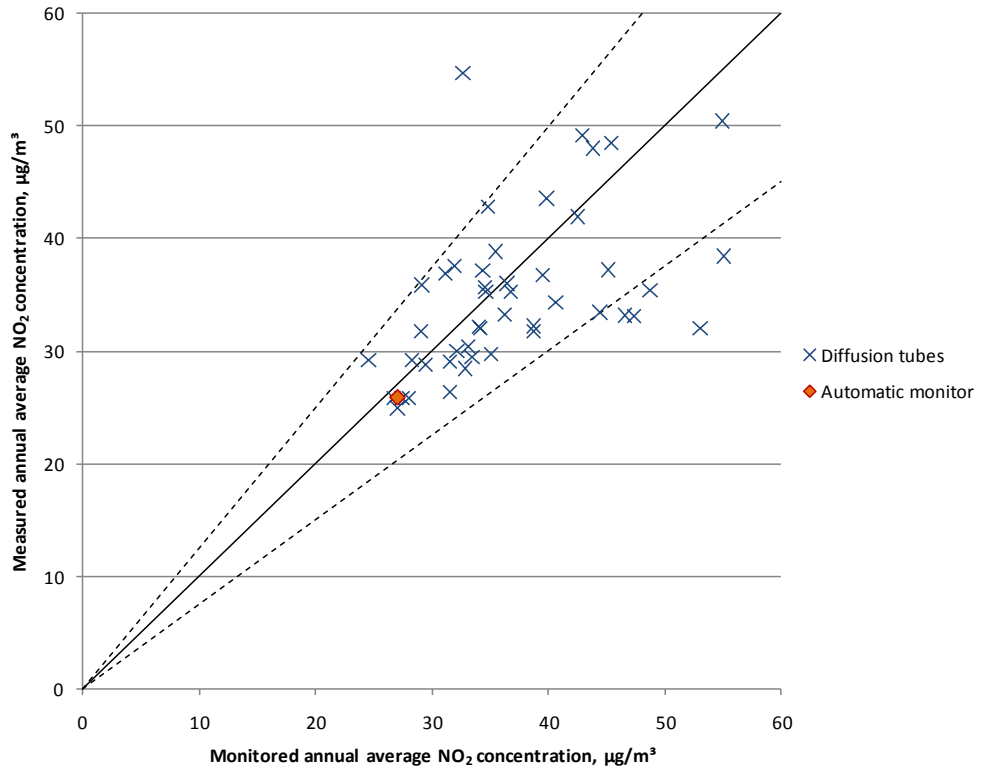


Figure 6.2: Measured and modelled annual average NO_2 concentrations, 2012

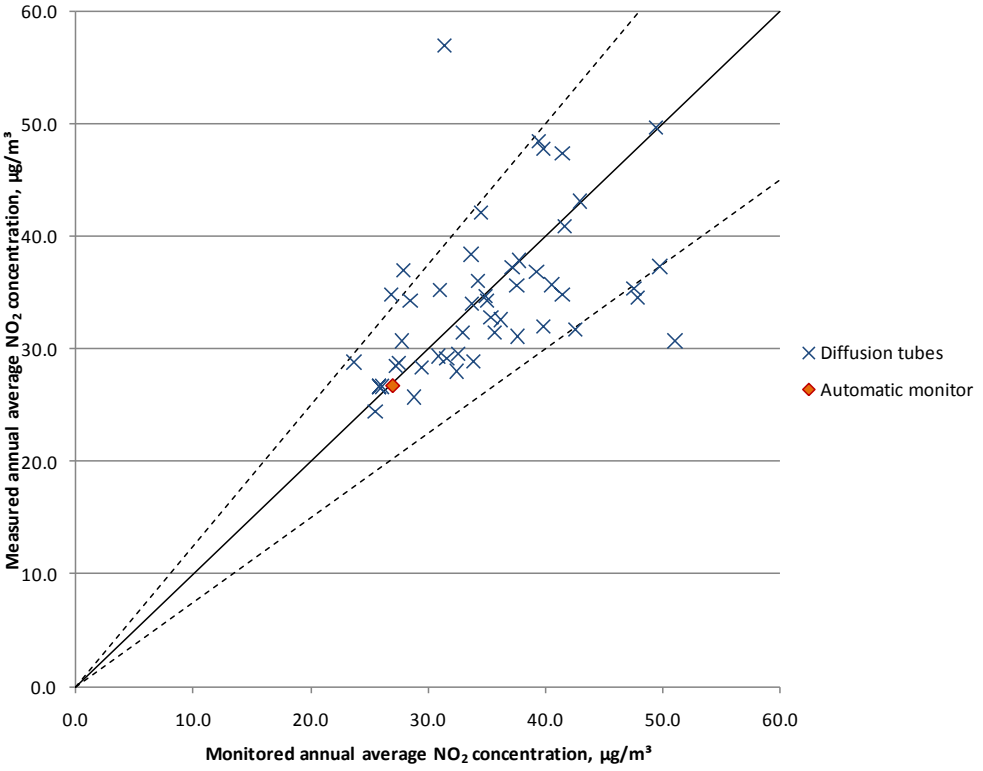


Figure 6.3: Measured and modelled annual average NO_2 concentrations, 2013

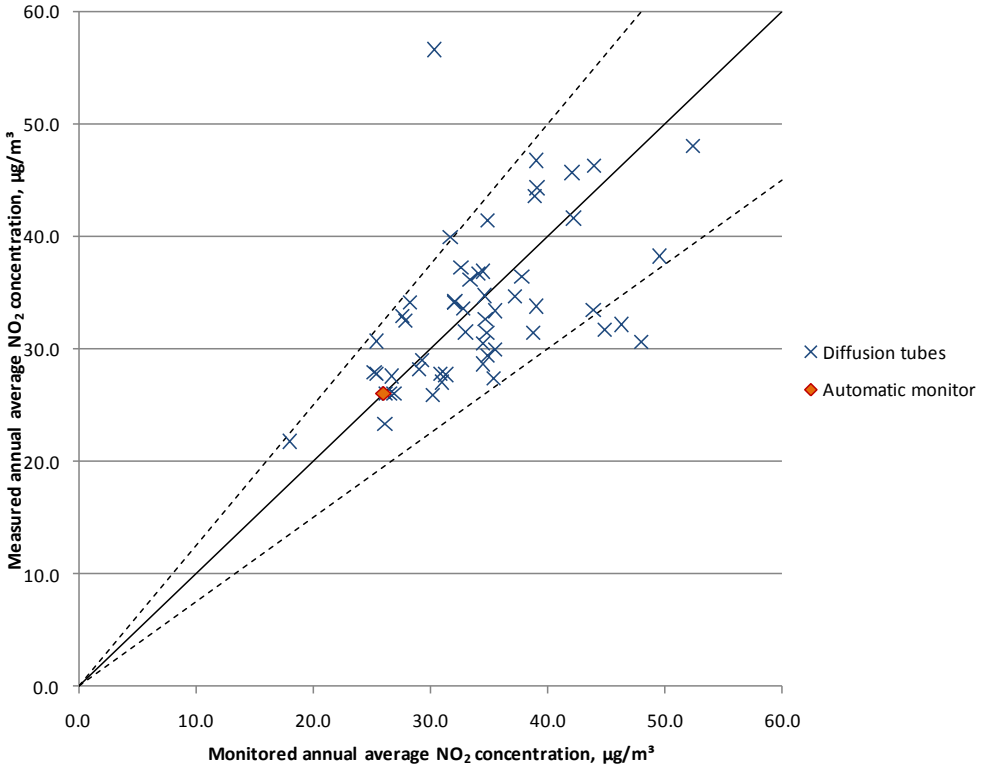


Figure 6.4: Measured and modelled annual average NO_2 concentrations, 2014

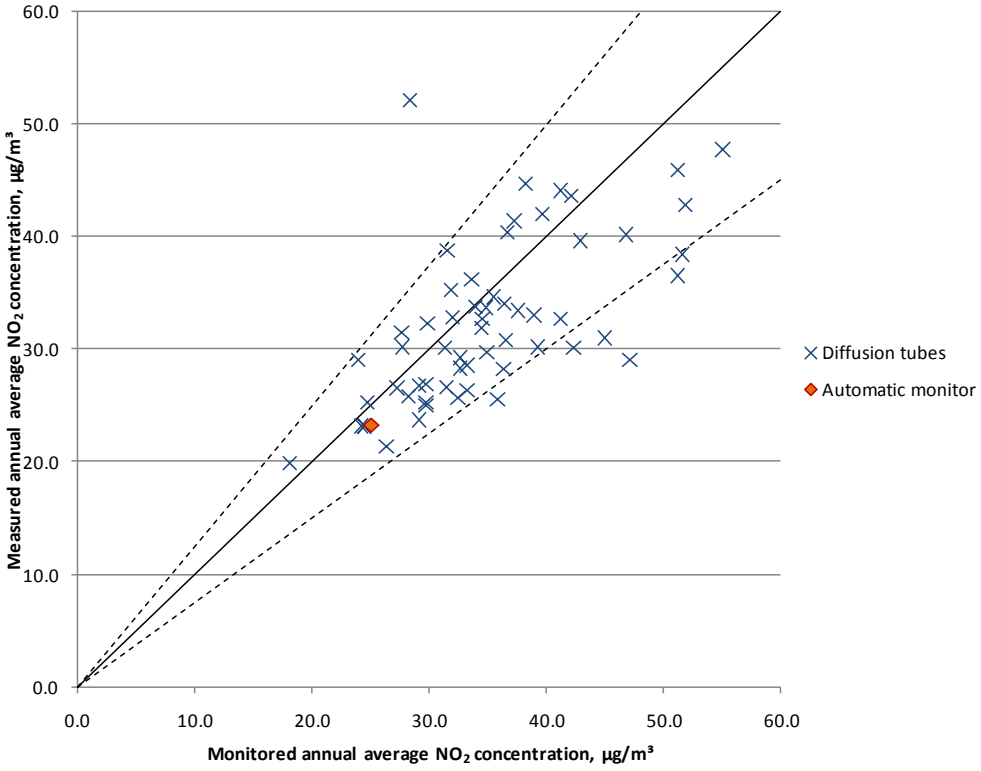
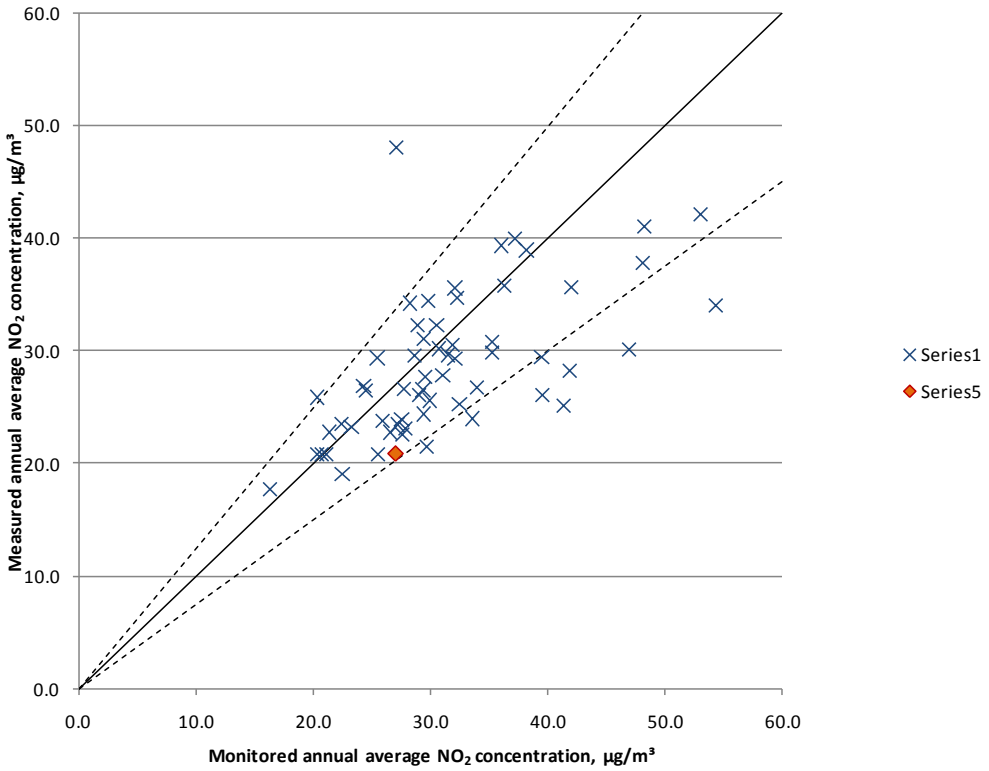


Figure 6.5: Measured and modelled annual average NO_2 concentrations, 2015



7 Contour plots

In this section, contour plots of annual average concentrations of NO_2, PM_{10}, $PM_{2.5}$ and O_3 are presented, for each of the ten years 2006 to 2015 inclusive.

