Nitrogen Oxides Trends in the UK 2013 to 2019

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Executive Summary

In October 2019, AQC reported significant reductions in ambient nitrogen oxides (NOx) concentrations across the UK over the period 2005 to 2018. This current report extends the earlier analysis to include measurements made in 2019.

The reductions in average NOx concentrations have continued through 2019. Furthermore, the average rate of reduction over the period 2013 to 2019 is considerably steeper than that for the 2010 to 2018 period reported previously. This is particularly true at roadside sites and is principally because of the non-linearity of the trend, with the steepest reductions occurring since 2016.

A separate analysis has been carried out to nominally remove the effects of inter-year differences in meteorology. This is because meteorology can obscure any underlying trends associated with factors such as emissions reductions. With these meteorological effects removed there is still a non-linear trend in average concentrations, with the greatest reductions occurring since 2016. NOx concentrations at roadside sites have reduced by an average of 5.14% per year since 2013, with the average reductions since 2016 being greater than this.

1 Introduction

1.1 A report was produced by Air Quality Consultants Ltd in October 2019 (Laxen et al., 2019) that analysed nitrogen dioxide (NO_2) and nitrogen oxides (NOx) trends over the period 2005 to 2018 (the '2019 Trends Report'). This identified significant downward trends in concentrations of both pollutants over this period. For example, for the sub-period 2010 to 2018, overall downward trends were -3.1% per year for NO_2 and -3.0% per year for NOx.

1.2 This current report extends the earlier analysis to include measurements made in 2019. For simplicity, this update has focussed solely on NOx concentrations, and has also reduced the number of years considered to the seven-year period 2013 to 2019. This has also allowed the inclusion of 34 additional monitoring sites as compared to the 2010 to 2018 analysis. At the time of writing, some of the 2019 measurements are provisional, but it is considered highly unlikely that ratification will alter the overall conclusions of this report[1].

1.3 The analysis shows that the rate of change in concentrations is non-linear, becoming steeper downward around 2015 to 2016. These years also appear to be associated with atypical meteorological conditions. Thus, an additional analysis has been carried out which seeks to remove the effects of inter-year variations due to meteorology, using the 'deweather' statistical module available in the *openair* software package (Carslaw and Ropkins, 2012).

1 Ratification of the data for the last three months of 2019 is unlikely to alter the concentrations at individual sites appreciably, with any changes to multi-site averages being even smaller.

2 Methodology

2.1 The *openair* software package has been used to analyse the measurements. The focus has been on trends across sites, rather than at specific sites; with trends presented separately for “Road”, “Urban” and “Rural” sites (See Paragraph 2.16 of the 2019 Trends Report for a full description of this categorisation).

2.2 The methodology applied in terms of data compilation and data processing is identical to that described in Section 2 of the 2019 Trends Report. 217 sites were identified for the analysis, of which 15 were in a rural setting, 71 were in an urban setting and 131 were in a road setting. The full list of sites considered is presented in Appendix 1. The data analysis applied to the 2013 to 2019 NOx measurements is largely as described in Section 2 of the 2019 Trends Report, with the exception that no consideration is given to geographical/spatial trends. This report also does not present the individual trends by site.

2.3 This analysis has expanded on that carried out for the 2019 Trends Report by seeking to determine the trends in NOx concentrations with the influence of meteorology removed, using the openair ‘deweather’ module. This has been used to create a set of modelled NOx concentrations at each individual monitoring site with the influence of wind speed, wind direction, temperature, relative humidity and cloud cover removed. The influences of “hour”, “weekday” and “week” (i.e. week of the year) have not been removed because the analysis is seeking to remove inter-year differences in meteorology rather than the effects of meteorology on a shorter time period[2]. Individual models have been created for each site, because the statistical performance of these individual models was far superior to that of any model that sought to use data from more than one site. The combined set of modelled concentrations has then been used to determine the trends across the three different site types.

2.4 In order to use the ‘deweather’ module, it has been necessary to pair the NOx measurements with meteorological observations. Figure 1 shows the meteorological station used for each of the NOx monitoring sites.

[2] For example, there would be no benefit to this analysis of removing the effect of differences in meteorology between a week in the summer and a week in the winter.

