The Greater London Authority

Comparison of Air Quality in London with a Number of World and European Cities

AMEC Environment & Infrastructure UK Limited

September 2014

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Comparison of Air Quality in London with a Number of World and European Cities

Comparison Report

AMEC Environment & Infrastructure UK Limited

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Executive Summary

AMEC Environment & Infrastructure UK Ltd (AMEC) was commissioned by the Greater London Authority (GLA) to undertake a comparison of air quality in cities around the world. This comparison is intended to be viewed as a benchmark against which efforts to improve air quality in London can be assessed.

A new ranking system was developed and used to rank air quality in the 36 cities for which sufficient data was available. Three indices were developed:

- the Citywide index which includes sulphur dioxide (SO_2) concentrations to account for industrial and local heating emission sources;
- the Citywide/Traffic focussed index which only includes the traffic-related pollutants for which the objective concentrations are most commonly exceeded in Europe, nitrogen dioxide (NO_2) and particulate matter (PM_{10}); and
- the Health Impacts index, which uses Defra damage costs for the pollutants in the Citywide index, and gives a high priority to PM, reflecting the evidence base on the severity of impacts for this pollutant relative to the other pollutants included.

Overall, the city with the best air quality (least polluted) is Vancouver and the city with the worst air quality (most polluted) is Cairo. London ranked 9th on the Health Impacts index, 15th on the citywide index and 17th on the traffic focused index.

Citywide Index		Citywide/Traffic Focussed Index		Health Impact Index	
City	**Rank**	**City**	**Rank**	**City**	**Rank**
Vancouver	1	Vancouver	1	Vancouver	1
London	15	London	17	London	9
Cairo	36	Mumbai	36	Cairo	36

The ranking goes beyond existing comparisons and rankings in terms of the breadth of cities, the use of a multi-pollutant index (NO_2, PM_{10}, SO_2 and $PM_{2.5}$) and its use of recent data (2008-2012).

The comparison required development of a method to rank cities based on their *monitored* air quality. It was intended that the ranking scheme adopted should be a robust and justifiable basis for the comparison and ranking of outdoor air quality in different cities. It should be a method that can be understood by an interested member of the public and not just by air quality professionals. The proposed ranking method was used to rank air quality in the 36 cities for which sufficient data was available cities (of which 15 are in the European Union (EU) and 21 are outside the EU). The three cities with insufficient data are: Dubai, Johannesburg-Gauteng and Lagos.

The selection of cities was based on a combination of factors as follows: population and size; significance, to include capital cities and major European cities; geographical spread across the EU and the world; representation of the “BRIC” (Brazil, Russia, India and China) countries and other large developing countries; countries that are part of the World Cities Culture Report 2012, established by the Mayor of London; cities that have launched initiatives or taken measures to address air quality issues; cities where a need for air quality improvement is acknowledged; and cities that compete with London on economic or financial levels. Meteorological and local factors such as the effect of sea, ocean, hills and mountains affecting air quality in each city are presented in the report.

In any comparison the overriding principle is that data from all cities be treated on the same basis. In order to make a wide global comparison annual average concentrations have been used. The ranking method is flexible enough that it can be adapted so that, for instance, when comparing cities with high quality, detailed data, more information can be gleaned from the comparison, for example by considering different monitoring sites classifications separately, and using short term measures of pollution, than when comparing cities with limited data. A comparison of short term measures of pollution, from those cities with sufficient data, is recommended for future work. Future work could also include ozone as a pollutant. Ozone, despite its impact on health has not been included as its impact on human health is short-term.

Ambient monitoring data were gathered from the EEA’s AirBase database for EU Cities, the CleanAir Asia database and from publicly available data sources published by the cities or regions. Data for Los Angeles and Vancouver were sent on request, the Vancouver data being supplied with a disclaimer. It should also be noted that amongst the EU cities considered in this study, London has by far the highest number of monitoring sites with 157 and it was the only city with a significant number of high quality monitoring data sets from sites not in AirBase (139 sites). The ranking has, therefore, been carried out for AirBase sites only for the EU cities, except for London, where all available sites were included.

Contents

1. Introduction

1.1 Purpose of this Report

AMEC Environment & Infrastructure UK Ltd (AMEC) has been commissioned by the Greater London Authority (GLA) to undertake a comparison of air quality in cities around the world. This global comparison aims to make the best use of the data available to inform stakeholders of the GLA about the comparative "ranking" of cities around the world, and to inform the response of the GLA to similar assessments produced by third parties. This comparison can be viewed as a baseline against which efforts to improve air quality in London can be assessed.