7.1 NO_2

Figure 7.1: Annual average NO_2 concentration, 2006

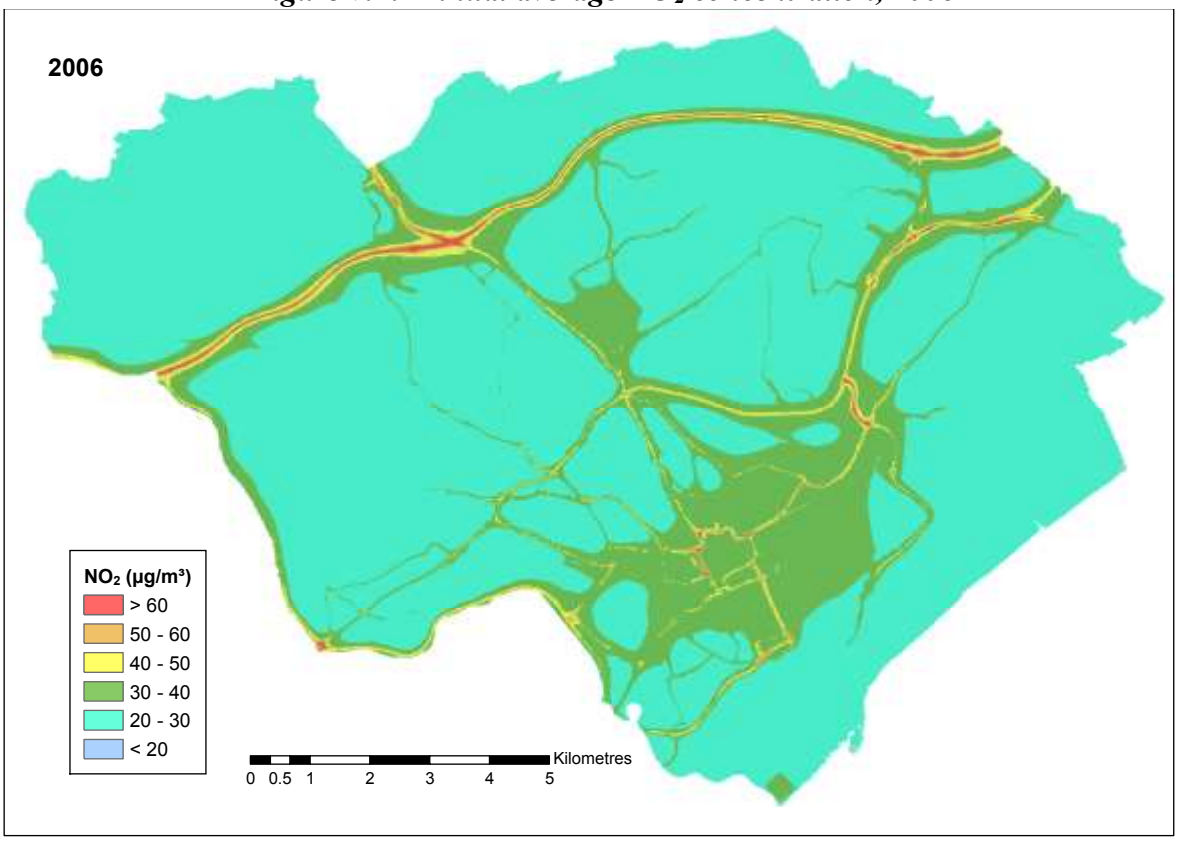


Figure 7.2: Annual average NO_2 concentration, 2007

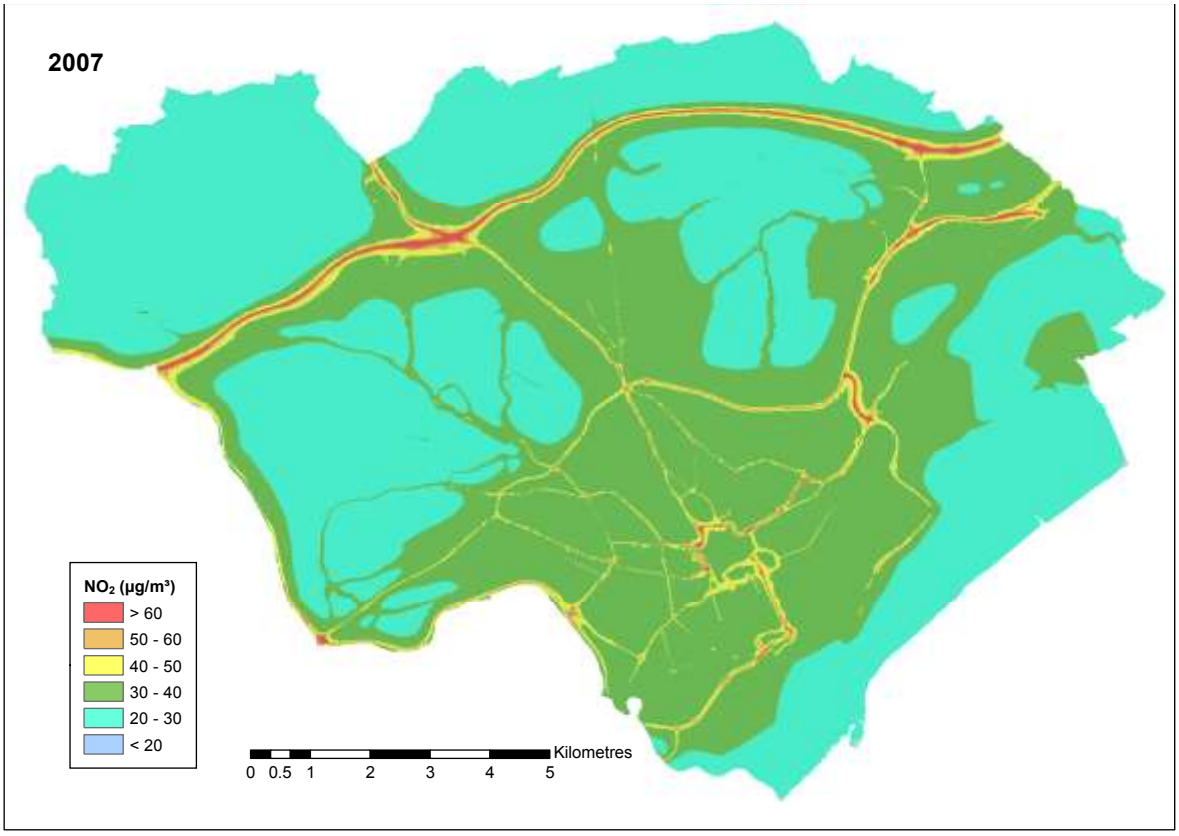


Figure 7.3: Annual average NO_2 concentration, 2008

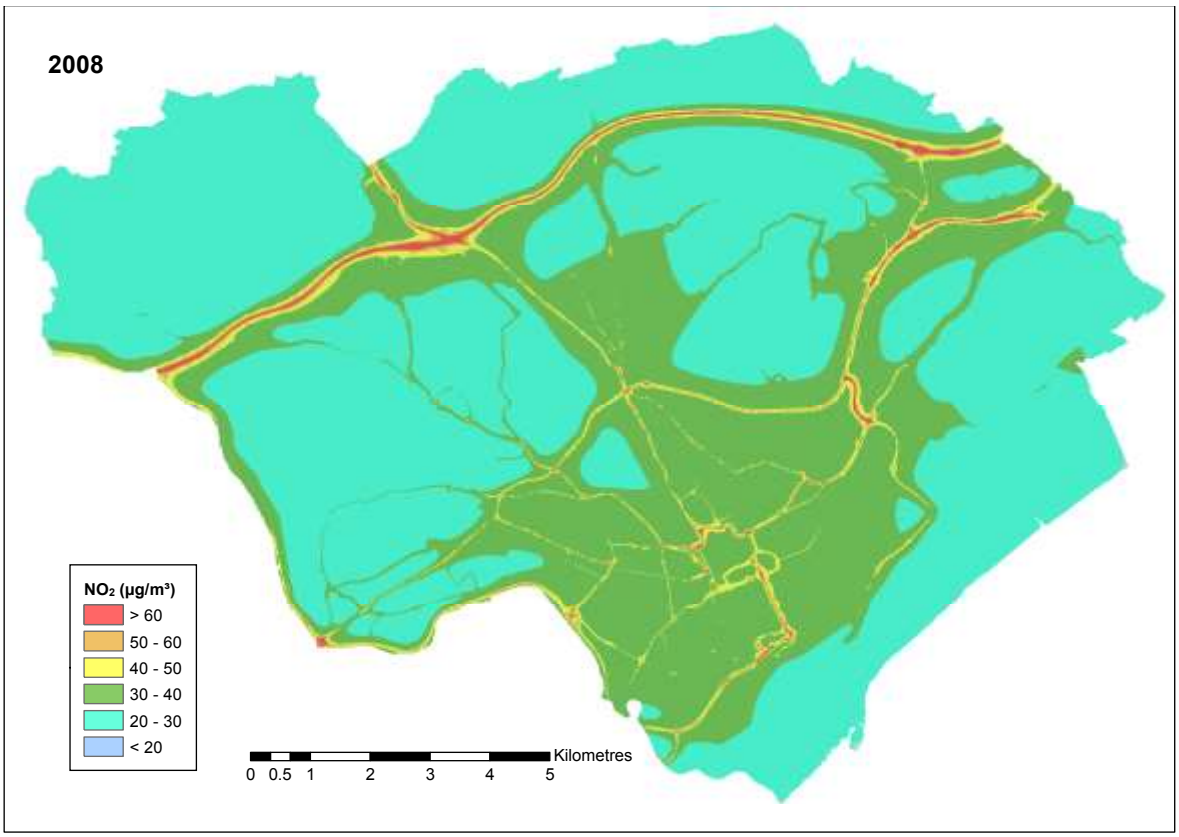


Figure 7.4: Annual average NO_2 concentration, 2009

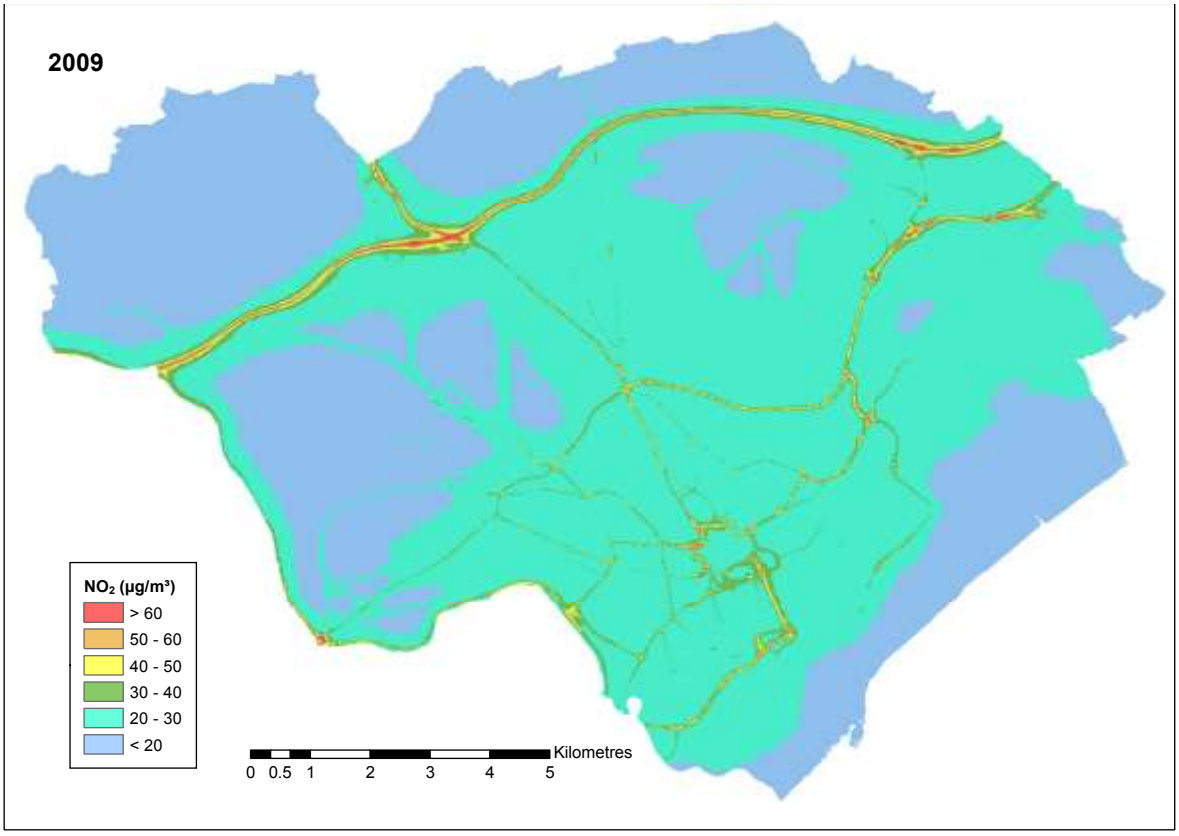


Figure 7.5: Annual average NO_2 concentration, 2010