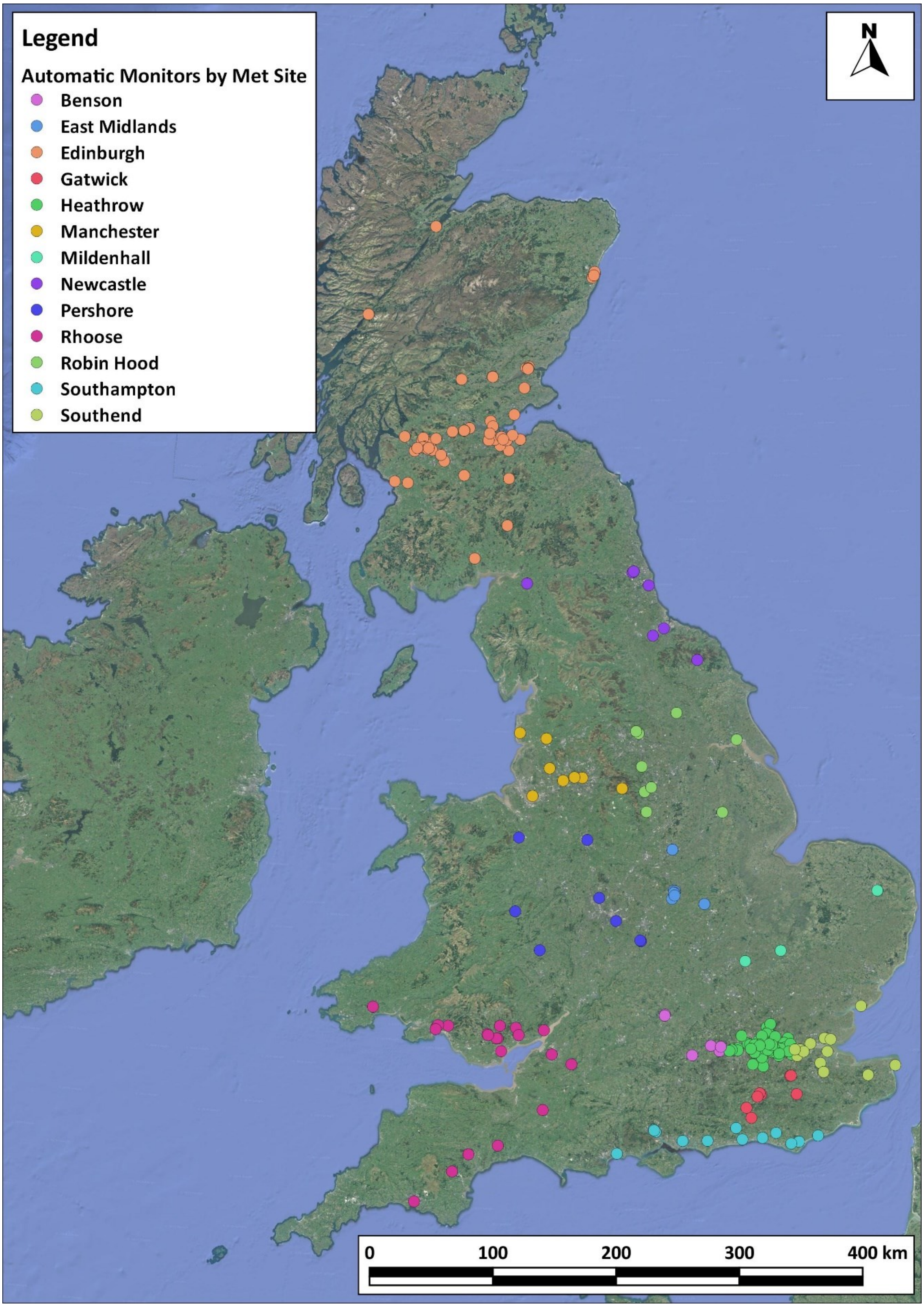

Figure 1: Air Quality and Meteorological Monitoring Sites Used in the Analysis

Imagery © NASA, Terrametrics

3 Results

Unadjusted Data

3.1 Table 1 summarises the trend in NOx concentrations by site type over the period 2013 to 2019, using the unadjusted NOx measurements (i.e. without applying the ‘deweather’ calculations). Figure 2 and Figure 3 present visualisations of the trend in the form of SmoothTrend and TheilSen plots, respectively.