The comparison requires development of a method to rank cities based on their *monitored* air quality. This method will then be used to rank air quality in 39 globally important cities (of which 18 are in the European Union (EU) and 21 are elsewhere in the world). The ranking scheme adopted should be a robust and justifiable basis for the comparison and ranking of outdoor air quality in different cities. It should be a method that can be understood by an interested member of the public and not just by air quality professionals. The specific goal is to develop a method that will be able to cover the wide range of air quality that is likely to exist and enable inclusion of cities with high quality, detailed data as well as those where information is less abundant. As such, this comparison will make use of annual mean pollutant concentration data, as this is the most readily available form of air quality data around the world. Use of measurements over more specialised time periods (e.g. 15-minute, 1-hour, 24-hour), corresponding to local or regional air quality objectives, would exclude available data from some cities. Use of annual mean data is considered to be the most inclusive method with present data sources. A focus on exceedences of EU limits, whilst important to EU cities, is already adequately addressed by the reporting of the Member States to the Commission and is less important in a worldwide comparison, as the EU limit values may not be appropriate for cities outside Europe.

This report starts by considering the potential issues involved in defining a ranking method and proposes ways to manage the issues (section 2). In sections 3 and 4 the different methods that have been used to rank and to classify air quality in cities are reviewed. Building on existing approaches, the report presents a ranking method in section 5. Section 6 then presents the cities selected for the comparison and the reasons for their selection. In sections 7, 8 and 9 the meteorological and other local factors, data availability and monitoring sites are described. Section 10 presents the ranking of air quality in the 39 cities and section 11 provides the conclusions. In Appendix A the wind roses and weather summaries for each city are presented and Appendix B provides detailed information on the monitoring sites in each city. The data gathered by AMEC on air quality in various cities, whilst obtained from publicly available sources may, nonetheless, require explicit permission from the originators of the data for GLA to publish it.

2. Ranking Scheme: Issues and Mitigation

The ranking scheme needs to be a robust and justifiable method for the comparison of outdoor air quality in globally important cities. It should be simple enough to be understood by an interested member of the public, not just by air quality professionals. A method has therefore been developed that will be able to cover the range of air quality that is likely to occur and to include cities for which high quality, detailed data are available, as well as those with less abundant information.

The method has been designed in such a way that it can accommodate all commonly regulated pollutants but also be flexible enough to focus on specific pollutants e.g. the most harmful to human health:

- Particulate Matter less than 10 µg in aerodynamic diameter - PM_{10};
- Particulate Matter less than 2.5 µg in aerodynamic diameter - $PM_{2.5}$;
- Sulphur dioxide - SO_2;
- Ozone - O_3; and
- Nitrogen dioxide - NO_2

However, the choice of pollutants included in the ranking has been constrained by the data available for the selected cities.

The following sections consider issues that have arisen and measures taken to manage their impact. The issues are:

- Quality and quantity of data;
- Number, locations and types of monitoring stations;
- Geographical and meteorological factors;
- An index of multiple pollutants; and
- The role of short-term exceedences.

2.1 Quality and Quantity of Data

The quality of the data available to produce an air quality ranking scheme has impacted on the approach taken. The quantity, quality and reliability of data vary greatly between the different cities.

For European cities, existing EU legislation such as Decision 97/101/EC provides guidance for reporting ambient air quality (e.g. pollutants, units of measurement, averaging times, characteristics of monitoring sites) as well as data validation procedures in order to ensure a certain quality of data. Data are reported each year by Member

States and stored in the AirBase air quality database[1] managed by the European Topic Centre on Air Pollution and Climate Change and Mitigation (ETC/ ACM) on behalf of the European Environment Agency (EEA). The data reported in AirBase, therefore, have a high level of quality. A data capture threshold for inclusion in the ranking scheme has been set at 75% for annual averages, in accordance with commonly used data quality requirements[2].

For certain pollutants (e.g. ozone, PM_{10}, NO_2) compliance with locally relevant air quality objectives is assessed using short-term data measures rather than annual averages; it has, however, not been possible to include this, as insufficient short-term data were available due to the variation in monitoring regimes between countries.