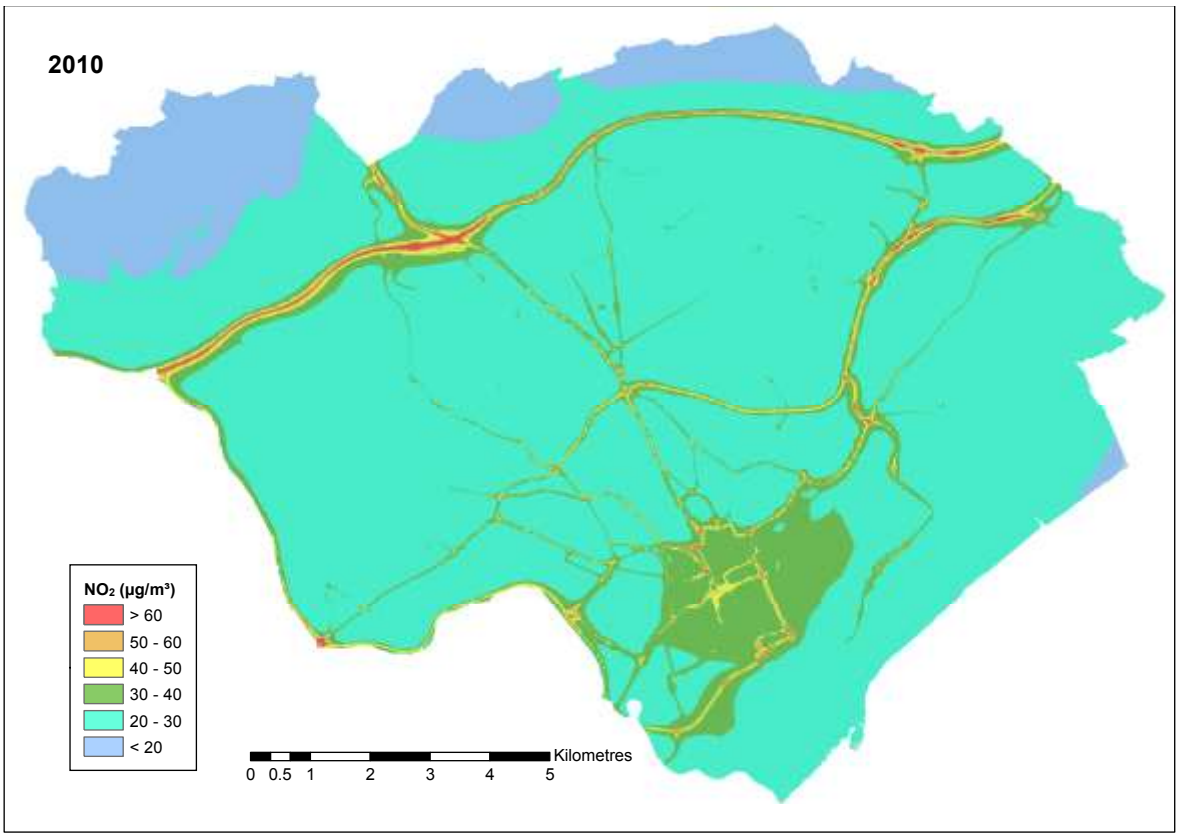


Figure 7.6: Annual average NO_2 concentration, 2011

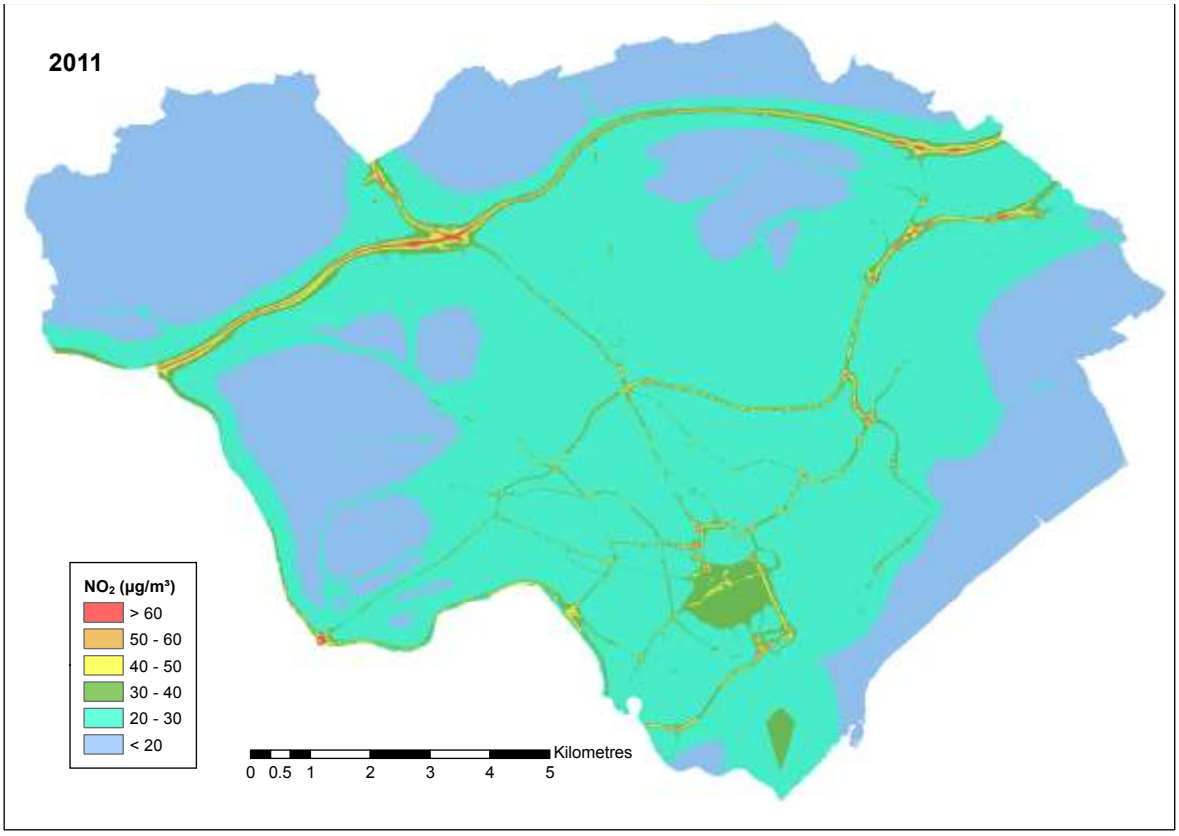


Figure 7.7: Annual average NO_2 concentration, 2012

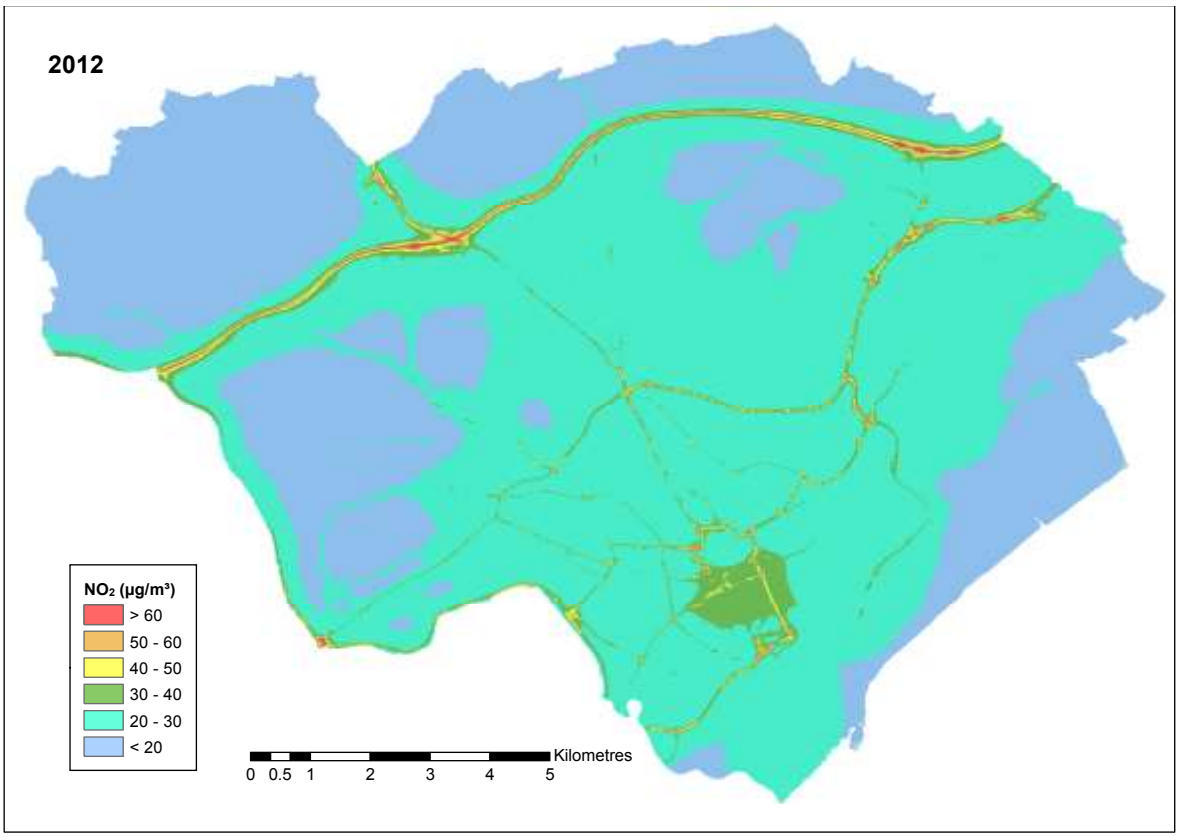


Figure 7.8: Annual average NO_2 concentration, 2013

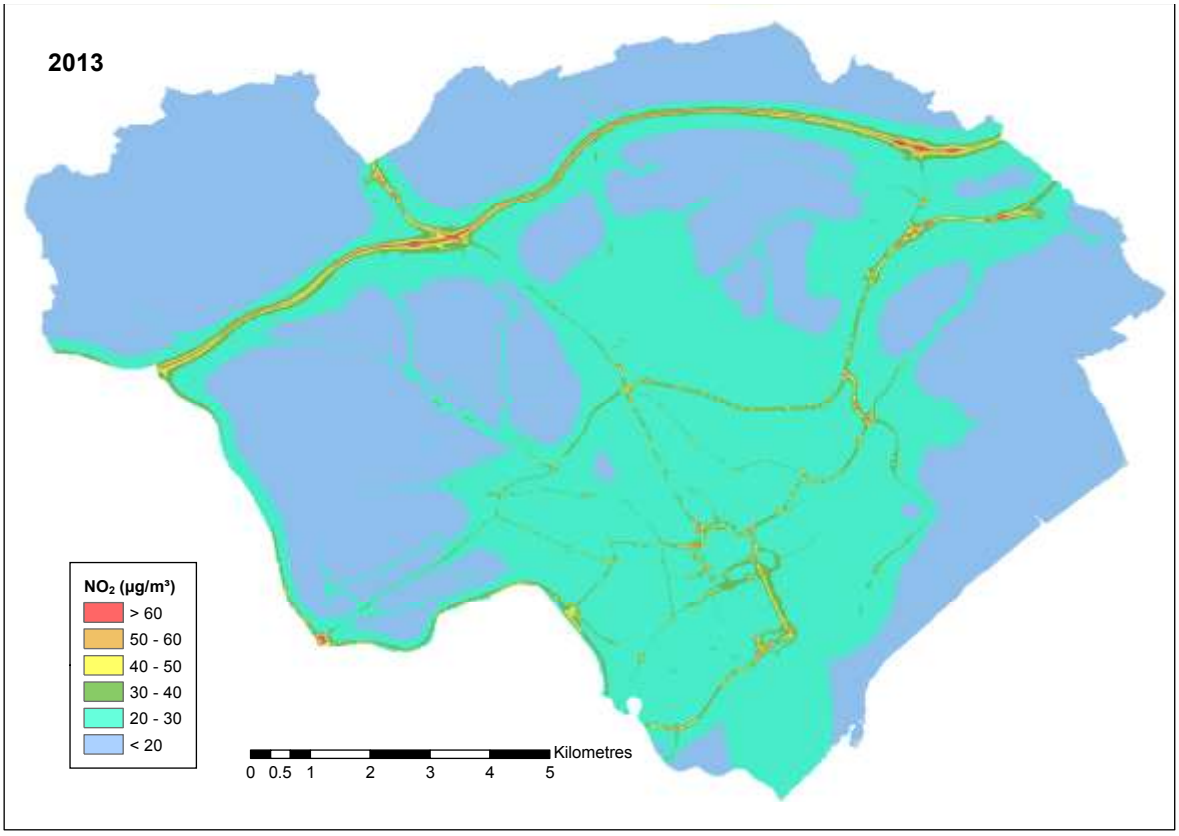


Figure 7.9: Annual average NO_2 concentration, 2014

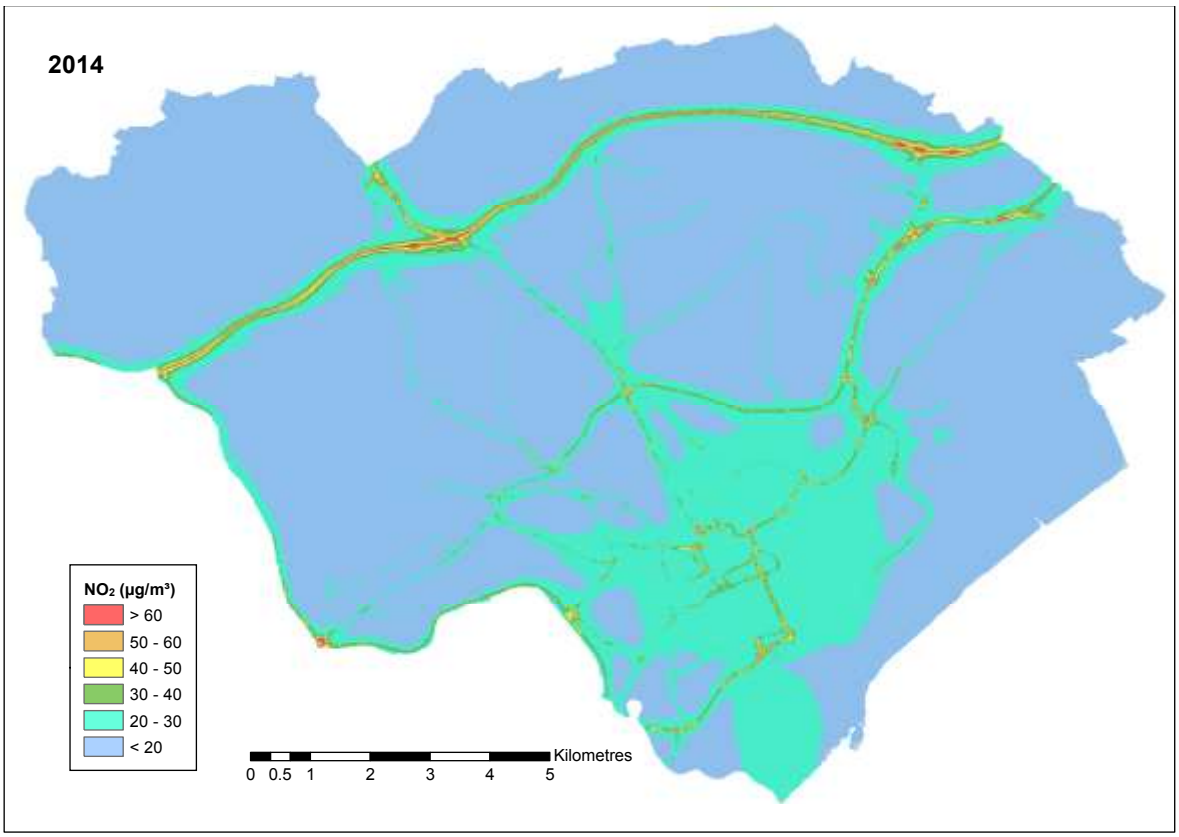
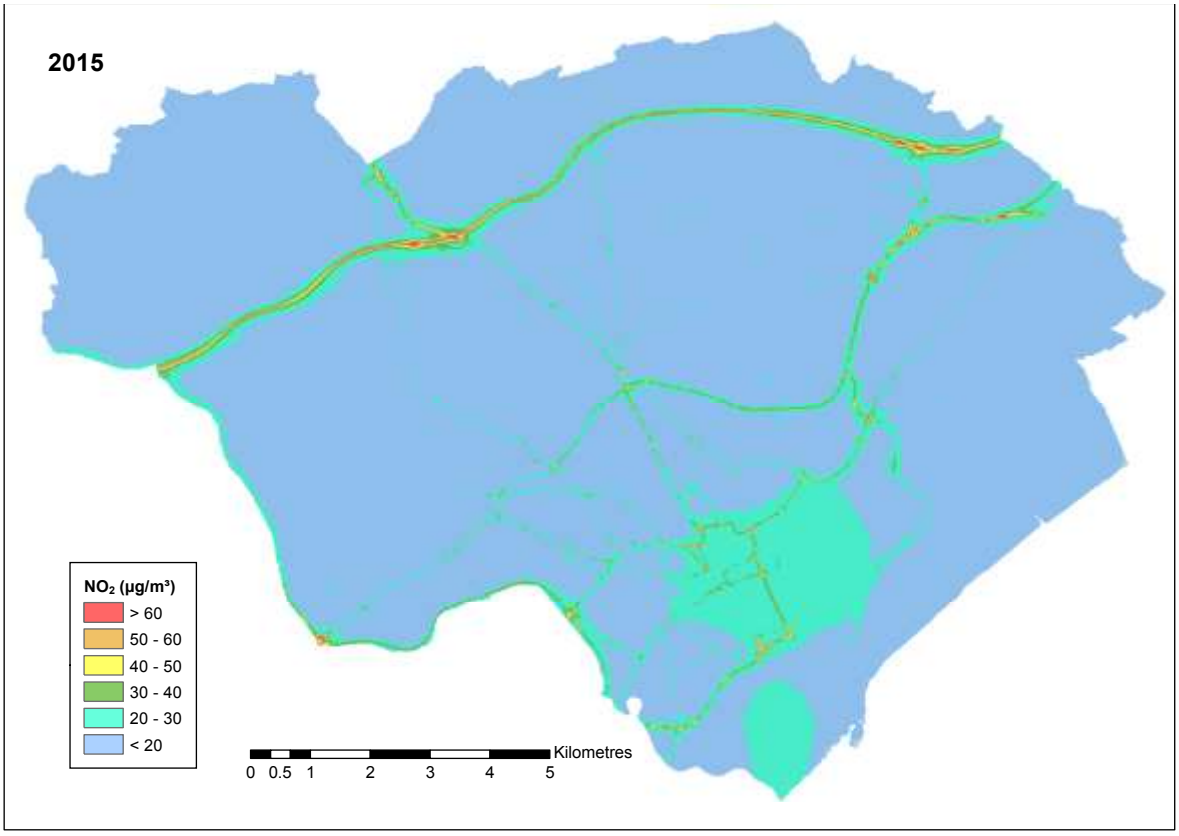