3.2 The reductions previously observed for the period up to 2018 have clearly continued through to 2019. Furthermore, the reductions over the period 2013 to 2019 were considerably steeper than those over the period 2010 to 2018 identified in the 2019 Trends Report. This is principally because of the non-linearity of trends over this period, with the steepest reductions occurring since 2016. Concentrations at rural sites reduced by 4.37% per year over the period 2013 to 2019, as compared to 4.09% per year over the period 2010 to 2018. Concentrations at urban sites reduced by 3.72% per year over the period 2013 to 2019, as compared to 3.08% per year over the period 2010 to 2018. The greatest change though is at road sites, where concentrations reduced by 4.94% per year over the period 2013 to 2019, as compared to 3.02% per year over the period 2010 to 2018. The 2019 Trends Report identified rural sites as having the steepest reduction in concentration, but this new analysis highlights that this rural reduction rate has been overtaken by that at road sites.

3.3 Because the trend appears to be non-linear (Figure 2), the rate of reduction in roadside NOx concentrations over the period 2016 to 2019 is considerably greater than the 4.94% per year calculated for the entire period since 2013. However, it is likely that measurements in 2016 were atypically high as a result of meteorological influences. The next section seeks to remove these influences.

Table 1: Results of TheilSen Analysis of Monthly-Mean Concentrations, 2013 to 2019 [a]

Site Type	Number of Sites	Mean Trend (%/yr)	Mean Trend (µg/m^3/yr)
Road	131	-4.94***	-5.55
Urban	71	-3.72*	-1.44
Rural	15	-4.37**	-0.51