Mitigation

To ensure that, as far as possible, there is a consistency in the quality and reliability of the data sets used in the ranking process, data have been collected from reputable sources such as government databases and scientific reports in order to ensure a certain level of quality and the study has focussed on annual averages, as this is the most frequently reported data. It is a straightforward measure of the overall air quality situation and easily understood by members of the public. In this way, it has been possible to include more cities for comparison on a like-for-like basis.

2.2 Numbers, Locations and Types of the Monitoring Sites

Another consideration when developing the ranking methodology has been the numbers and the locations of the monitoring sites in each city. The number of sites affects the comprehensiveness of the air quality data in a city. When assessing the rankings, it is important to consider the number of monitoring sites in every city by providing details of the number of monitoring sites both per km^2 and per population.

Pollutants, such as $PM_{2.5}$, Polycyclic Aromatic Hydrocarbon (PAH), Benzene, 1,3-butadiaene, are monitored at some locations but they are not universally monitored so a global comparison is not possible.

Pollutant levels at different site types are quite different; for instance, concentrations of NO_2 and PM_{10} at trafficked sites are often higher than at urban background sites, whereas the opposite would be true for ozone (as it is removed from the atmosphere by reaction with nitric oxide - NO). At industrial sites quite high concentrations are often measured but these are usually localised (limited in spatial extent).

Mitigation

Ideally, to mitigate against cities having a different balance between the site types, indices for different site types would be reported separately. This information is, however, not available for all cities, so this has not been possible. The comparison therefore relies upon cities that have a similar balance of urban background and trafficked monitoring sites.

[1] European Environment Agency, AirBase – The European air quality database http://www.eea.europa.eu/data-and-maps/data/airbase-the-european-air-quality-database-7, accessed 21 May 2013.

[2] Defra (2009). Local Air Quality Management Technical Guidance LAQM.TG (09).

2.3 Geographical and Meteorological Factors

The concentrations of certain pollutants e.g. ozone and PM_{10} are influenced by regional factors, geographical and meteorological factors beyond the control of a city. Ozone is formed from precursor gases: NO_X; volatile organic compounds (VOC); and carbon monoxide (CO) that may be due to anthropogenic emissions or non-anthropogenic sources such as wild forest fires. The formation of ozone requires sunlight, so ozone concentrations in Europe tend to be greatest in the southern latitudes. Particulate matter may also be natural in origin, for instance: sea salt, pollen, naturally suspended dust from outside the city including desert dust and particulates from fires and volcanic dust. This mixture of natural and anthropogenic sources is recognised by the EU and Member States can report the proportion of monitored concentrations attributable to natural sources of PM_{10} in mitigation.

Changes in meteorology from year to year will influence the monitored ambient concentration. This will be particularly true for exceedences of a threshold by a short-term average concentration as it involves extremes of concentration that will be highly variable and, for ozone, which relies on sunlight for its creation. The EU limit for ozone averages exceedences over three years to smooth out the impact of inter-annual variations.

Mitigation

AMEC has taken the steps outlined below to account for geographical and meteorological factors in the ranking process:

- Regional, geographical and meteorological factors have been reported for each city; and
- The index has considered an average over several years to smooth out variations between years.

2.4 An Index of Multiple Pollutants

An index based simply on annual average concentrations might take an average across all the pollutant annual averages, but it would be wrong to do so, as the concentrations at which health effects occur are so different. For instance, whilst NO_2 and PM_{10} are usually reported in units of $\mu g\ m^{-3}$, CO is reported in $mg\ m^{-3}$, as the concentrations are so much higher. A multi-pollutant index therefore requires a normalisation of each pollutant with respect to its annual average standard. The normalisation can produce a normalised concentration that is linearly related to the monitored concentration, which is the case if the concentration is simply divided by the standard, or the relationship can be non-linear, which is the case with the COMEAP and CITEAIR hourly and daily indices discussed later in sections 4.1 and 4.2. A non-linear normalisation is useful for amplifying differences in a range of interest, but the disadvantage is that the choice of that range of interest reflects local concerns and may not be appropriate for comparison of cities with a wide range of air pollutants.

Note that no long-term limit or guideline value for ozone concentrations is published by the EU or World Health Organization (WHO), so focussing on annual means alone excludes ozone from consideration. Given the link between ozone concentrations and factors beyond the control of a city, such as latitude and meteorology, it has been considered acceptable to exclude ozone.