Figure 7.10: Annual average NO_2 concentration, 2015



7.2 PM_{10}

Figure 7.11: Annual average PM_{10} concentration, 2006

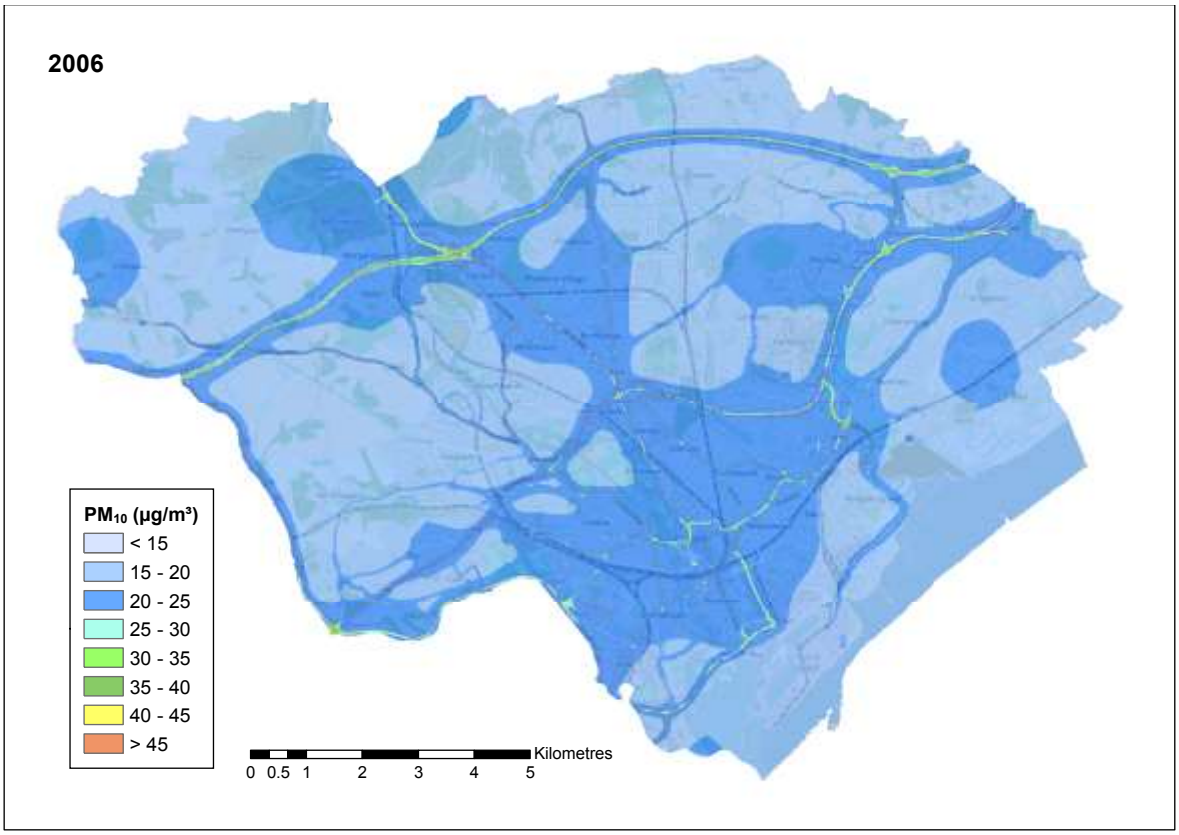


Figure 7.12: Annual average PM_{10} concentration, 2007

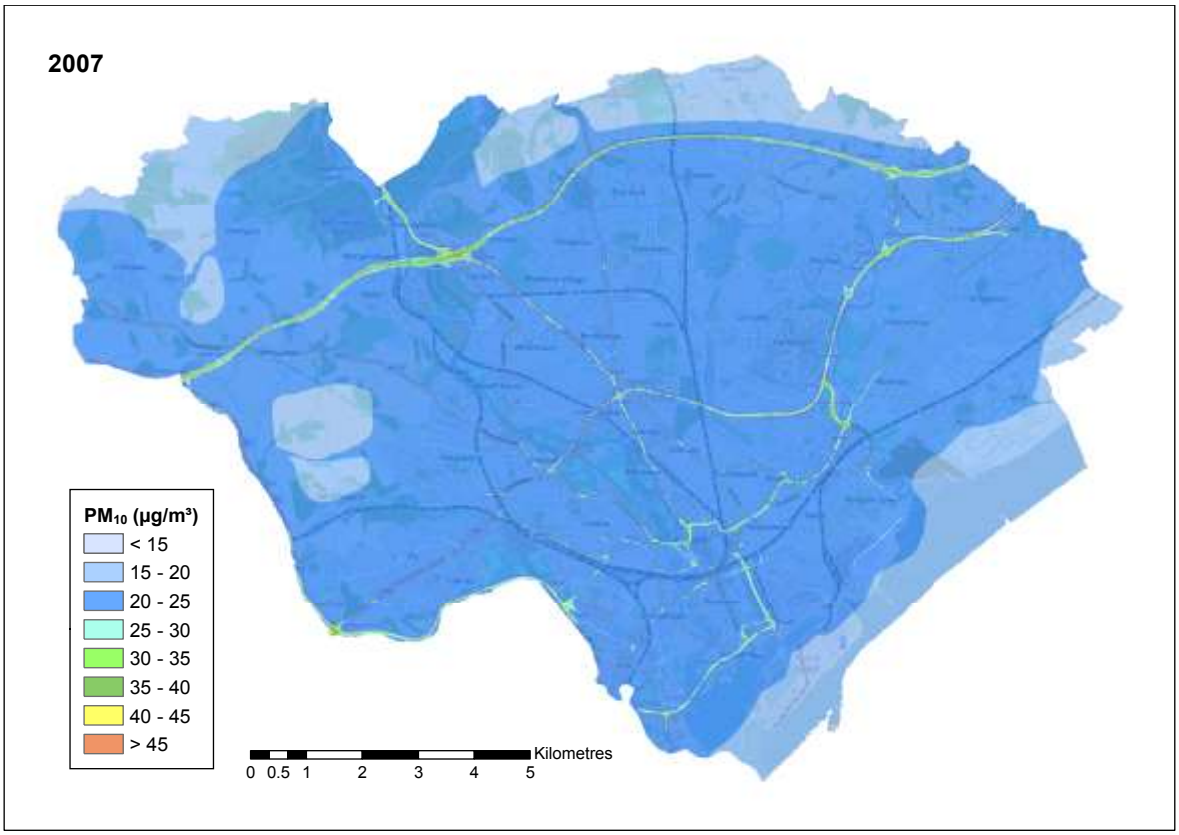


Figure 7.13: Annual average PM_{10} concentration, 2008

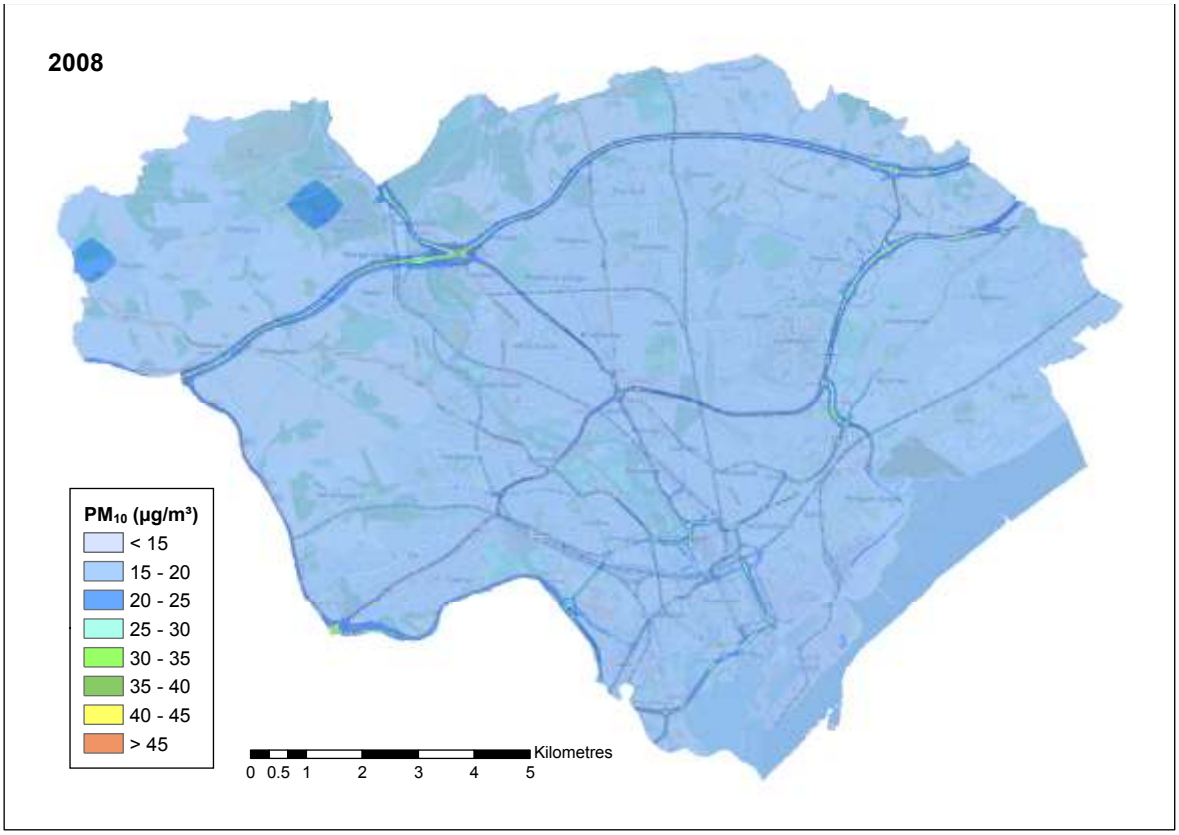


Figure 7.14: Annual average PM_{10} concentration, 2009

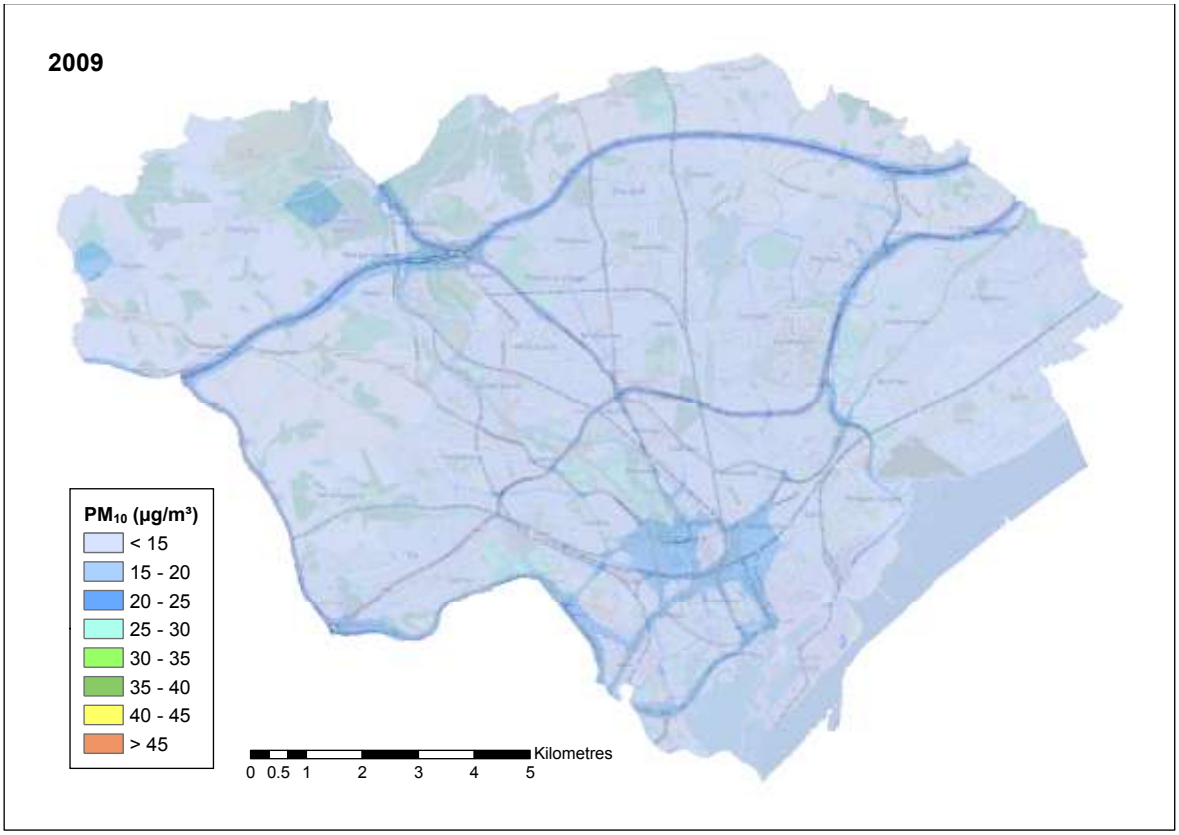


Figure 7.15: Annual average PM_{10} concentration, 2010