* = trend statistically significant to p=0.05

** = trend statistically significant to p=0.01

*** = trend statistically significant to p=0.001

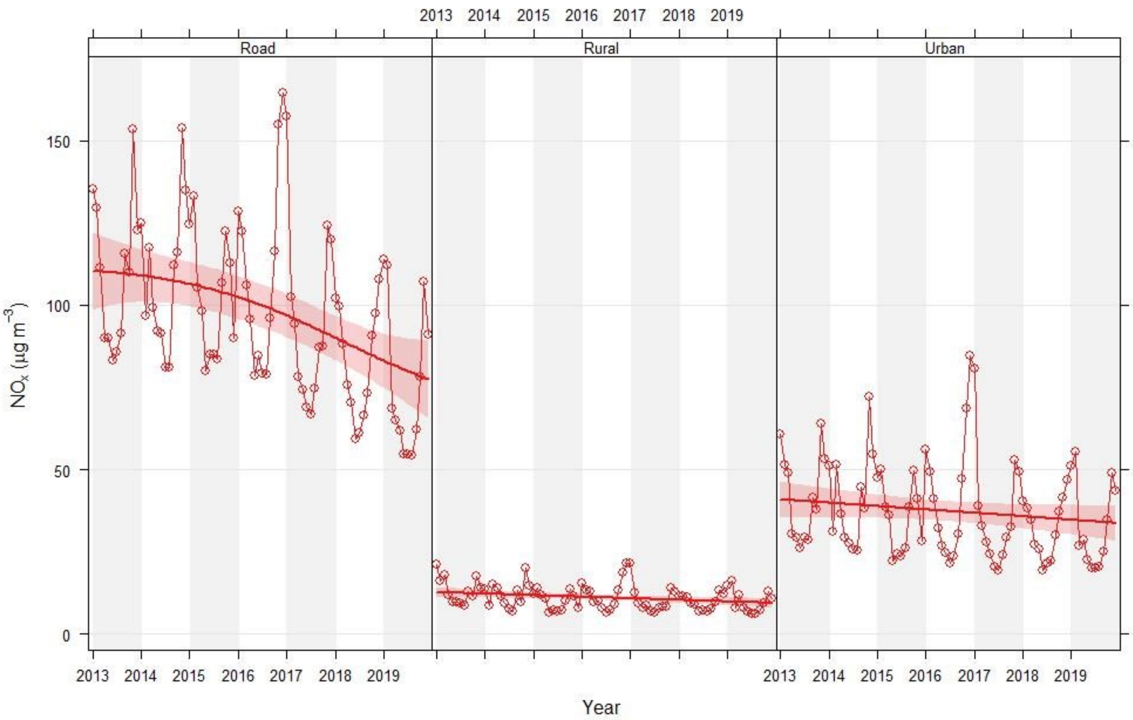

Figure 2: NOx SmoothTrend Fit by Site Type, 2013 to 2019

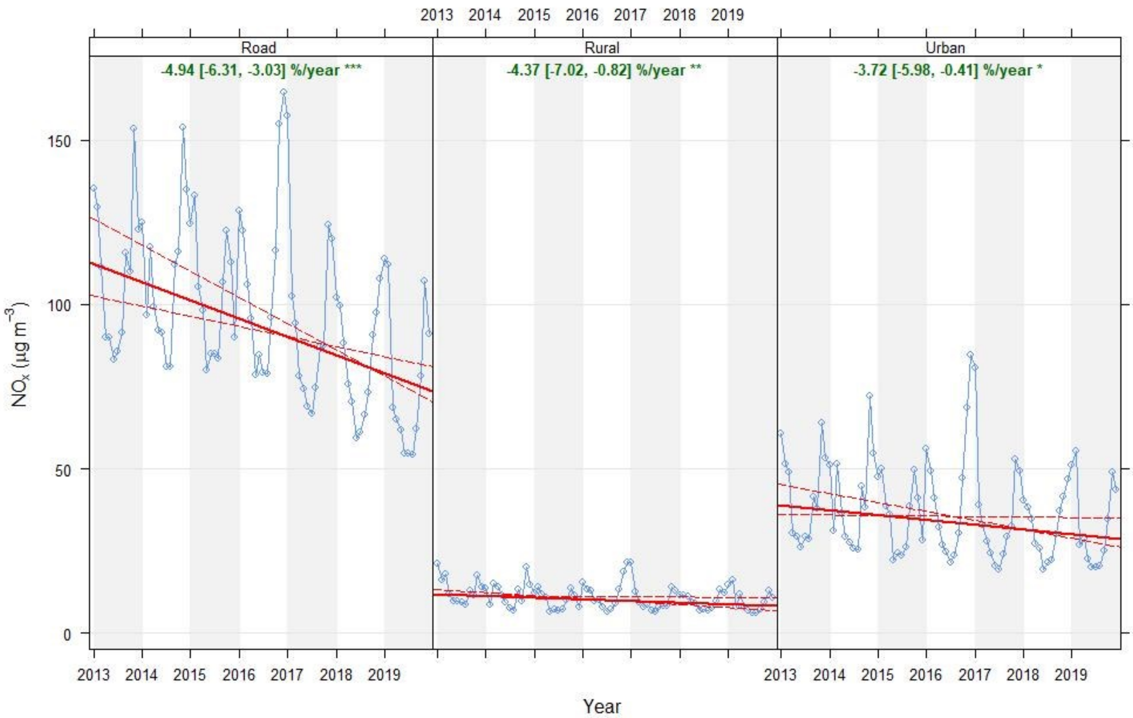

Figure 3: NOx Trend TheilSen Fit (% per year) by Site Type, 2013 to 2019

‘Deweathered’ Data

3.4 Table 2 summarises the trend in NOx concentrations by site type over the period 2013 to 2019, using the NOx concentrations predicted by the ‘deweather’ model. Figure 4 and Figure 5 present visualisations of this trend in the form of SmoothTrend and TheilSen plots, respectively.

3.5 Comparing Figure 4 with Figure 2 shows the ability of the ‘deweather’ model to remove the effects of inter-year differences in meteorology. While 2015 stands out as atypically low in the unadjusted measurements, with 2016 atypically high, these effects are largely absent from the ‘deweathered’ data. Despite this, it is particularly striking that the rate of reduction in roadside concentrations over the period 2016 to 2019 is notably *steeper* in the ‘deweathered’ data in Figure 4 than in the unadjusted measurements. Thus, having nominally removed the effects of inter-year differences in meteorology, there still appears to be a non-linear trend at the roadside sites, with smaller or no reductions prior to 2016 and steeper reductions thereafter.

3.6 Taking the 2013 to 2019 period as a whole, the ‘deweathered’ reductions in NOx are even steeper than in the unadjusted data, with significant downward trends of greater than 5% per year at both road and rural sites (Table 2). The rate of reduction over the four years 2016 to 2019 has, on average, been greater than this, due to the curvilinear fit to the data.