Mitigation

Each pollutant has been normalised with respect to the relevant annual average standard. For example, as the air quality standard for annual mean NO_2 is 40µgm^{-3}, an monitored annual average of 80µgm^{-3} would give a score of 2.0. This approach relies on the annual average standard being a suitable measure of the importance of a pollutant.

2.5 The Role of Short-Term Exceedences

Pollutants such as ozone and PM_{10} have acute health effects, i.e., can occur following short-term exposure, as well as chronic effects after long-term exposure, so some indices consider the numbers of exceeedences of threshold values and of the EU short-term limits. Whilst compliance with the EU air quality limits is important to EU cities, an international comparison need not be bound by a focus on the EU limits, which is already adequately addressed by annual reporting of exceedences by Member States to the Commission. These are summarised in annual reports from the European Environment Agency, and are not relevant to cities outside the EU.

In addition, exceedences of a short-term concentration threshold relates to the top percentiles of the concentration distribution, which can vary greatly from year to year and can be very sensitive to the value of threshold chosen. It is therefore a more volatile measure than one based on annual averages that is likely to vary in response to the prevailing weather conditions in any particular year.

Mitigation

Daily average PM_{10}, hourly average NO_2 and 8-hour average ozone have therefore not been included in the indices.

This addresses several of the issues with ozone: the isolation of the short-term volatile sub-index to a separate index, the isolation of effects that are beyond the control of the city; and the non-availability of data.

3. Review of Ranking Schemes for Air Pollution in Cities

In this section, seven schemes that have been used to rank cities in terms of air quality are described. Most are based on measured air quality but others are based on public perception and policies implemented. They have been included to show the range of approaches taken by different organisations and the advantages and disadvantages of each approach. Several are quantitative schemes which use the annual average concentrations of a single or several pollutants whilst others are largely or wholly subjective. The ranking schemes show how the data and method used influence results. The media profile given to the results of the ranking schemes received was taken into consideration when deciding which to review.

3.1 Ranking Schemes for EU Cities

3.1.1 The European Environment - State and Outlook 2010 (EEA)

The European Environment, State and Outlook 2010 (SOER 2010) is aimed primarily at policymakers, in Europe and beyond, involved with framing and implementing policies that support environmental improvements in Europe. The document covers many aspects of the environment. The thematic assessment for the Urban Environment[3] contains a short section on air quality and includes a table, as shown below in Table 3.1, which reports the 10 most polluted cities in Europe for PM_{10}, O_3 and NO_2 based on urban background sites in the AirBase database for a base year of 2008.

For PM_{10} the list is dominated by cities from Bulgaria, Romania and Poland, whilst for O_3 and NO_2 the lists are almost exclusively cities from Italy. Interestingly, it is not the largest cities which appear to be the worst. Milan is the only city which has been selected for analysis in this study which appears on the list. The advantages and disadvantages of this approach are commented upon below the Table.

[3] European Environment Agency (2010), The European Environment State and Outlook 2010, Urban Environment. 2010, Copenhagen, ISBN 978-92-9213-151-7, doi:10.2800/57739
http://www.eea.europa.eu/soer/europe/urban-environment

Table 3.1 The 10 Most Polluted Cities for Daily PM_{10} and O_3 and Annual Mean NO_2 Concentration in 2008 at Urban Background Locations (SOER (2010)[3])

Number of Days of PM_{10} exceedences of EU limit value of 50 µgm^{-3} (daily mean)		Number of Days of O_3 Exceedences of EU Target Value of 120 µgm^{-3} (maximum daily 8 hours mean)		NO_2 Annual Mean Concentrations in µgm^{-3} (the EU limit value is 40 µgm^{-3})	
Plovdiv, Bulgaria	208	Turin, Italy	77	Brescia, Italy	62
Pleven, Bulgaria	185	Campobasso, Italy	74	Turin, Italy	60
Sofia, Bulgaria	176	Bologna, Italy	72	Brasov, Romania	58
Krakow, Poland	152	Bergamo, Italy	69	Modena, Italy	50
Timisoara, Romania	136	Athens, Greece	68	Milan, Italy	49
Rybnik, Poland	122	Novara, Italy	65	Trieste, Italy	48
Nowy Sacz, Poland	116	Cremona, Italy	64	Rome, Italy	43
Craiova, Romania	112	Brescia, Italy	64	Athens, Greece	42
Zabrze, Poland	108	Milan, Italy	62	Padua, Italy	41
Turin, Italy	106	Reggio nell Emilia, Italy	61	Genoa, Italy	41

Notes: Turkish PM_{10} data are not validated and therefore not part of this table reflecting the situation in 2008. Source of data: AirBase (2010).