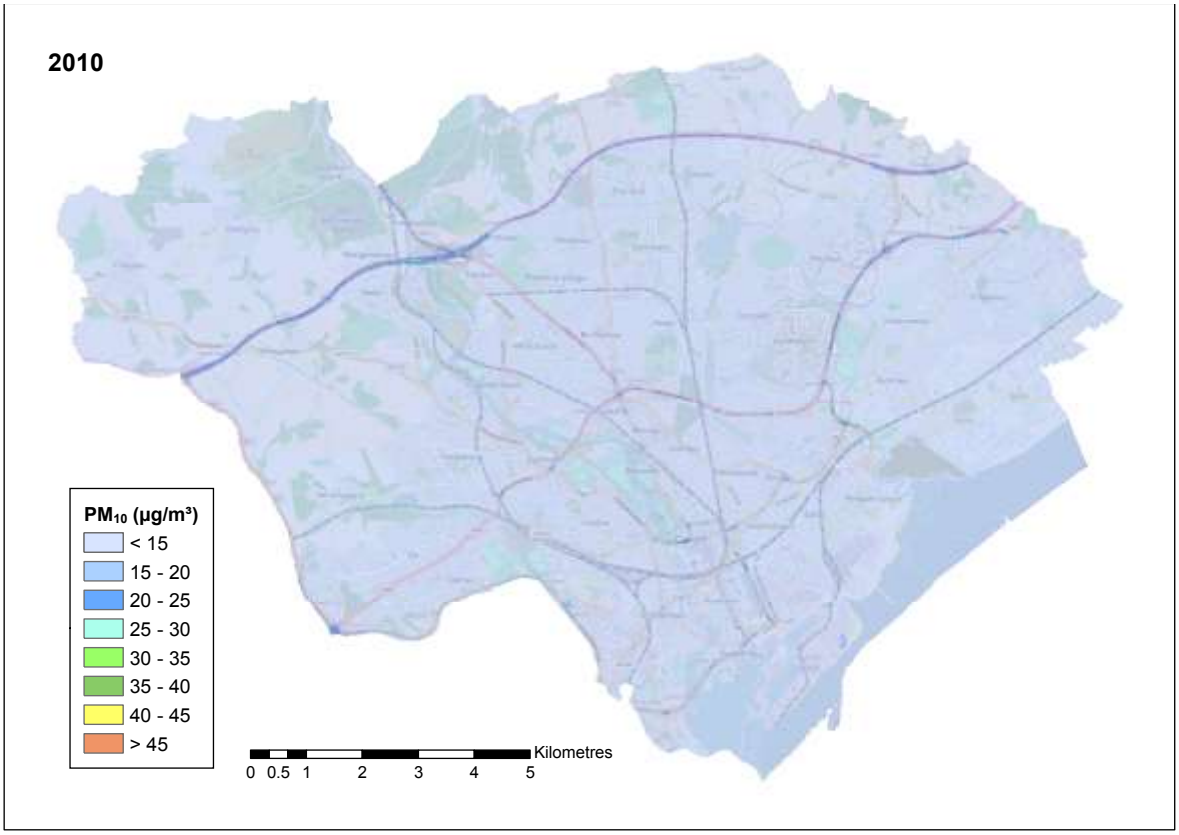


Figure 7.16: Annual average PM_{10} concentration, 2011

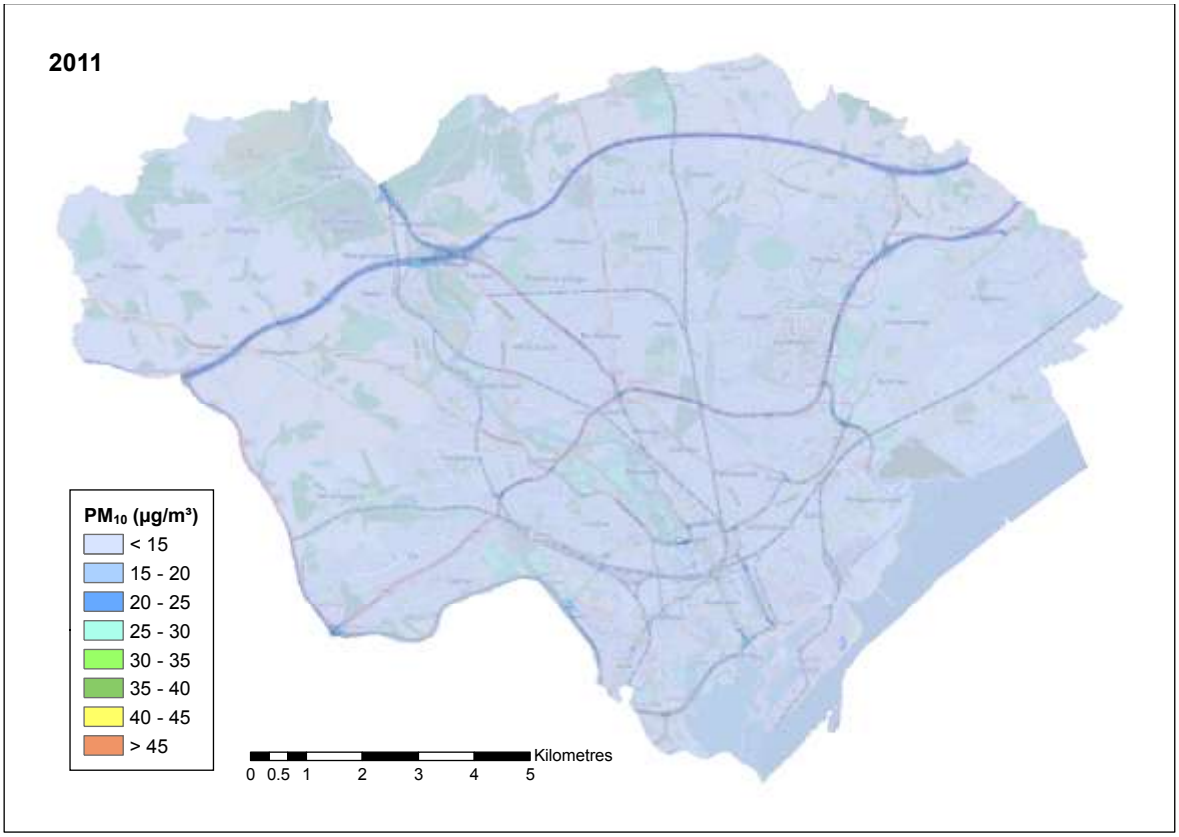


Figure 7.17: Annual average PM_{10} concentration, 2012

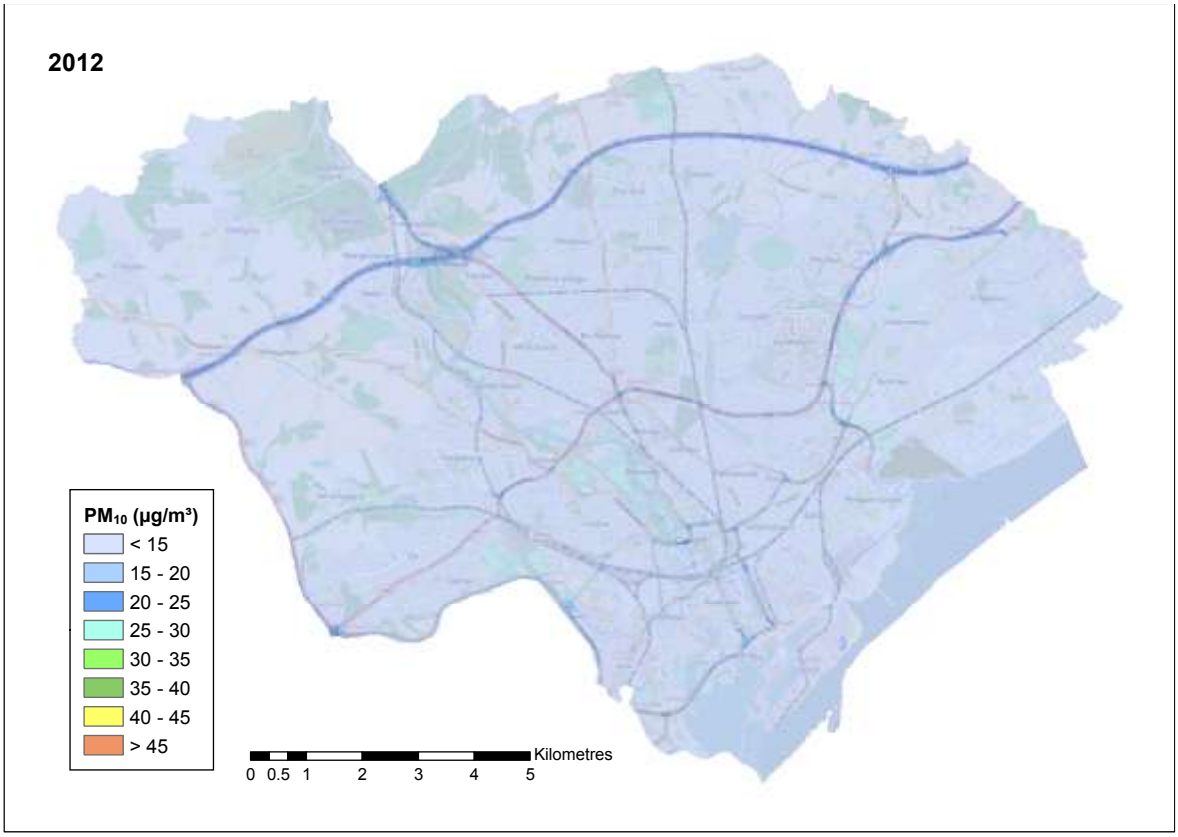


Figure 7.18: Annual average PM_{10} concentration, 2013

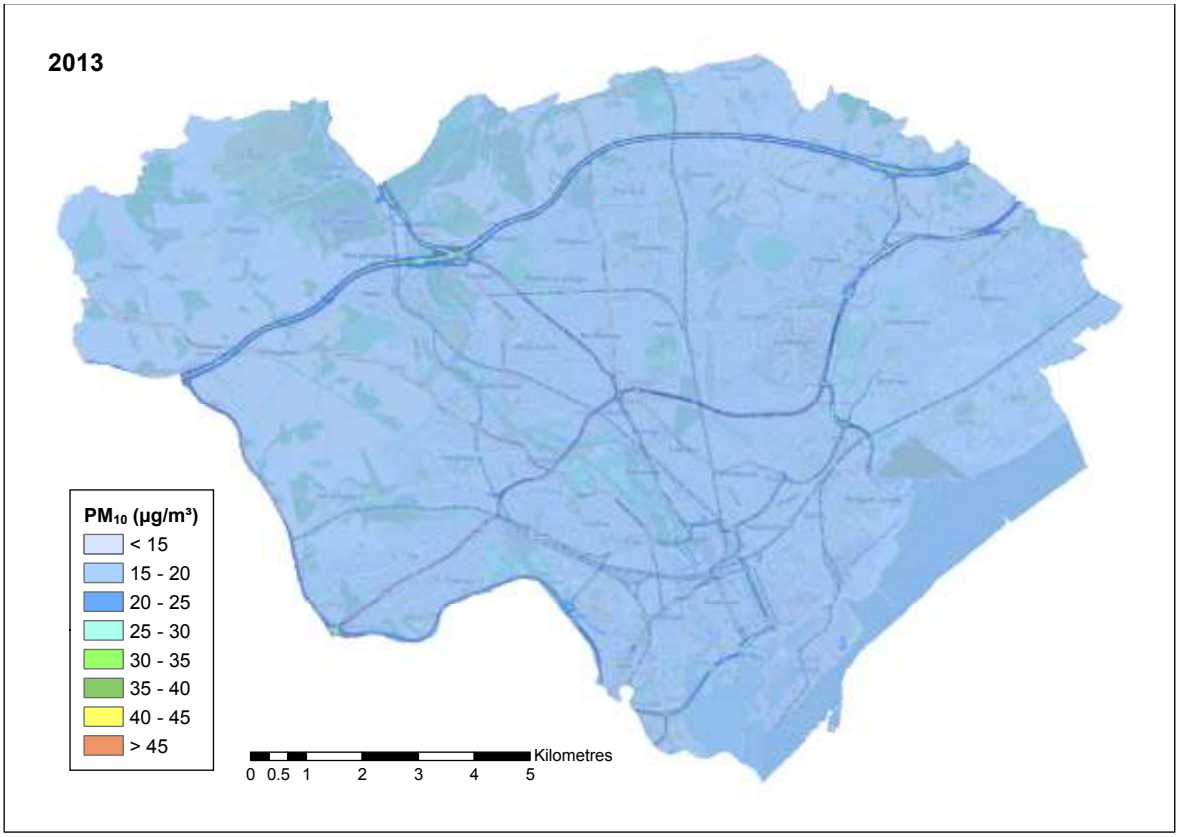


Figure 7.19: Annual average PM_{10} concentration, 2014

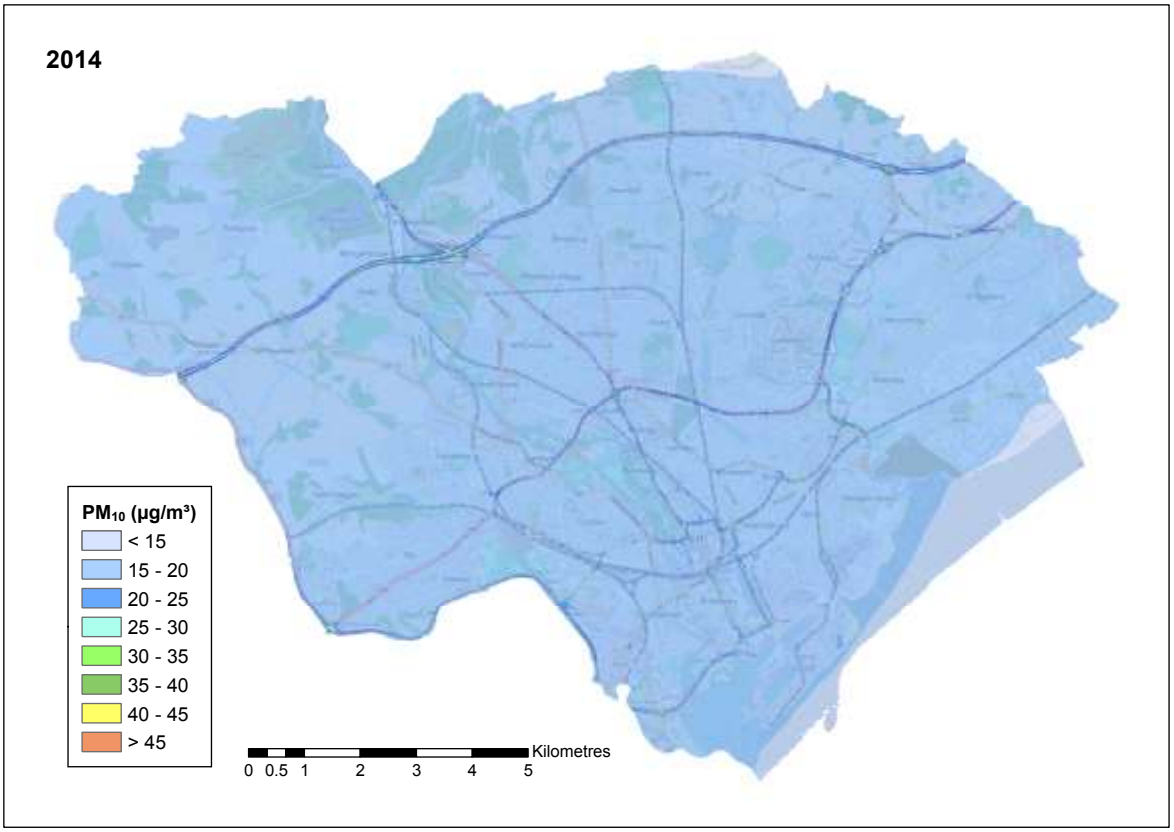
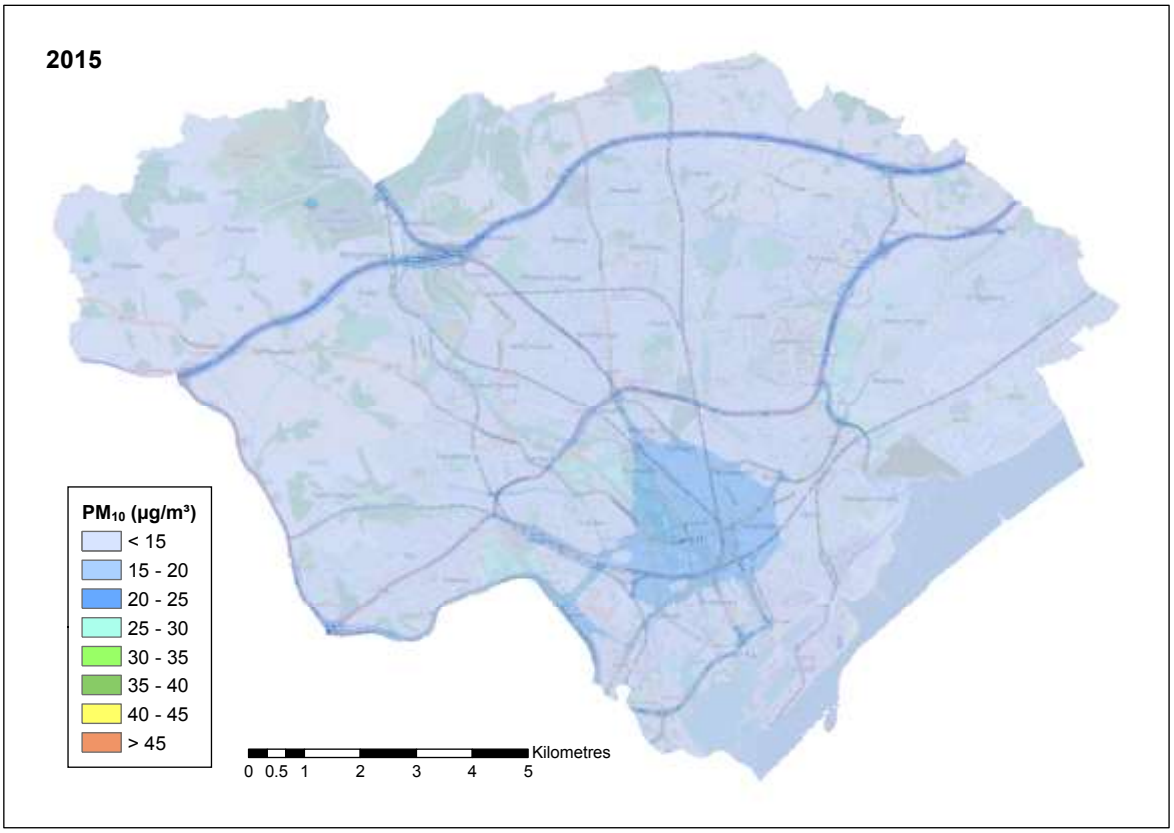