Table 2: Results of TheilSen Analysis of ‘Deweathered’ Monthly-Mean Concentrations, 2013 to 2019 [a]

Site Type	Number of Sites	Mean Trend (%/yr)	Mean Trend (µg/m^3/yr)
Road	131	-5.14	-6.40
Urban	71	-4.03	-1.80
Rural	15	-5.03	-0.70

[a] All trends are significant to p=0.001

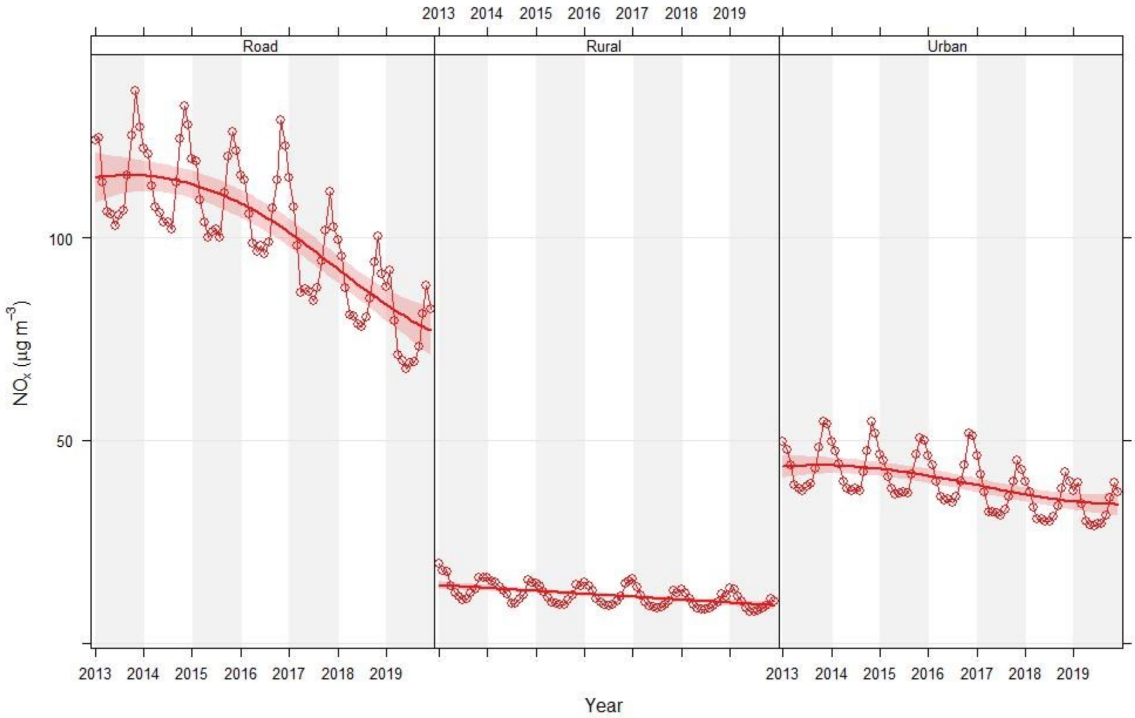

Figure 4: ‘Deweathered’ NOx SmoothTrend Fit by Site Type, 2013 to 2019

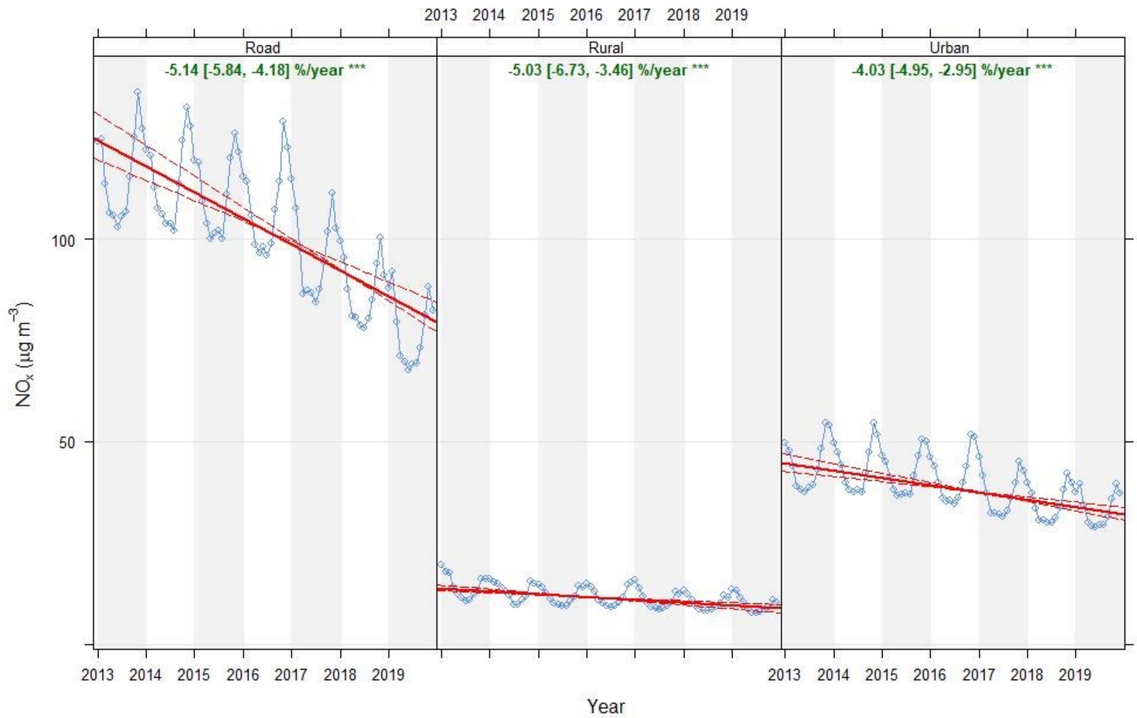

Figure 5: ‘Deweathered’ NOx Trend TheilSen Fit (% per year) by Site Type, 2013 to 2019

4 References

Carslaw, D.C. and Ropkins, K. (2012) 'openair - An R package for air quality data analysis', *Environmental. Modelling & Software*, vol. 27-28, pp. 52-61.

Laxen, D., Gellatly, R., Richardson, T. and Marner, B. (2019) *Nitrogen Dioxide and Nitrogen Oxides Trends in the UK 2005 to 2018*, Available: https://www.aqconsultants.co.uk/CMSPages/GetFile.aspx?guid=feb92332-26f7-4989-b86a-21e5732a5404.

Appendix 1 Included Sites

A1 Table A1 is a list of the sites included in the analyses set out in this report, together with the network that they are part of and the categorisation by site type.

Table A1: Sites Included in the Analyses and their Categorisation

Name	Network [a]	Type
Aberdeen	AURN	Urban
Aberdeen Union Street Roadside	AURN	Road
Aston Hill	AURN	Rural
Barnsley Gawber	AURN	Urban
Bath Roadside	AURN	Road
Birmingham Acocks Green	AURN	Urban
Blackpool Marton	AURN	Urban
Bournemouth	AURN	Urban
Brighton Preston Park	AURN	Urban