Advantages

- A quantitative comparison of exceedences of the EU limits for NO_2, O_3 and PM_{10} at urban background sites.

Disadvantages

- The comparison does not discriminate between different sizes of towns and cities, e.g. the population of Campobasso is about 50,000 whereas the population of Milan is 1.4 million; and
- The reporting for some towns and cities may be based on a few or even one monitoring site.

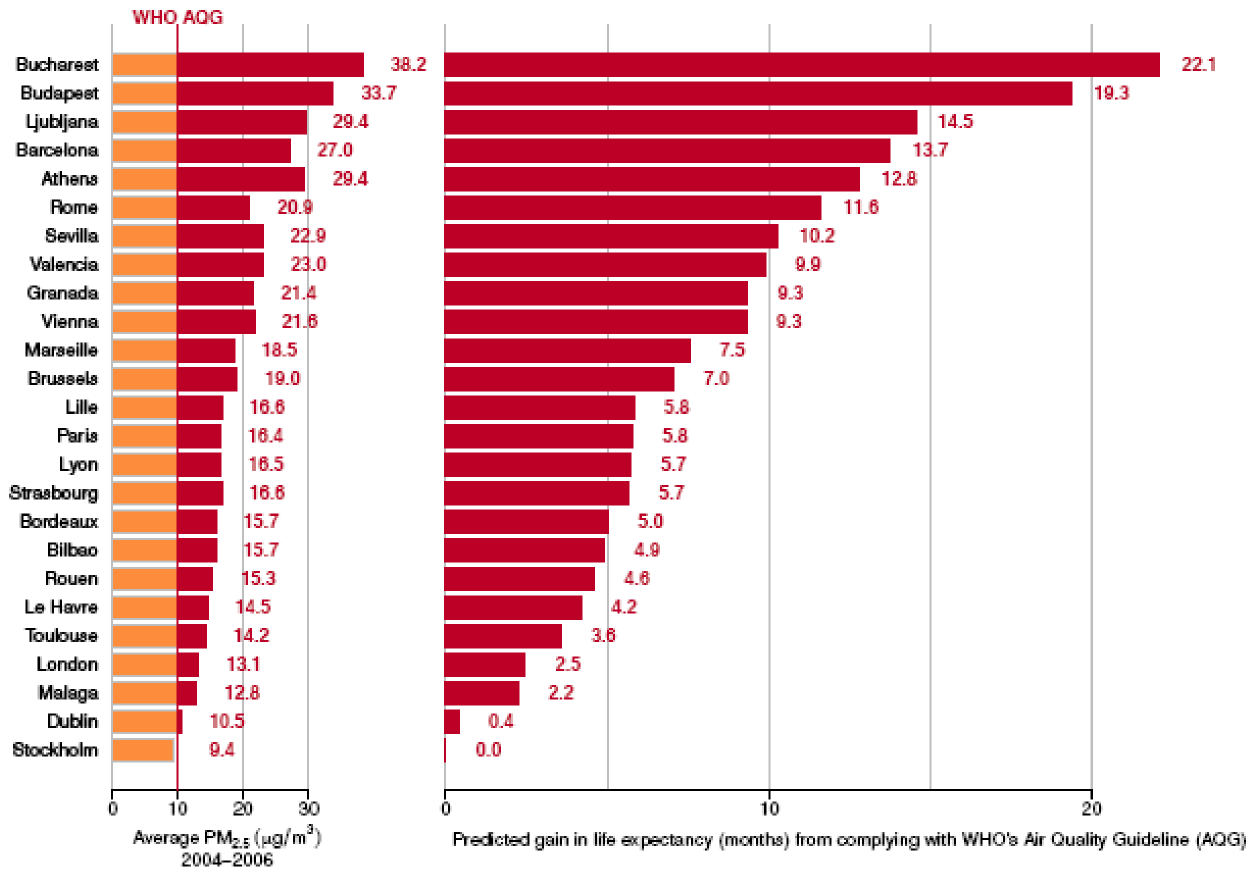
3.1.2 Aphekom Project 2008-2011

The Aphekom Project was a collaborative study undertaken by over 60 scientists across 12 European countries to provide new information and tools that enable decision makers to set more effective European, national and local policies[4].