Figure 7.20: Annual average PM_{10} concentration, 2015



7.3 $PM_{2.5}$

Figure 7.21: Annual average $PM_{2.5}$ concentration, 2006

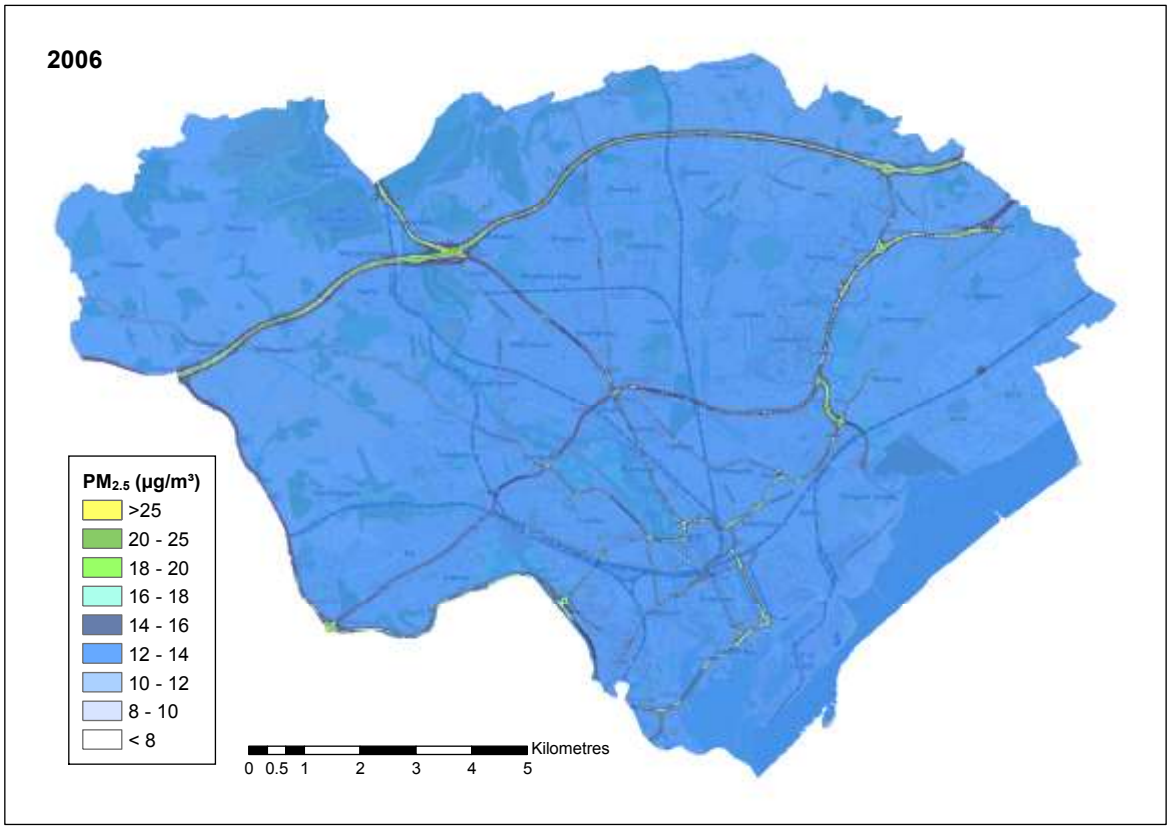


Figure 7.22: Annual average $PM_{2.5}$ concentration, 2007

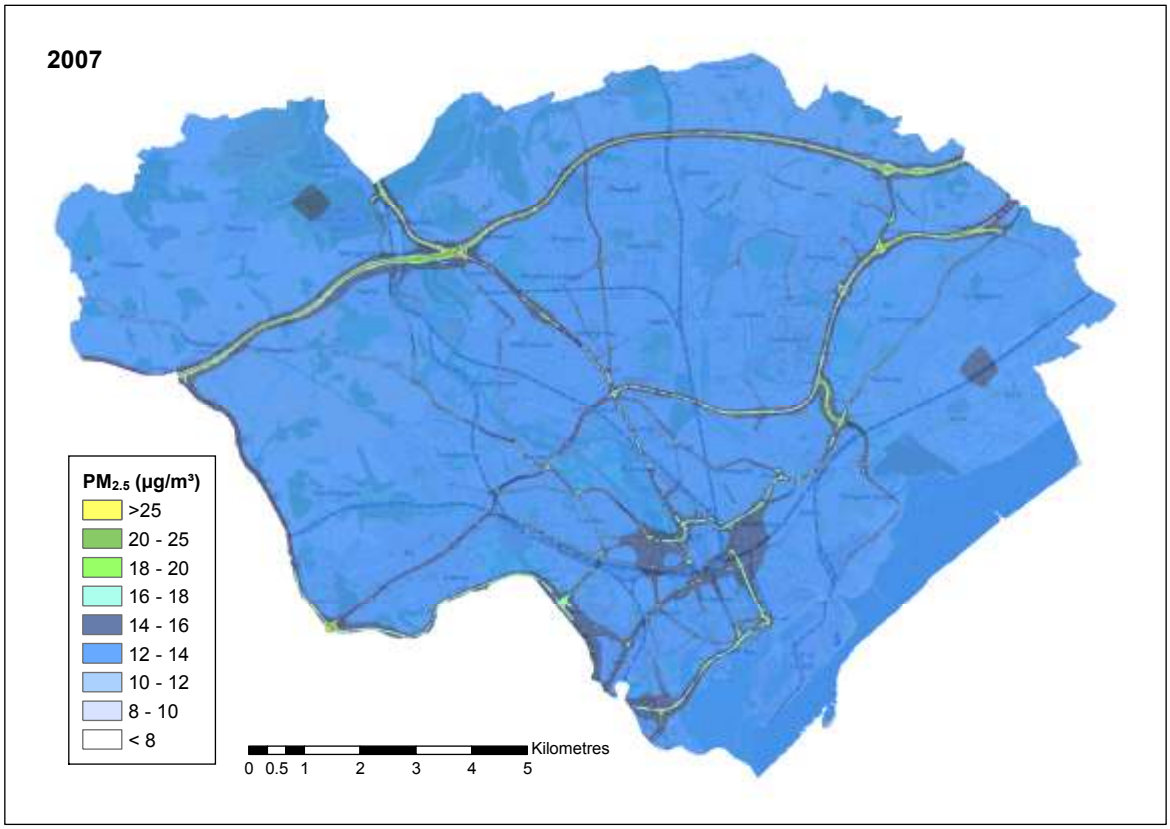


Figure 7.23: Annual average $PM_{2.5}$ concentration, 2008

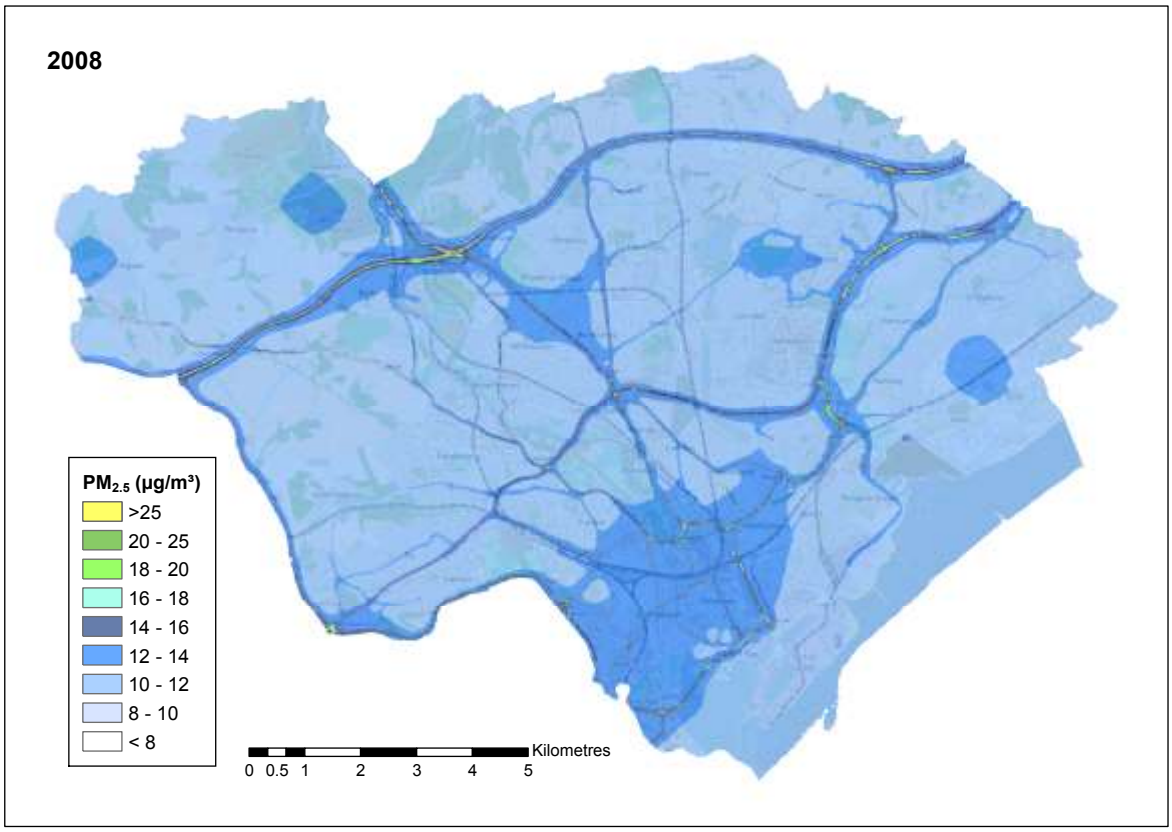


Figure 7.24: Annual average $PM_{2.5}$ concentration, 2009

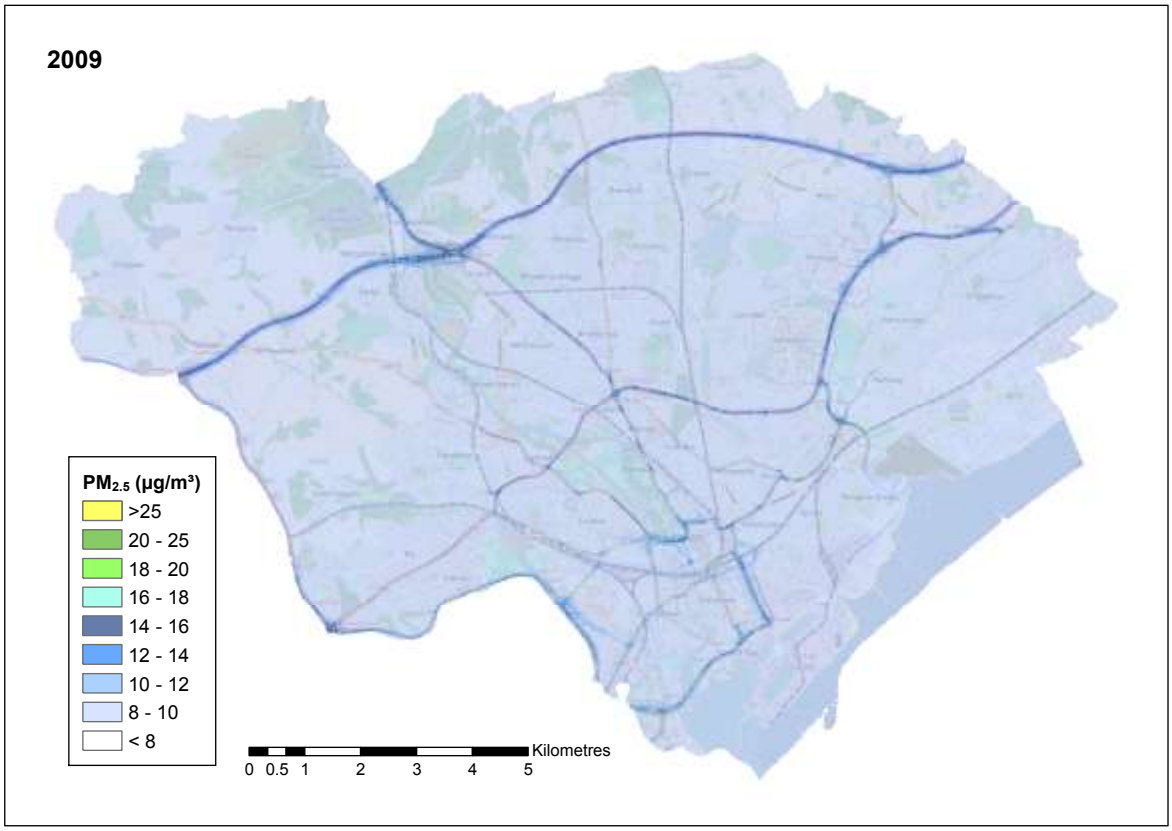


Figure 7.25: Annual average $PM_{2.5}$ concentration, 2010

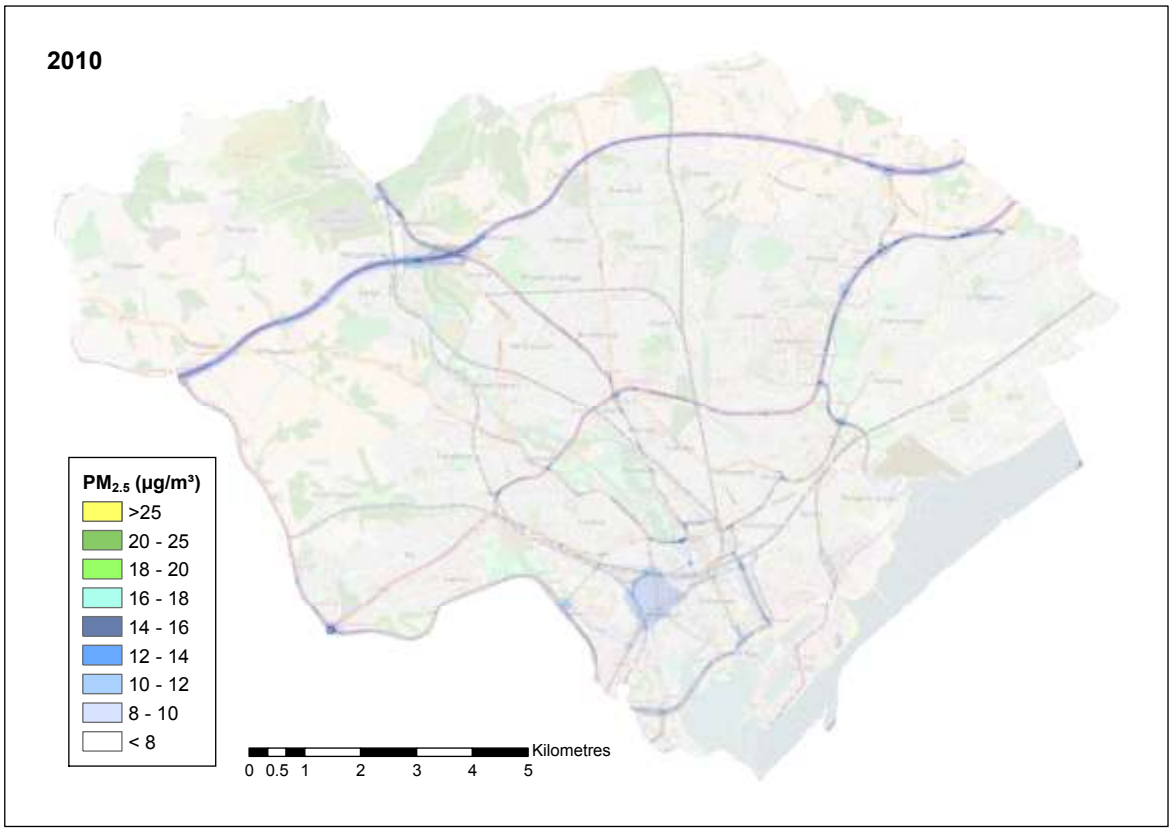


Figure 7.26: Annual average $PM_{2.5}$ concentration, 2011

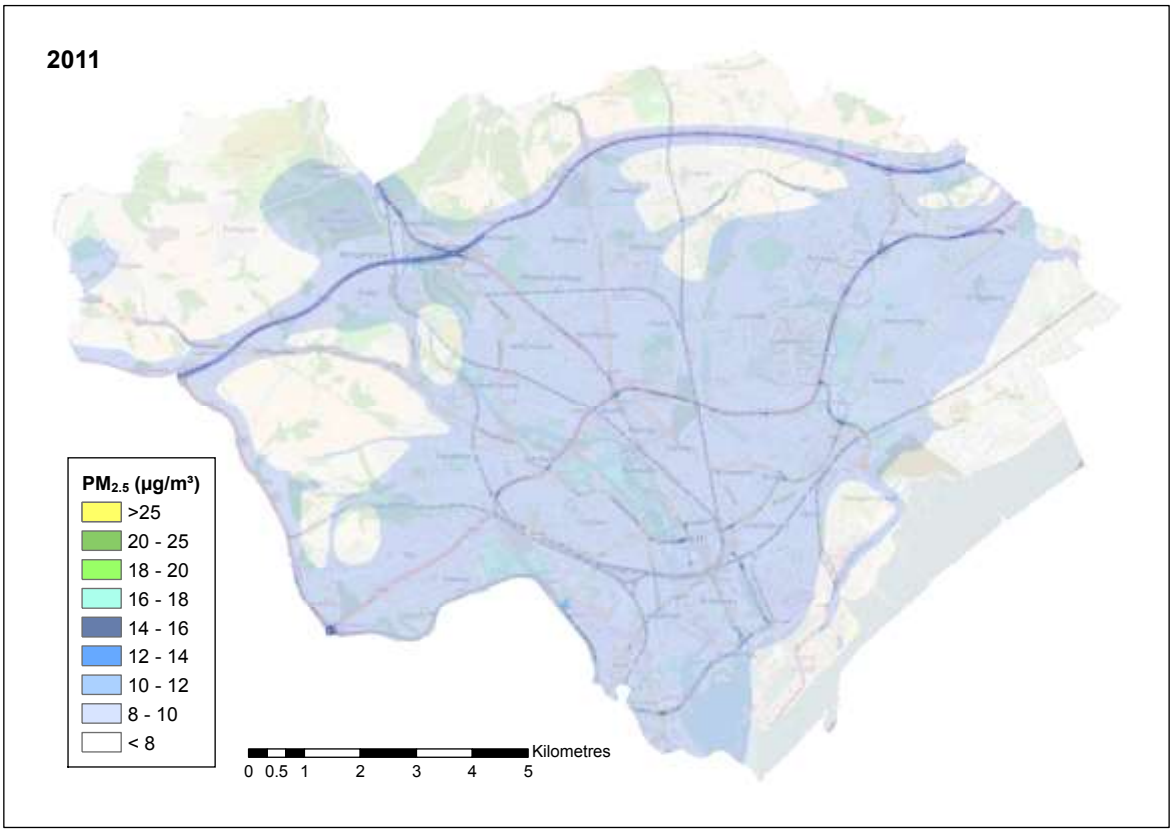


Figure 7.27: Annual average $PM_{2.5}$ concentration, 2012

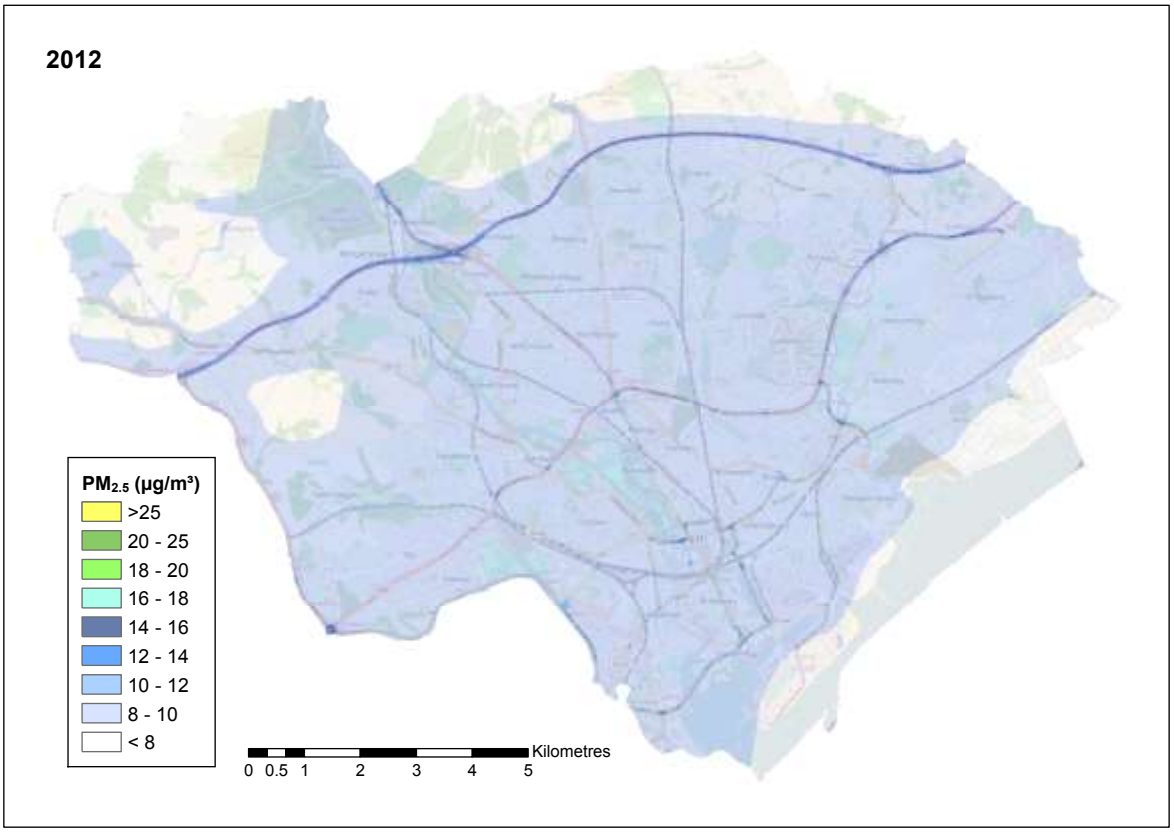


Figure 7.28: Annual average $PM_{2.5}$ concentration, 2013

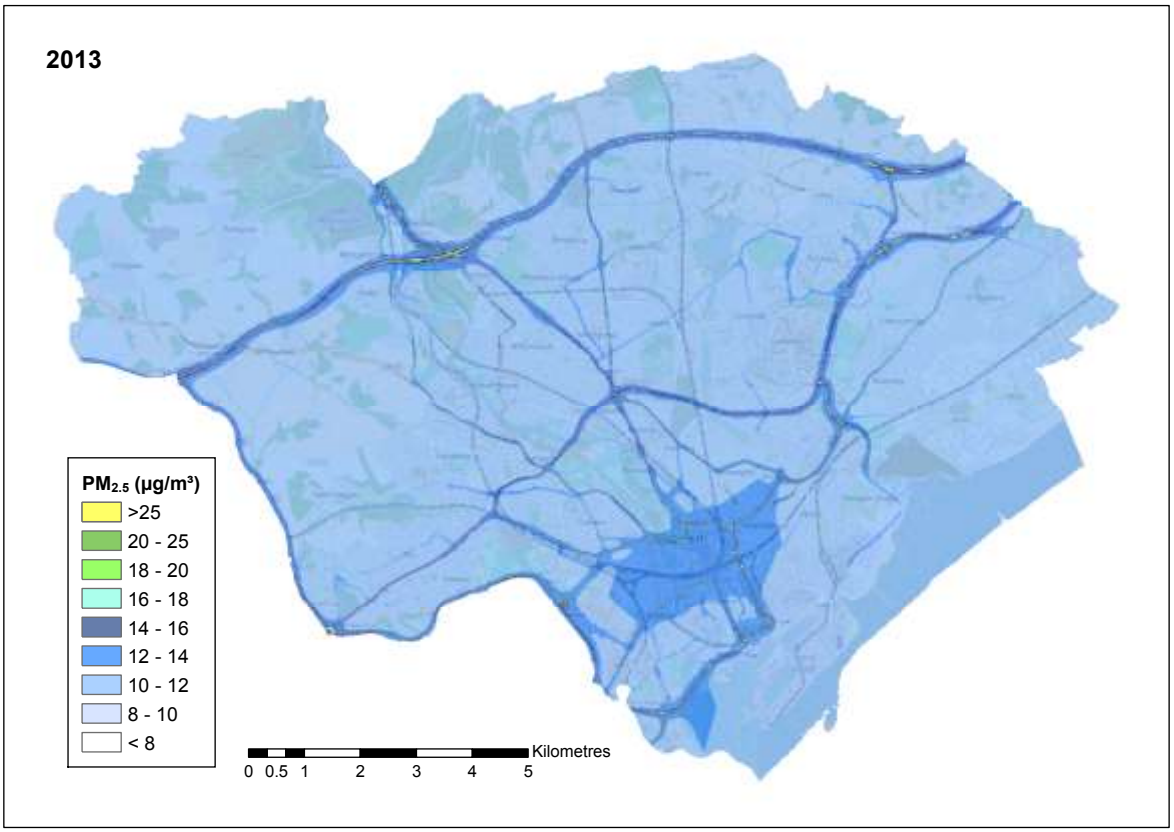


Figure 7.29: Annual average $PM_{2.5}$ concentration, 2014

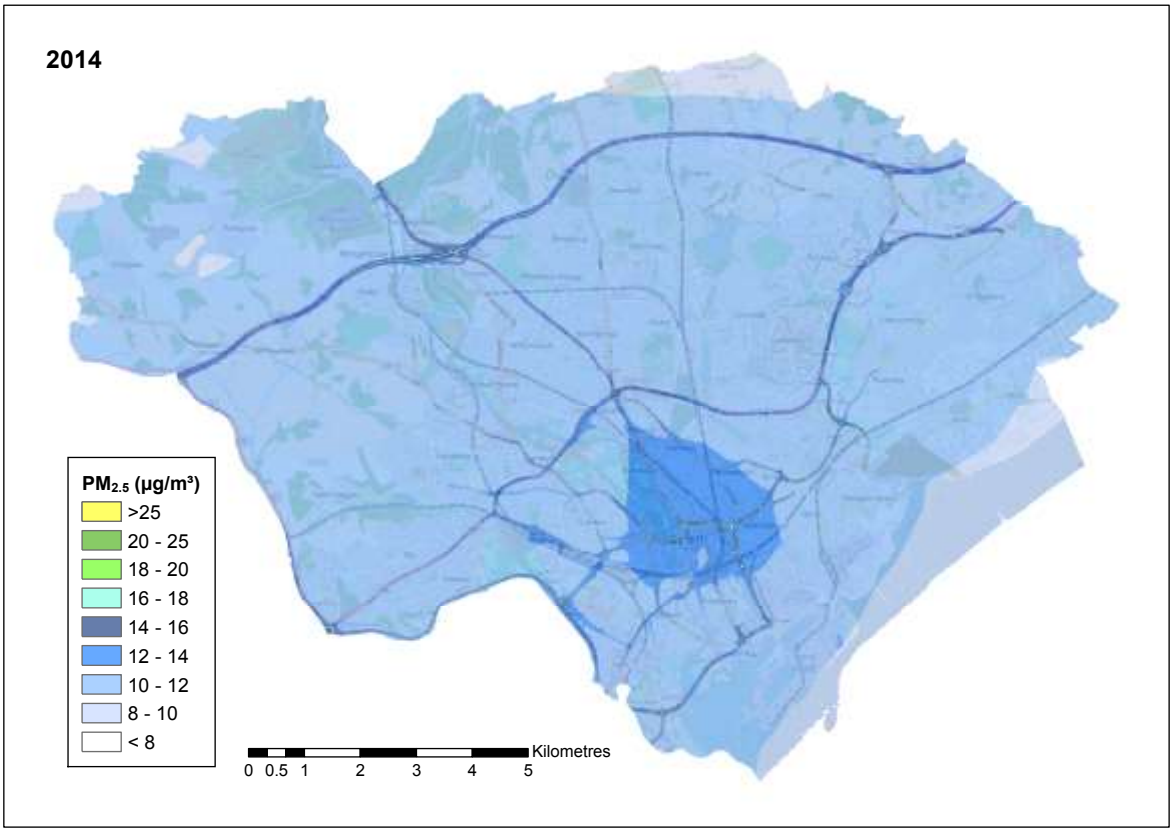
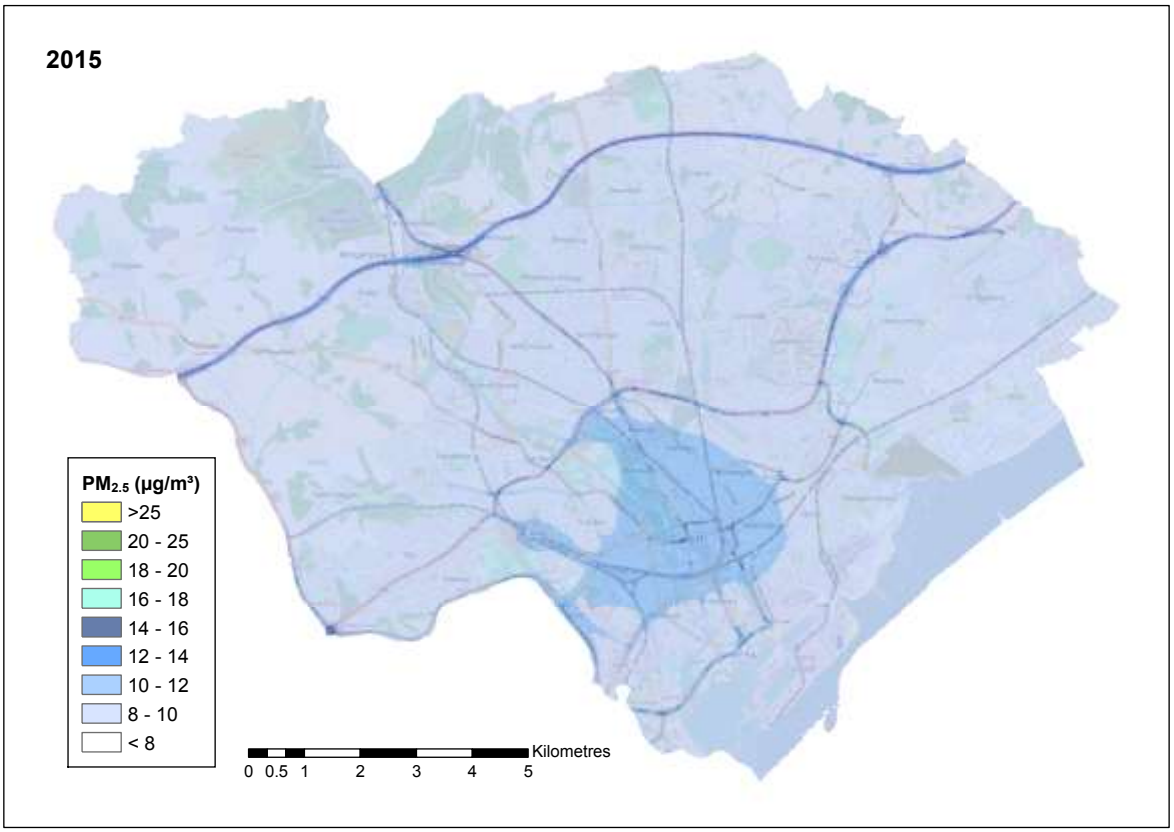