Bristol St Paul's	AURN	Urban
Bush Estate	AURN	Rural
Cambridge Roadside	AURN	Road
Camden Kerbside	AURN	Road
Canterbury	AURN	Urban
Cardiff Centre	AURN	Urban
Carlisle Roadside	AURN	Road
Charlton Mackrell	AURN	Rural
Chatham Roadside	AURN	Road
Chepstow A48	AURN	Road
Chesterfield Roadside	AURN	Road
Cwmbran	AURN	Urban
Dumbarton Roadside	AURN	Road
Dumfries	AURN	Road
Eastbourne	AURN	Urban
Eskdalemuir	AURN	Rural
Exeter Roadside	AURN	Road
Fort William	AURN	Urban
Glasgow Kerbside	AURN	Road

Name	Network [a]	Type
Glasgow Townhead	AURN	Urban
Glazebury	AURN	Rural
Haringey Roadside	AURN	Road
High Muffles	AURN	Rural
Honiton	AURN	Urban
Horley	AURN	Urban
Hull Freetown	AURN	Urban
Inverness	AURN	Road
Ladybower	AURN	Rural
Leamington Spa	AURN	Urban
Leamington Spa Rugby Road	AURN	Road
Leeds Centre	AURN	Urban
Leeds Headingley Kerbside	AURN	Road
Leicester University	AURN	Urban
Leominster	AURN	Urban
Lincoln Canwick Road	AURN	Road
Liverpool Speke	AURN	Urban
London Bexley	AURN	Urban
London Bloomsbury	AURN	Urban
London Eltham	AURN	Urban
London Haringey Priory Park South	AURN	Urban
London Harlington	AURN	Urban
London Hillingdon	AURN	Road
London Marylebone Road	AURN	Road
London N. Kensington	AURN	Urban
London Westminster	AURN	Urban
Lullington Heath	AURN	Rural
Manchester Piccadilly	AURN	Urban
Market Harborough	AURN	Rural
Middlesbrough	AURN	Urban
Narberth	AURN	Rural
Newcastle Centre	AURN	Urban
Newcastle Cradlewell Roadside	AURN	Road
Norwich Lakenfields	AURN	Urban