[4] www.aphekom.org Website of APHECOM: Improving Knowledge and Communication for Decision Making for Air Pollution and Health in Europe, accessed 16 May 2013.

The Aphekom project hopes to contribute to reducing both air pollution and its impact on health and well-being across Europe. The project summary report[5] featured the following figure which used WHO data from 2004-2006 for annual average $PM_{2.5}$ concentrations to rank European cities in terms of the gain in life expectancy if annual average $PM_{2.5}$ concentrations achieved the WHO guideline of 10µg m^{-3}.

Figure 3.1 Predicted average gain in life expectancy (months) for persons 30 years of age and older in 25 Aphekom cities for a decrease in average annual level of $PM_{2.5}$ to 10 µg m^{-3} (WHO's Air Quality Guideline), taken from the summary report of the Aphekom Project[4]



Bucharest had the highest $PM_{2.5}$ concentrations and its citizens were, therefore, calculated to have the highest predicted gain in life expectancy from complying with the WHO 10µg m^{-3} Air Quality Guideline (AQG). Several media outlets picked-up on this study and reported Bucharest to have the worst air quality in Europe.

It should be noted that the purpose of the summary paper was to provide an introduction to the Aphekom project as a whole and not to provide a ranking method for air pollution in cities.

[5] Summary report of the Aphekom project, 2008-2011 (March 2011)
http://www.aphekom.org/c/document_library/get_file?uuid=e711dffa-8b6f-4712-a794-b73fcf351572&groupId=10347

Advantages

- A clear quantitative comparison of $PM_{2.5}$ concentrations and the impact on life expectancy.

Disadvantages

- None within the parameters of looking at $PM_{2.5}$ only, but no other air pollutants considered.

3.1.3 Air Pollution at Street Level in European Cities (EEA)

This report from the European Environment Agency (EEA)[6] studies air pollution levels at traffic hotspot areas in 20 European cities in 2000 (the reference year) and forecasts forward for 2030 for two scenarios: a current legislation scenario, and a maximum feasible reductions scenario. Future concentrations are calculated by dispersion modelling, but, at the outset, the study compares measured concentrations of NO_2, NO_X, PM_{10} and $PM_{2.5}$ at urban trafficked and urban background sites in the reference year with modelled concentrations. All measured results used in the study are taken from AirBase[1].