Figure 7.30: Annual average $PM_{2.5}$ concentration, 2015



7.4 Ozone

Figure 7.31: Annual average O_3 concentration, 2006

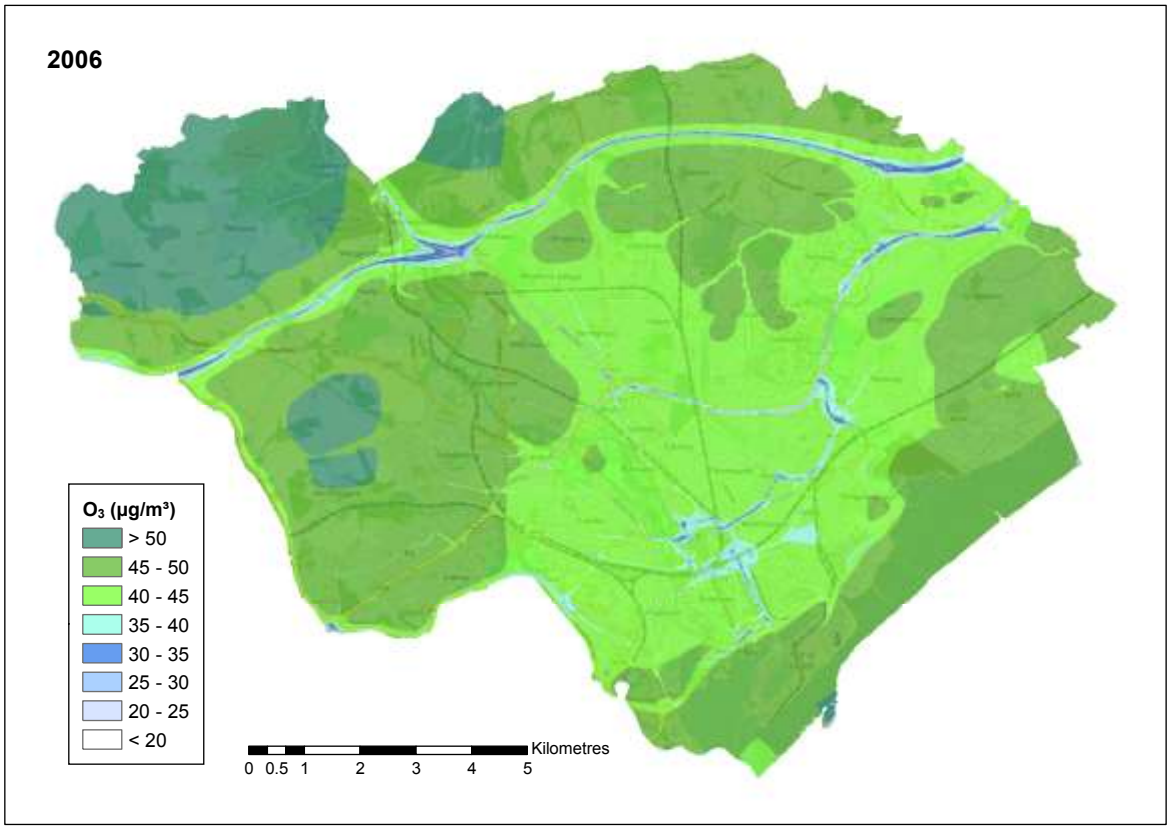


Figure 7.32: Annual average O_3 concentration, 2007

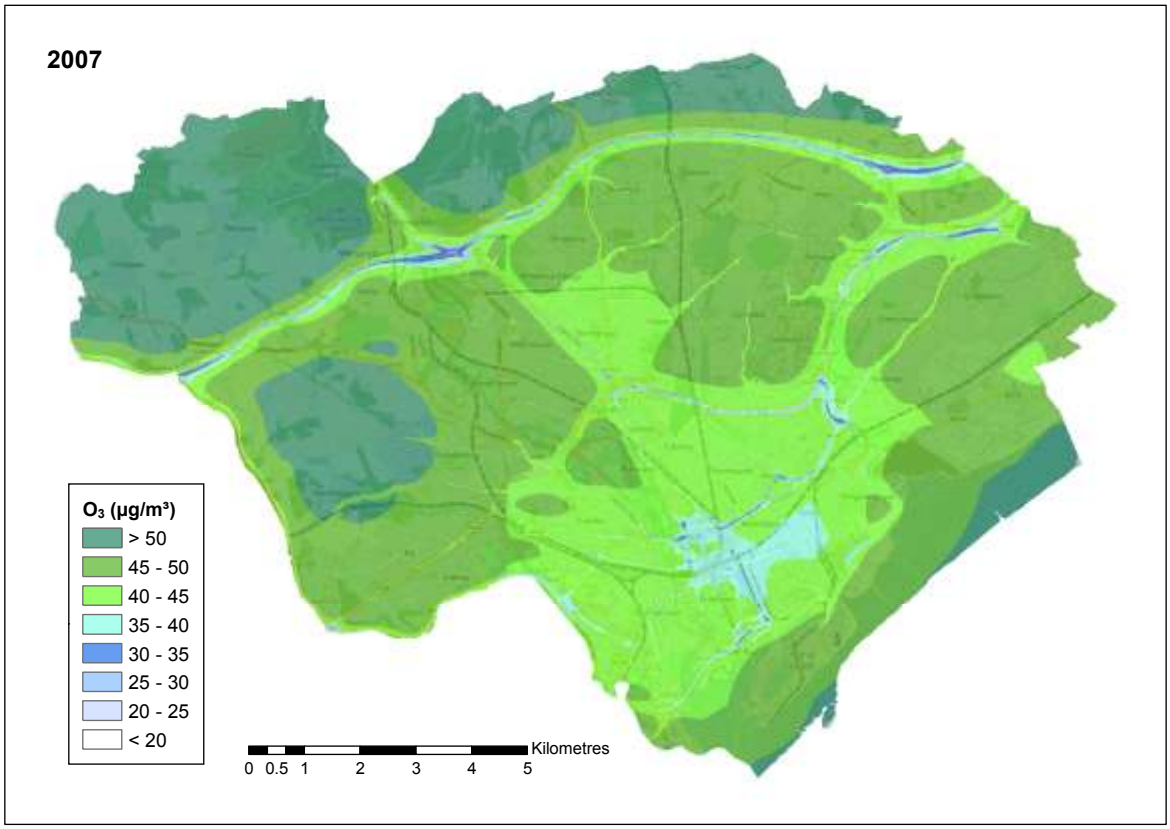


Figure 7.33: Annual average O_3 concentration, 2008

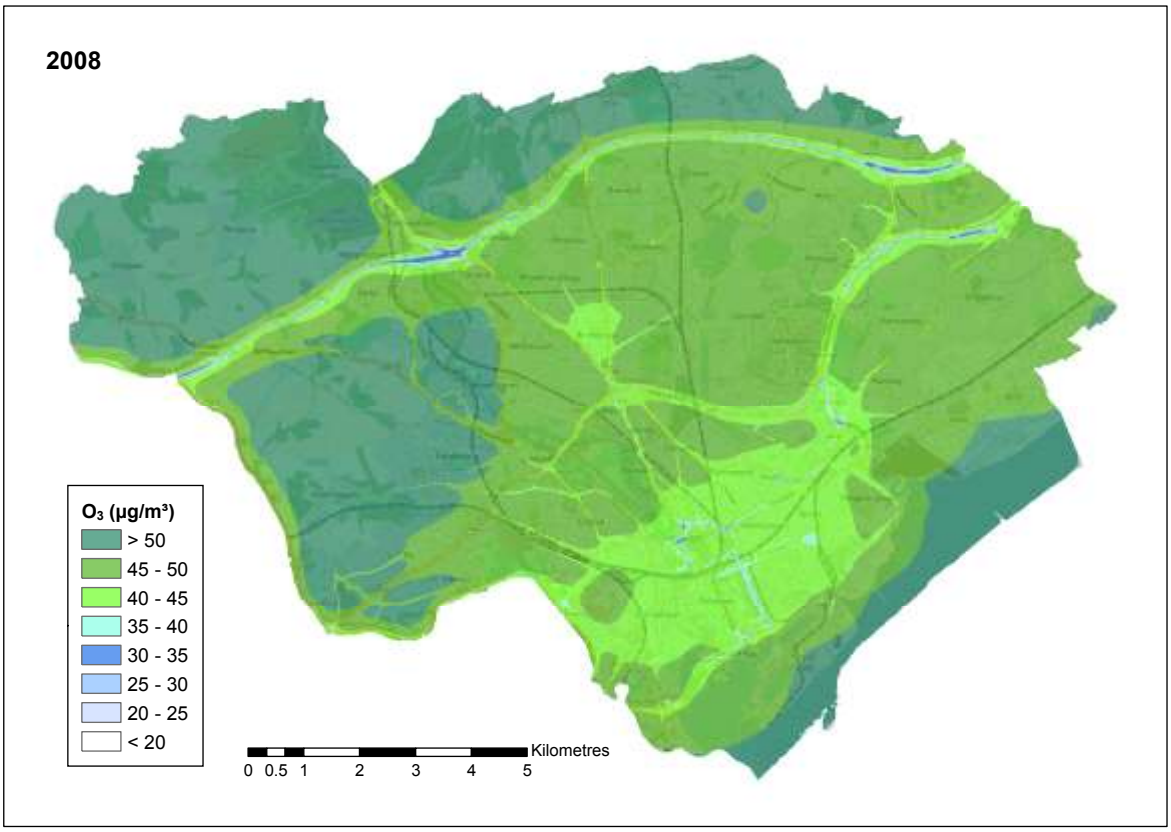


Figure 7.34: Annual average O_3 concentration, 2009

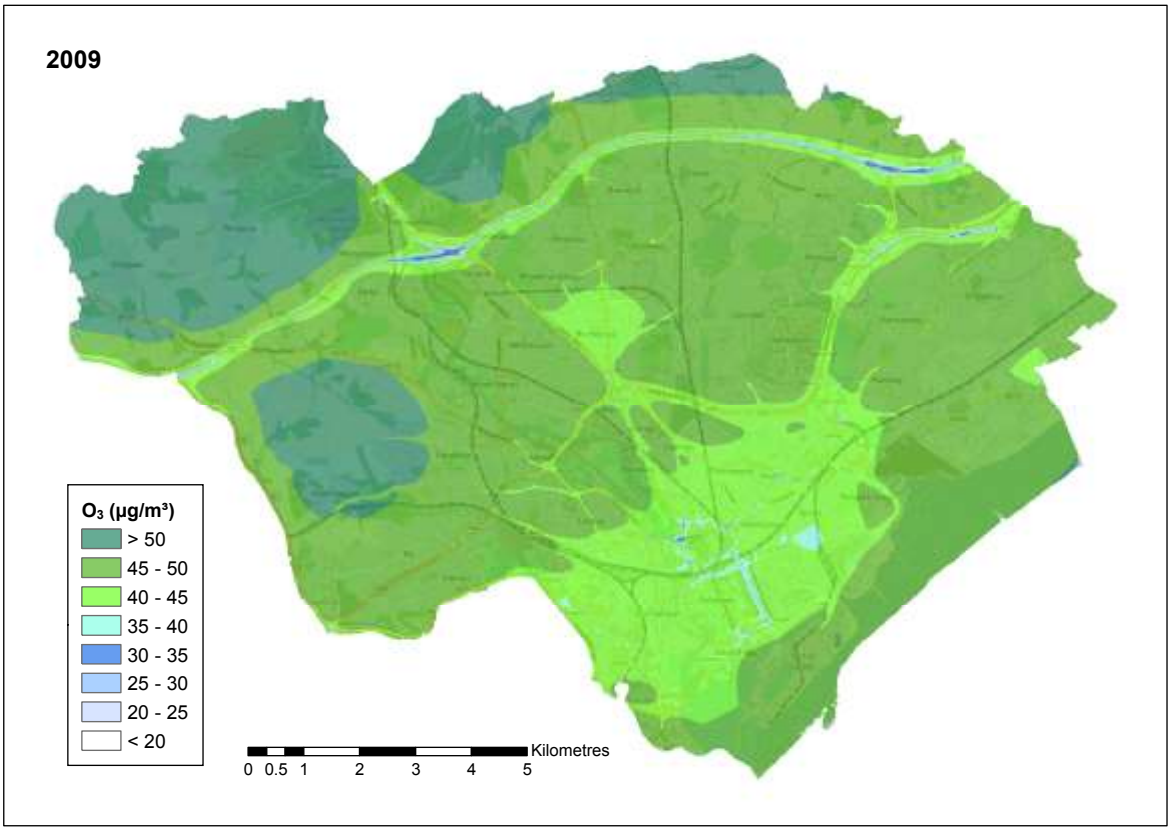


Figure 7.35: Annual average O_3 concentration, 2010

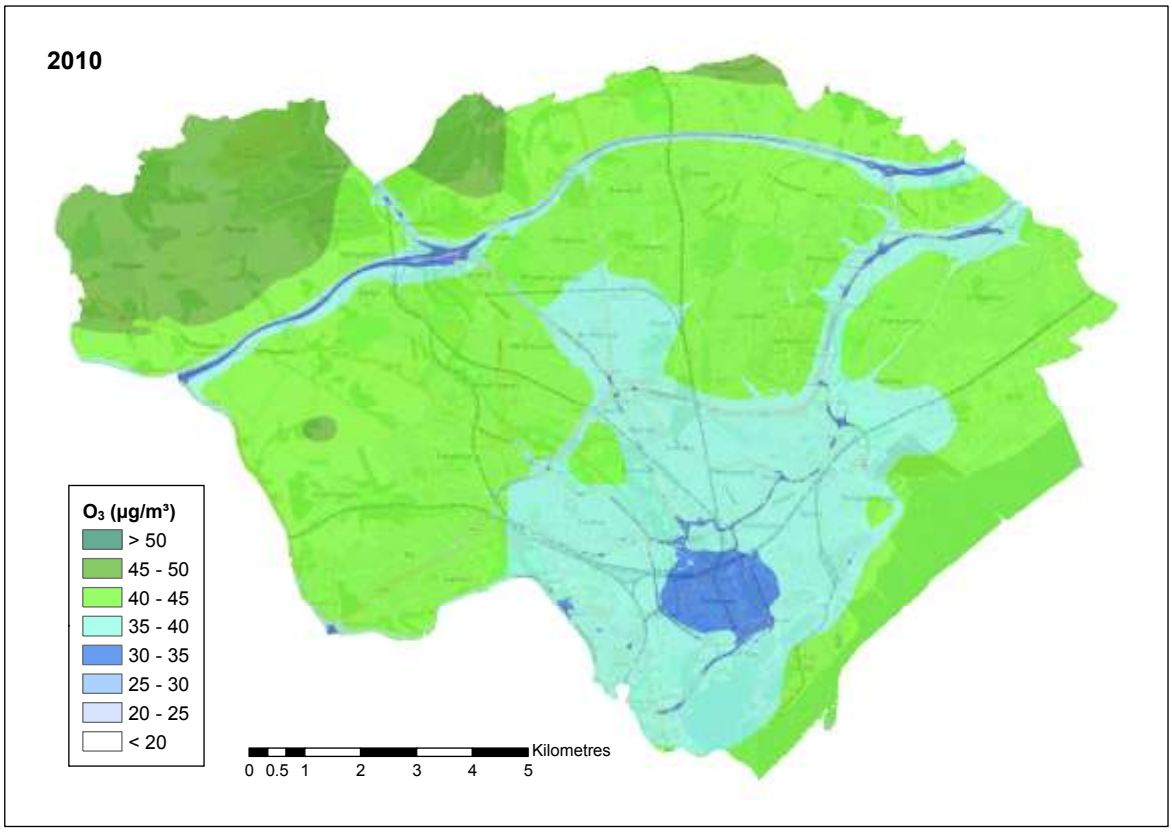


Figure 7.36: Annual average O_3 concentration, 2011

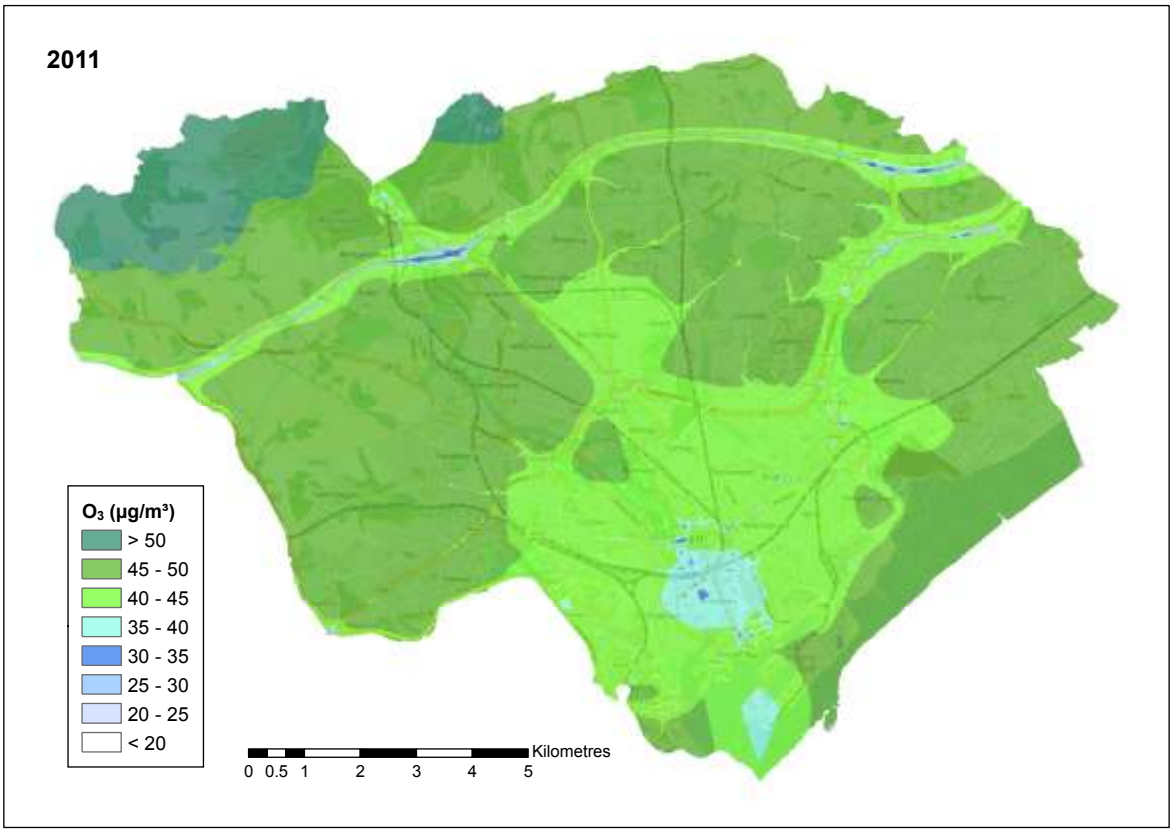


Figure 7.37: Annual average O_3 concentration, 2012

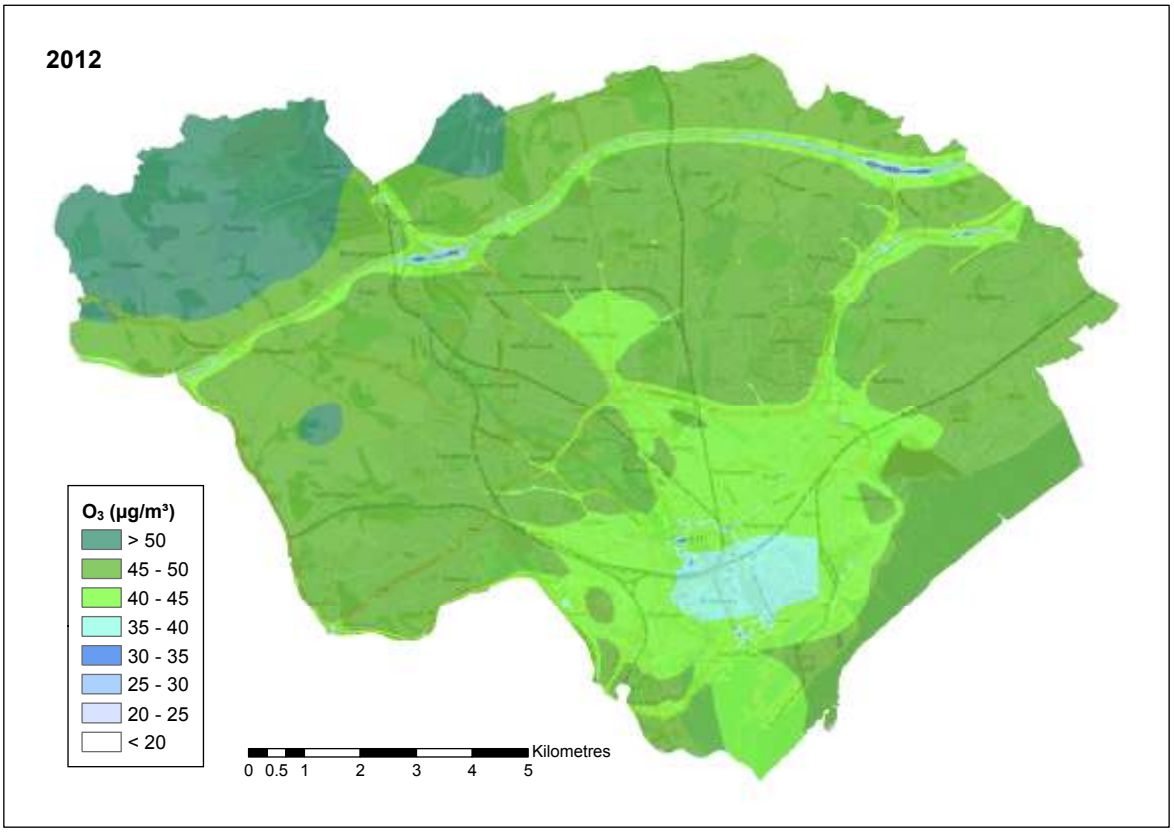


Figure 7.38: Annual average O_{10} concentration, 2013

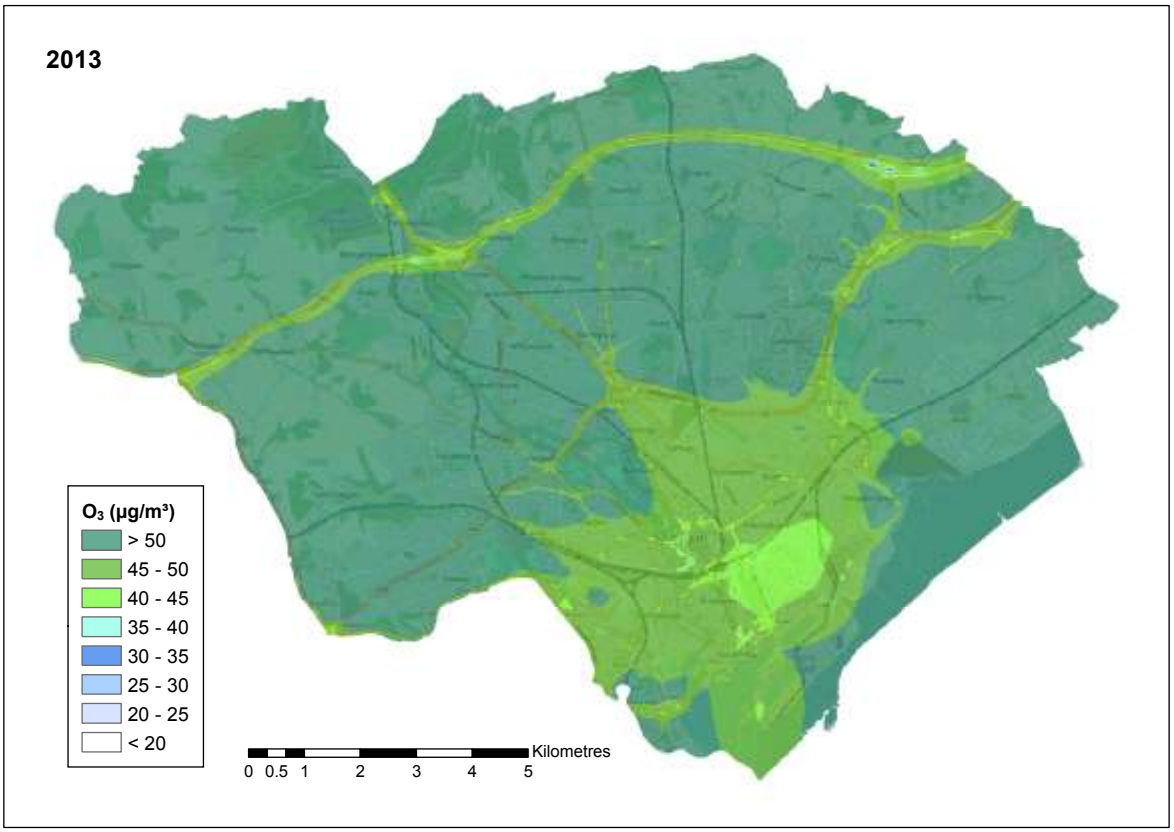


Figure 7.39: Annual average O_3 concentration, 2014

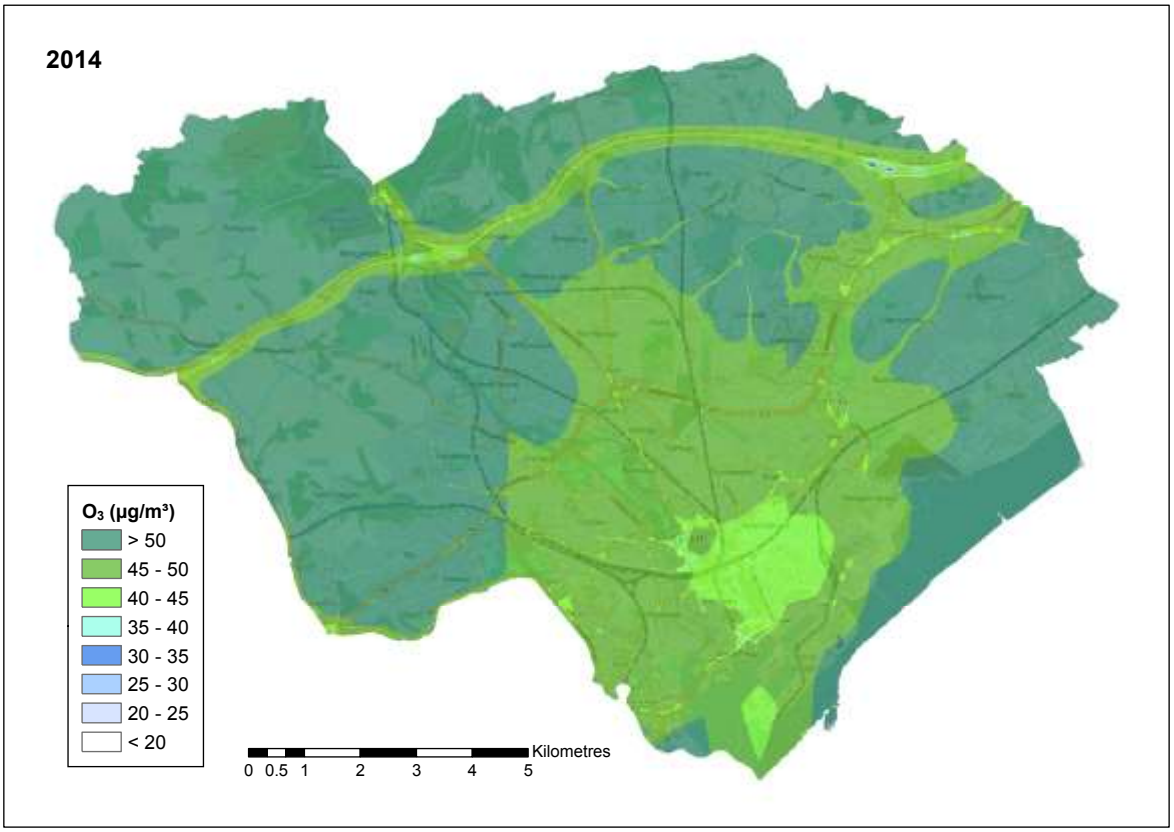
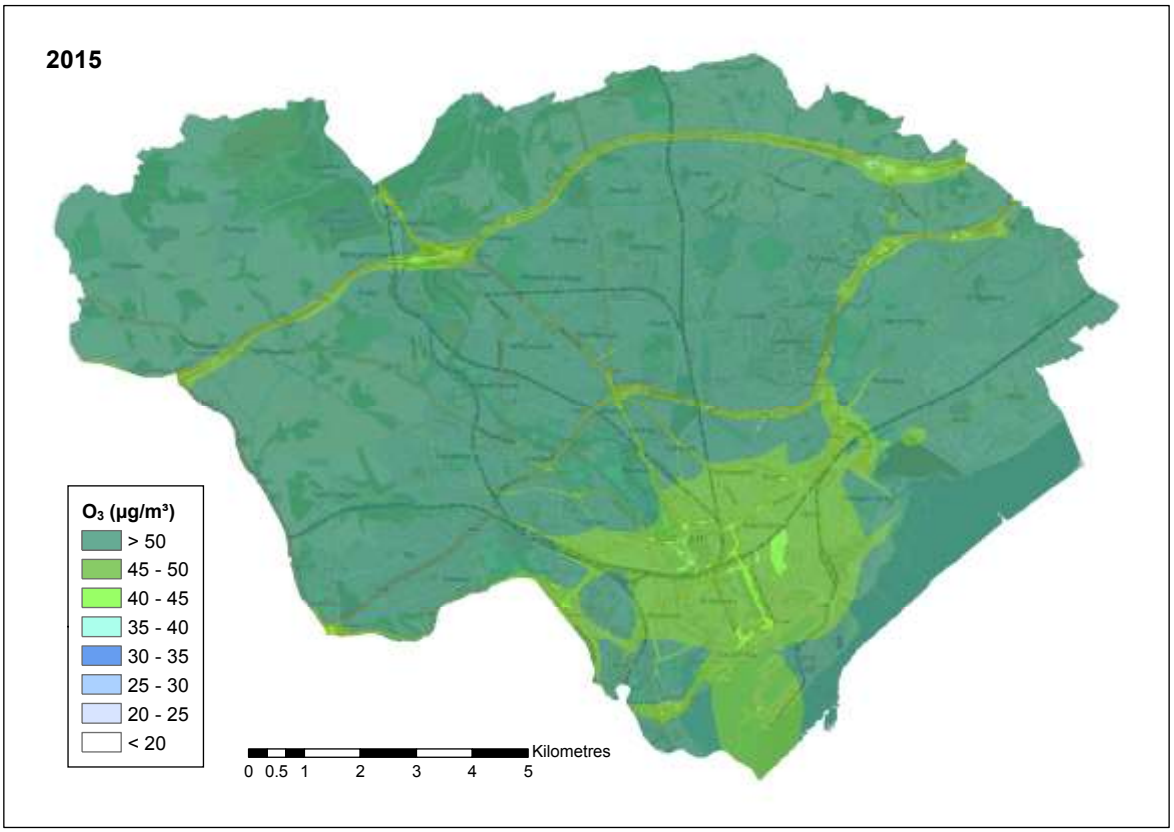


Figure 7.40: Annual average O_3 concentration, 2015



APPENDIX A: Summary of ADMS-Urban

ADMS-Urban is a practical air pollution modelling tool, which has been developed to provide detailed predictions of pollution concentrations for all sizes of study area. The model can be used to look at concentrations near a single road junction or over a region extending across the whole of a major city. ADMS-Urban has been extensively used for the Review and Assessment of Air Quality carried out by Local Authorities in the UK. The following is a summary of the capabilities and validation of ADMS-Urban. More details can be found on the CERC web site at www.cerc.co.uk.