Name	Network [a]	Type
Nottingham Centre	AURN	Urban
Oxford Centre Roadside	AURN	Road
Oxford St Ebbes	AURN	Urban
Peebles	AURN	Urban
Plymouth Centre	AURN	Urban
Portsmouth	AURN	Urban
Preston	AURN	Urban
Reading New Town	AURN	Urban
Rochester Stoke	AURN	Rural
Salford Eccles	AURN	Urban
Sandy Roadside	AURN	Road
Sheffield Devonshire Green	AURN	Urban
Sheffield Tinsley	AURN	Urban
Southampton Centre	AURN	Urban
Southend-on-Sea	AURN	Urban
Southwark A2 Old Kent Road	AURN	Road
St Osyth	AURN	Rural
Stanford-le-Hope Roadside	AURN	Road
Stockton-on-Tees Eaglescliffe	AURN	Road
Stoke-on-Trent Centre	AURN	Urban
Storrington Roadside	AURN	Road
Sunderland Silksworth	AURN	Urban
Swansea Roadside	AURN	Road
Thurrock	AURN	Urban
Tower Hamlets Roadside	AURN	Road
Walsall Woodlands	AURN	Urban
Wigan Centre	AURN	Urban
Wrexham	AURN	Road
Yarner Wood	AURN	Rural
York Fishergate	AURN	Road
Hillingdon Hayes	HAW	Road
Hillingdon Sipson	HAW	Urban
Hounslow 2 - Cranford	HAW	Urban
Hounslow 4 - Chiswick High Road	HAW	Road

Name	Network [a]	Type
London Hillingdon Harmondsworth	HAW	Urban
Slough Colnbrook	HAW	Urban
Slough Town Centre A4	HAW	Road
Maidstone Rural	KA	Rural
Thanet Ramsgate Roadside	KA	Road
Barking and Dagenham - Rush Green	KCL	Urban
Barking and Dagenham - Scrattons Farm	KCL	Urban
Bexley - Belvedere	KCL	Urban
Bexley - Belvedere West	KCL	Urban
Camden - Euston Road	KCL	Road
Castle Point - Hadleigh	KCL	Road
Chichester - A27 Chichester Bypass	KCL	Road
City of London - Beech Street	KCL	Road
City of London - Sir John Cass School	KCL	Urban
City of London - Walbrook Wharf	KCL	Road
Crawley - Gatwick Airport	KCL	Urban
Croydon - Norbury	KCL	Road
Croydon - Purley Way A23	KCL	Road
Dartford Roadside 2 - Town Centre	KCL	Road
Dartford Roadside 3 - Bean Interchange	KCL	Road
Ealing - Hanger Lane Gyratory	KCL	Road
Ealing - Western Avenue	KCL	Road
Enfield - Bush Hill Park	KCL	Urban
Enfield - Derby Road	KCL	Road
Enfield - Prince of Wales School	KCL	Urban
Greenwich - A206 Burrage Grove	KCL	Road
Greenwich - Blackheath	KCL	Road
Greenwich - Falconwood	KCL	Road
Greenwich - Fiveways Sidcup Rd A20	KCL	Road
Greenwich - Plumstead High Street	KCL	Road
Greenwich - Westhorne Avenue	KCL	Road
Greenwich - Woolwich Flyover	KCL	Road
Hackney - Old Street	KCL	Road
Harrow - Pinner Road	KCL	Road

Name	Network [a]	Type
Havering - Rainham	KCL	Road
Horsham - Cowfold	KCL	Road
Horsham - Park Way	KCL	Road
Islington - Arsenal	KCL	Urban
Islington - Holloway Road	KCL	Road
Lambeth - Bondway Interchange	KCL	Road
Lambeth - Streatham Green	KCL	Urban
Leicester - Abbey Lane	KCL	Road
Leicester - Glenhills Way	KCL	Road
Leicester - Melton Road	KCL	Road
Leicester - St Matthews Way	KCL	Road
Leicester - Vaughan Way	KCL	Road
Lewes - West Street	KCL	Road
Lewisham - Loampit Vale	KCL	Road
Lewisham - New Cross	KCL	Road
Redbridge - Gardner Close	KCL	Road
Reigate and Banstead - Poles Lane	KCL	Rural
Richmond Upon Thames - Barnes Wetlands	KCL	Urban
Richmond Upon Thames - Castelnau	KCL	Road
Rother - De La Warr Road	KCL	Road
Sevenoaks - Bat and Ball	KCL	Road
Sevenoaks - Greatness Park	KCL	Urban
Southampton - Onslow Road	KCL	Road
Southampton - Victoria Road	KCL	Road
Southwark - Elephant and Castle	KCL	Urban
Sutton - Worcester Park	KCL	Road
Thurrock - Calcutta Road Tilbury	KCL	Road
Thurrock - London Road (Purfleet)	KCL	Road
Tower Hamlets - Blackwall	KCL	Road
Tunbridge Wells Roadside - St Johns	KCL	Road
Wandsworth - Putney	KCL	Urban
Wandsworth - Putney High Street	KCL	Road
Wandsworth - Putney High Street Facade	KCL	Road
Westminster - Oxford Street	KCL	Road

Name	Network [a]	Type
Windsor and Maidenhead - Clarence Road	KCL	Road
Windsor and Maidenhead - Frascati Way	KCL	Road
Worthing - Grove Lodge	KCL	Road
Aberdeen Anderson Dr	SAQN	Road
Aberdeen King Street	SAQN	Road
Dundee Lochee Road	SAQN	Road
Dundee Mains Loan	SAQN	Urban
Dundee Meadowside	SAQN	Road
Dundee Seagate	SAQN	Road
Dundee Whitehall Street	SAQN	Road
E Ayrshire Kilmarnock St Marnock St	SAQN	Road
East Dunbartonshire Bearsden	SAQN	Road
East Dunbartonshire Bishopbriggs	SAQN	Road
East Dunbartonshire Kirkintilloch	SAQN	Road
East Dunbartonshire Milngavie	SAQN	Road
East Lothian Musselburgh N High St	SAQN	Road
Edinburgh Currie	SAQN	Urban
Edinburgh Glasgow Road	SAQN	Road
Edinburgh Gorgie Road	SAQN	Road
Edinburgh Queensferry Road	SAQN	Road
Edinburgh Salamander St	SAQN	Road
Edinburgh St John's Road	SAQN	Road
Falkirk Grangemouth MC	SAQN	Urban
Falkirk Haggs	SAQN	Road
Falkirk Hope St	SAQN	Road
Falkirk West Bridge Street	SAQN	Road
Fife Cupar	SAQN	Road
Fife Dunfermline	SAQN	Road
Fife Kirkcaldy	SAQN	Road
Fife Rosyth	SAQN	Road
Glasgow Burgher St.	SAQN	Road
Glasgow Byres Road	SAQN	Road
Glasgow Dumbarton Road	SAQN	Road
North Ayrshire Irvine High St	SAQN	Road

Name	Network [a]	Type
Paisley Gordon Street	SAQN	Road
Perth Atholl Street	SAQN	Road
Perth Crieff	SAQN	Road
Perth High Street	SAQN	Road
Renfrew Cockels Loan	SAQN	Road
South Lanarkshire Hamilton	SAQN	Road
South Lanarkshire Lanark	SAQN	Road
South Lanarkshire Uddingston	SAQN	Road
West Lothian Broxburn	SAQN	Road
West Lothian Newton	SAQN	Road
Caerphilly Blackwood High Street	WAQN	Road
Caerphilly White Street	WAQN	Road
Cimla Road / Victoria Gardens	WAQN	Road
Nantgarw Road	WAQN	Road
Newport M4 Junction 25	WAQN	Road
Rhondda Pontypridd Gelliwastad Rd	WAQN	Road
Rhondda-Cynon-Taf Broadway	WAQN	Road
Swansea Cwm Level Park	WAQN	Urban
Swansea Morriston Roadside	WAQN	Road

[a] AURN = Defra's Automatic Urban and Rural Network
HAW = Heathrow Air Watch
KCL = Kings College London London Air
SAQN = Scottish Air Quality Network
WAQN = Welsh Air Quality Network