ADMS-Urban is a development of the Atmospheric Dispersion Modelling System (ADMS), which has been developed to investigate the impacts of emissions from industrial facilities. ADMS-Urban allows full characterisation of the wide variety of emissions in urban areas, including an extensively validated road traffic emissions model. It also boasts a number of other features, which include consideration of:

- the effects of vehicle movement on the dispersion of traffic emissions;
- the behaviour of material released into street-canyons;
- the chemical reactions occurring between nitrogen oxides, ozone and Volatile Organic Compounds (VOCs);
- the pollution entering a study area from beyond its boundaries;
- the effects of complex terrain on the dispersion of pollutants; and
- the effects of a building on the dispersion of pollutants emitted nearby.

More details of these features are given below.

Studies of extensive urban areas are necessarily complex, requiring the manipulation of large amounts of data. To allow users to cope effectively with this requirement, ADMS-Urban has been designed to operate in the widely familiar PC environment, under Microsoft Windows. The manipulation of data is further facilitated by the possible integration of ADMS-Urban with a Geographical Information System (GIS) such as MapInfo or ArcGIS, and with the CERC Emissions Inventory Toolkit, EMIT.

Dispersion Modelling

ADMS-Urban uses boundary layer similarity profiles in which the boundary layer structure is characterised by the height of the boundary layer and the Monin-Obukhov length, a length scale dependent on the friction velocity and the heat flux at the ground. This has significant advantages over earlier methods in which the dispersion parameters did not vary with height within the boundary layer.

In stable and neutral conditions, dispersion is represented by a Gaussian distribution. In convective conditions, the vertical distribution takes account of the skewed structure of the vertical component of turbulence. This is necessary to reflect the fact that, under convective conditions, rising air is typically of limited spatial extent but is balanced by descending air extending over a much larger area. This leads to higher ground-level concentrations than would be given by a simple Gaussian representation.

Emissions

Emissions into the atmosphere across an urban area typically come from a wide variety of sources. There are likely to be industrial emissions from chimneys as well as emissions from road traffic and domestic heating systems. To represent the full range of emissions configurations, the explicit source types available within ADMS-Urban are:

- **Industrial points**, for which plume rise and stack downwash are included in the modelling.
- **Roads**, for which emissions are specified in terms of vehicle flows and the additional initial dispersion caused by moving vehicles is also taken into account.
- **Areas**, where a source or sources is best represented as uniformly spread over an area.
- **Volumes**, where a source or sources is best represented as uniformly spread throughout a volume.

In addition, sources can also be modelled as a regular grid of emissions. This allows the contributions of large numbers of minor sources to be efficiently included in a study while the majority of the modelling effort is used for the relatively few significant sources.

ADMS-Urban can be used in conjunction with CERC's Emissions Inventory Toolkit, EMIT, which facilitates the management and manipulation of large and complex data sets into usable emissions inventories.

Presentation of Results

For most situations ADMS-Urban is used to model the fate of emissions for a large number of different meteorological conditions. Typically, meteorological data are input for every hour during a year or for a set of conditions representing all those occurring at a given location. ADMS-Urban uses these individual results to calculate statistics for the whole data set. These are usually average values, including rolling averages, percentiles and the number of hours for which specified concentration thresholds are exceeded. This allows ADMS-Urban to be used to calculate concentrations for direct comparison with existing air quality limits, guidelines and objectives, in whatever form they are specified.

ADMS-Urban can be integrated with the ArcGIS or MapInfo GIS to facilitate both the compilation and manipulation of the emissions information required as input to the model and the interpretation and presentation of the air quality results provided.

Complex Effects - Street Canyons

ADMS-Urban includes two options for modelling the effects of street canyons:
1. The *basic* street canyon option uses the *Operational Street Pollution Model (OSPM)*[13], developed by the Danish National Environmental Research Institute (NERI). The OSPM uses a simplified flow and dispersion model to simulate the effects of the vortex that occurs within street canyons when the wind-flow above the buildings has a component perpendicular to the direction of the street. The model takes account of vehicle-induced turbulence. The model has been validated against Danish and Norwegian data.
2. The *advanced* street canyon option modifies the dispersion of pollutants from a road source according to the presence and properties of canyon walls on one or both sides of the road. It differs from the basic canyon option in the following ways:
(i) It can consider a wide range of canyon geometries, including tall canyons and asymmetric canyons;
(ii) The modelled concentrations vary with height within the canyon;
(iii) Emissions can be restricted only to the carriageway with no emissions on pedestrian areas; and
(iv) Concentrations both inside and outside a particular street canyon are affected.

Complex Effects - Chemistry

ADMS-Urban includes the *Generic Reaction Set (GRS)*[14] atmospheric chemistry scheme. The original scheme has seven reactions, including those occurring between nitrogen oxides and ozone. The remaining reactions are parameterisations of the large number of reactions involving a wide range of Volatile Organic Compounds (VOCs). In addition, an eighth reaction has been included within ADMS-Urban for the situation when high concentrations of nitric oxide (NO) can convert to nitrogen dioxide (NO_2) using molecular oxygen.

In addition to the basic GRS scheme, ADMS-Urban also includes a trajectory model[15] for use when modelling large areas. This permits the chemical conversions of the emissions and background concentrations upwind of each location to be properly taken into account.

[13] Hertel, O., Berkowicz, R. and Larssen, S., 1990, 'The Operational Street Pollution Model (OSPM).' *18th International meeting of NATO/CCMS on Air Pollution Modelling and its Applications.* Vancouver, Canada, pp741-749.
[14] Venkatram, A., Karamchandani, P., Pai, P. and Goldstein, R., 1994, 'The Development and Application of a Simplified Ozone Modelling System.' *Atmospheric Environment,* Vol 28, No 22, pp3665-3678.
[15] Singles, R.J., Sutton, M.A. and Weston, K.J., 1997, 'A multi-layer model to describe the atmospheric transport and deposition of ammonia in Great Britain.' In: *International Conference on Atmospheric Ammonia: Emission, Deposition and Environmental Impacts. Atmospheric Environment*, Vol 32, No 3.

Complex Effects – Terrain and Roughness

Complex terrain can have a significant impact on wind-flow and consequently on the fate of dispersing material. Primarily, terrain can deflect the wind and therefore change the route taken by dispersing material. Terrain can also increase the levels of turbulence in the atmosphere, resulting in increased dilution of material. This is of particular significance during stable conditions, under which a sharp change with height can exist between flows deflected over hills and those deflected around hills or through valleys. The height of dispersing material is therefore important in determining the route it takes. In addition, areas of reverse flow, similar in form and effect to those occurring adjacent to buildings, can occur on the downwind side of a hill. Changes in the surface roughness can also change the vertical structure of the boundary layer, affecting both the mean wind and levels of turbulence.

The ADMS-Urban Complex Terrain Module models these effects using the wind-flow model FLOWSTAR[16]. This model uses linearised analytical solutions of the momentum and continuity equations, and includes the effects of stratification on the flow. Ideally hills should have moderate slopes (up to 1 in 2 on upwind slopes and hill summits, up to 1 in 3 in hill wakes), but the model is useful even when these criteria are not met. FLOWSTAR has been extensively tested with laboratory and field data.

Complex Effects - Buildings

A building or similar large obstruction can affect dispersion in three ways:
1. It deflects the wind flow and therefore the route followed by dispersing material;
2. This deflection increases levels of turbulence, possibly enhancing dispersion; and
3. Material can become entrained in a highly turbulent, recirculating flow region or cavity on the downwind side of the building.

The third effect is of particular importance because it can bring relatively concentrated material down to ground-level near to a source. From experience, this occurs to a significant extent in more than 95% of studies for industrial facilities.

The buildings effects module in ADMS-Urban has been developed using extensive published data from scale-model studies in wind-tunnels, CFD modelling and field experiments on the dispersion of pollution from sources near large structures. It operates in the following stages:

(i) A complex of buildings is reduced to a single rectangular block with the height of the dominant building and representative streamwise and crosswind lengths.

(ii) The disturbed flow field consists of a recirculating flow region in the lee of the building with a diminishing turbulent wake downwind, as shown in Figure A1.

(iii) Concentrations within the well-mixed recirculating flow region are uniform and based upon the fraction of the release that is entrained.

(iv) Concentrations further downwind in the main wake are the sum of those from two plumes: a ground level plume from the recirculating flow region and an elevated plume from the non-entrained remainder.

[16] Carruthers D.J., Hunt J.C.R. and Weng W-S. 1988. 'A computational model of stratified turbulent airflow over hills – FLOWSTAR I.' Proceedings of Envirosoft. In: *Computer Techniques in Environmental Studies,* P. Zanetti (Ed) pp 481-492. Springer-Verlag.

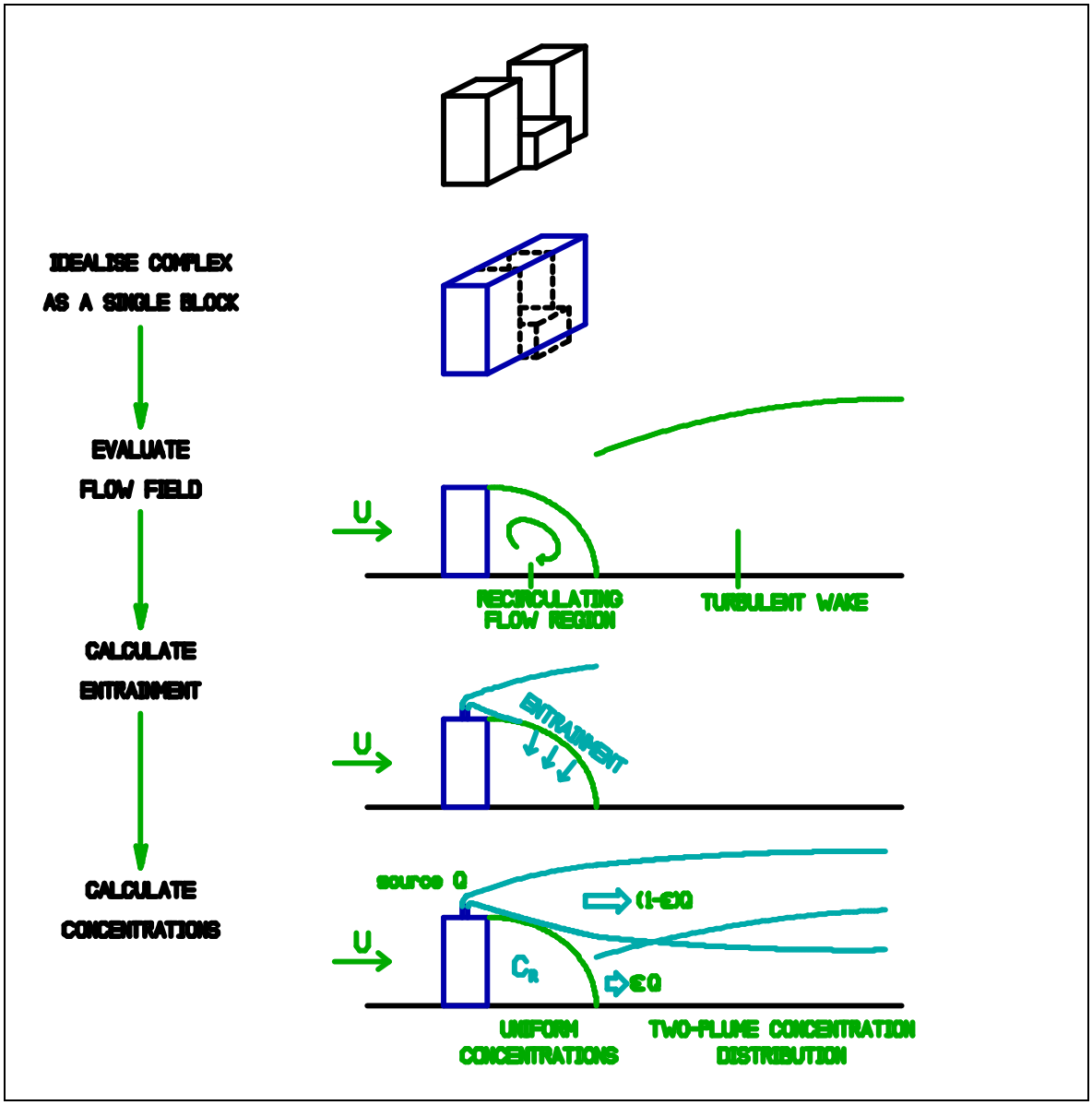


Figure A.1: Stages in the modelling of building effects

Data Comparisons – Model Validation

ADMS-Urban is a development of the Atmospheric Dispersion Modelling System (ADMS), which is used throughout the UK by industry and the Environment Agency to model emissions from industrial sources. ADMS has been subject to extensive validation, both of individual components (e.g. point source, street canyon, building effects and meteorological pre-processor) and of its overall performance.

ADMS-Urban has been extensively tested and validated against monitoring data for large urban areas in the UK, including Central London and Birmingham, for which a large scale project was carried out on behalf of the DETR (now DEFRA).

Further details of ADMS-Urban and model validation, including a full list of references, are available from the CERC website at www.cerc.co.uk.

Appendix B: NO_2 model verification results

Table B.1: Measured and modelled annual average NO_2 concentrations at monitoring sites

Site	Site type	Measured					Modelled				
		2011	2012	2013	2014	2015	2011	2012	2013	2014	2015
1	Cardiff Centre	27.0	25.9	27.0	26.7	26.0	26.1	25.0	23.2	27.0	20.9
16	Roadside	32.1	30.0	30.9	29.3	31.3	27.8	32.4	25.7	27.9	23.1
33	Kerbside	55.0	38.5	49.8	37.3	49.6	38.3	51.2	36.5	46.9	30.1
47	Kerbside	53.0	32.0	51.1	30.7	48.0	30.6	47.1	29.0	41.4	25.1
49	Roadside	31.9	37.6	27.9	37.0	32.1	34.2	32.6	29.2	29.4	26.5
56	Roadside	31.5	29.1	33.9	28.9	35.4	27.4	35.8	25.5	29.6	21.5
58	Kerbside	54.9	50.5	49.5	49.7	52.4	48.0	51.2	45.9	48.3	41.0
81	Roadside	40.6	34.3	40.6	35.7	37.2	34.7	36.4	34.0	35.3	30.8
85	Roadside	28.2	29.2	27.3	28.5	26.7	27.6	27.2	26.5	22.4	23.5
96	Roadside	34.5	35.6	35.4	32.9	35.5	33.4	34.4	31.9	31.1	27.8
97	Roadside	35.4	38.8	37.8	37.9	34.5	36.9	33.6	36.2	30.5	32.3
98	Roadside	29.1	35.9	26.9	34.8	28.3	34.1	29.8	32.2	25.4	29.4
99	Roadside	39.8	43.6	34.5	42.1	38.9	43.6	39.6	42.0	29.8	34.4
100	Roadside	34.8	42.8	33.7	38.4	32.6	37.3	31.8	35.3	28.9	32.3
101	Centre	26.7	25.8	25.8	26.7	26.5	26.0	24.4	23.2	20.3	20.8
102	Centre	28.0	25.8	26.1	26.7	26.9	26.0	24.2	23.2	21.1	20.8
103	Centre	27.4	25.8	25.8	26.7	26.2	26.0	24.4	23.2	20.7	20.8
106	Roadside	34.0	32.2	35.7	31.5	34.8	31.5	34.9	29.7	29.4	24.4
107	Roadside	36.4	36.0	37.6	35.6	34.6	34.7	34.8	33.7	30.7	30.2
111	Roadside	24.5	29.2	23.7	28.8	25.2	27.9	24.7	25.3	21.3	22.8
115	Roadside	38.7	31.8	37.7	31.1	35.5	29.9	36.3	28.2	32.5	25.3
117	Roadside	46.5	33.2	42.6	31.7	44.9	31.7	42.3	30.2	39.5	26.1
124	Roadside	27.0	24.9	25.5	24.5	26.1	23.3	26.3	21.4	22.5	19.0
126	Roadside	45.4	48.5	39.9	47.8	44.0	46.3	41.2	44.1	36.0	39.4
128	Roadside	36.7	35.2	35.1	34.3	34.7	32.7	36.5	30.8	29.6	27.7
129	Roadside	36.2	33.3	34.9	34.7	32.8	33.6	32.0	32.8	31.5	29.6
130	Roadside	44.4	33.4	41.5	34.9	39.0	33.8	38.9	33.0	35.2	29.8
131	Roadside	47.3	33.1	47.9	34.6	43.9	33.5	41.2	32.7	39.5	29.5
133	Roadside	39.5	36.7	39.3	36.9	37.8	36.4	37.5	33.4	31.9	30.5
134	Roadside	45.1	37.2	37.2	37.3	33.4	36.2	34.5	32.7	32.1	29.3
139	Kerbside	34.3	37.1	34.3	36.1	34.1	36.8	35.5	34.6	29.4	31.0
140	Kerbside	42.5	42.0	41.7	40.9	42.2	41.7	42.9	39.6	36.3	35.8
142	Kerbside	48.7	35.4	47.6	35.4	46.3	32.2	44.9	31.0	41.8	28.2
143	Roadside	43.8	48.1	41.5	47.4	42.1	45.7	42.1	43.6	38.2	39.0
144	Roadside	42.9	49.2	39.5	48.5	39.0	46.8	38.2	44.7	37.2	40.0
145	Roadside	34.6	35.3	33.8	34.0	34.5	30.5	32.6	28.3	29.9	25.6
146	Roadside	29.4	28.8	29.5	28.4	30.9	27.8	29.7	25.3	26.6	22.8
147	Roadside	31.1	36.9	31.0	35.2	32.0	34.2	31.3	30.1	27.7	26.6

Site	Site type	Measured					Modelled				
		2011	2012	2013	2014	2015	2011	2012	2013	2014	2015
148	Roadside	29.0	31.8	27.8	30.7	29.3	29.0	29.1	26.8	27.5	23.9
149	Roadside	34.1	32.1	33.0	31.5	34.5	28.7	33.2	26.4	33.6	24.0
152	Roadside	32.8	28.4	32.5	28.0	31.0	27.1	29.7	25.0	27.6	22.6
153	Roadside	35.0	29.8	36.2	32.6	33.0	31.5	33.2	28.6	29.0	26.1
156	Roadside	33.4	29.4	32.6	29.6	34.9	29.4	31.4	26.6	25.9	23.8
157	Roadside	33.1	30.4	31.6	29.1	29.0	28.2	29.7	26.9	27.2	23.4
158	Roadside	31.5	26.4	28.8	25.7	30.2	25.9	29.1	23.7	25.5	20.8
159	Roadside	38.7	32.2	39.9	32.0	38.8	31.4	39.2	30.2	34.0	26.8
160	Urban Centre	32.6	54.7	31.4	57.0	30.3	56.6	28.3	52.1	27.0	48.1
161	Roadside	-	43.5	43.0	43.1	39.1	44.4	37.2	41.4	32.3	34.7
162	Roadside	-	35.6	28.5	34.3	27.6	33.0	27.6	31.5	24.5	26.5
163	Roadside	-	32.5	27.5	28.7	25.4	27.8	28.2	25.8	23.2	23.3
164	Roadside	-	32.3	-	31.9	25.4	30.7	23.9	29.0	20.3	25.9
166	Roadside	-	44.0	-	43.2	34.9	41.4	36.6	40.4	32.1	35.6
167	Roadside	-	42.4	-	41.8	31.7	39.9	31.5	38.8	28.3	34.2
168	Roadside	-	33.5	-	33.2	27.9	32.5	27.7	30.2	24.3	26.9
169	Urban Centre	-	22.7	-	22.8	18.0	21.8	18.1	19.9	16.3	17.7
174	Kerbside	-	34.2	-	34.0	-	34.7	33.9	33.8	28.7	29.6
175	Kerbside	-	41.6	-	40.9	-	42.5	46.8	40.2	42.0	35.6
176	Roadside	-	56.5	-	55.2	-	53.0	55.0	47.7	53.1	42.1
177	Roadside	-	50.0	-	49.5	-	48.4	51.8	42.8	48.1	37.8
178	Kerbside	-	44.1	-	43.2	-	41.7	51.6	38.4	54.3	34.0