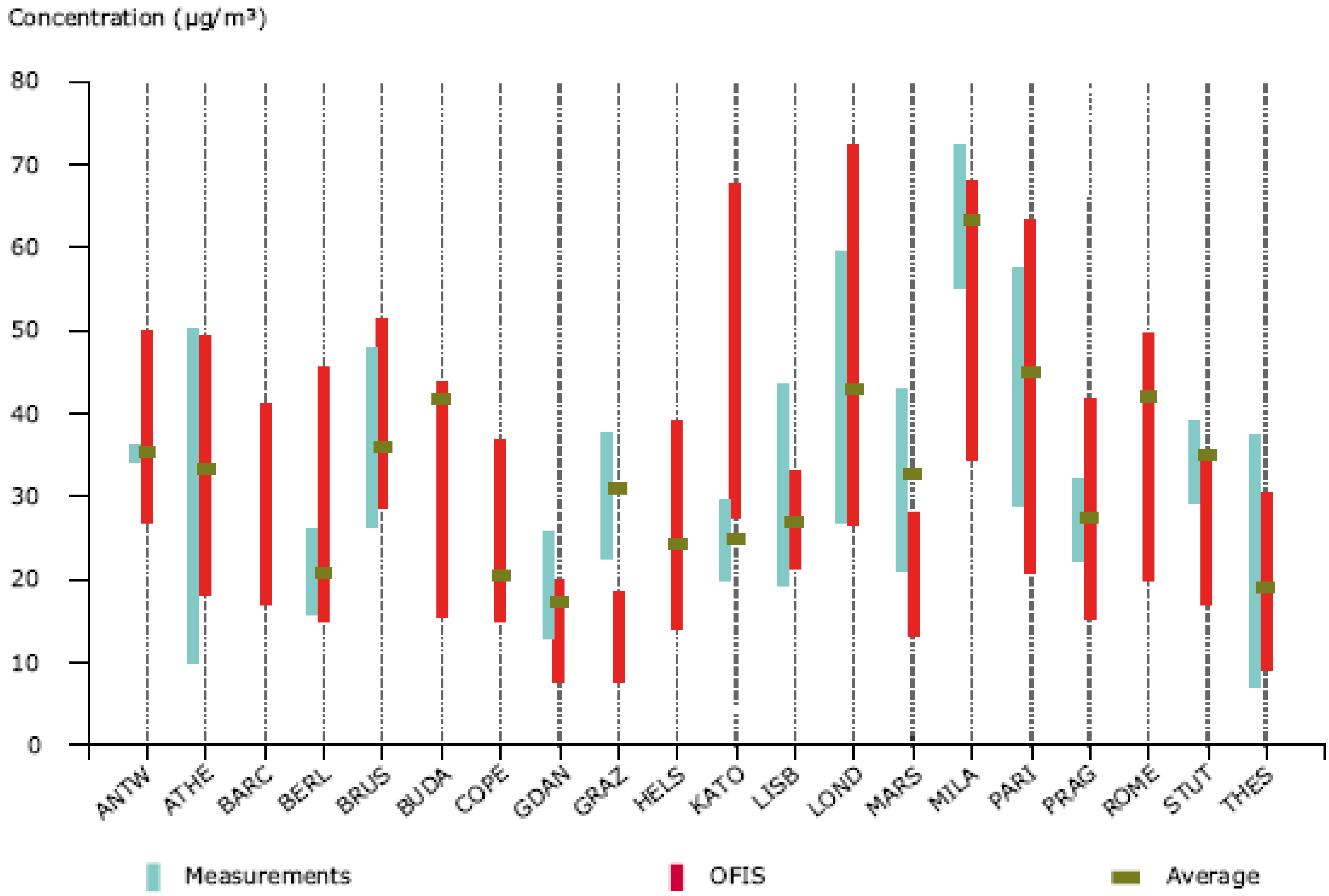
Regional background levels were derived from the European Monitoring and Evaluation Programme (EMEP) model results and the urban background concentrations were modelled using the urban scale model OFIS[7].

Figure 3.2 shows the range and the mean annual average NO_2 urban background concentrations ($\mu g\ m^{-3}$) for the 20 cities in 2000. Whilst the background concentrations in London, Milan and Paris are shown as amongst the highest, as found in this report, Stuttgart which ranks as having high concentrations in this report, does not rank highly in the EEA study. This is because most of the monitors in Stuttgart are at traffic rather than background monitoring sites.

[6] EEA (2006), Air pollution at street level in European cities, ISSN 1725-2237, EEA Technical report No 1/2006, http://www.eea.europa.eu/publications/technical_report_2006_1

[7] Arvanitis A.and Moussiopoulos N., (2003) Estimating long term urban exposure to particulate matter and ozone in Europe, J. Environmental Modelling & Software, Volume 21 Issue 4, April 2006, pp 447-453, Elsevier Science Publishers B. V. Amsterdam, The Netherlands, The Netherlands. doi:10.1016/j.envsoft.2004.05.009

Figure 3.2 Mean annual NO_2 urban background concentrations (µg m^{-3}) in 20 European cities: range of OFIS model results for the reference year 2000 compared to the range of observations and average value of all stations, taken from EEA (2006)[6]



Advantages

- A quantitative comparison of the range and mean annual average NO_2, NO_X, PM_{10} and $PM_{2.5}$ concentrations at urban traffic and urban background sites;

Disadvantages

- The data are from a mixture of years between 2000 and 2003, this adds the additional variables of different meteorological conditions in different years, and the possibility of pollution causing regional events (e.g. volcanic eruptions) in different years; and
- The data are now slightly historical.

3.1.4 Soot-free for the Climate!

The 'Soot-free for the Climate!' campaign has produced a European city ranking available at the web site http://sootfree cities.eu. It is a largely subjective study and the methodology has some notable drawbacks which are described below. The study compared Western European capitals, cities with high air pollution levels and cities which were expected to provide good examples. In total, over 20 municipalities received a detailed questionnaire of which 14 cities provided answers and 17 cities were ranked. Nine measures which have a high potential to reduce particulate matter (PM_{10}), were considered:

- Three categories focusing on technical reduction measures, i.e. retrofitting or equipping diesel engines with particulate filters (DPF) and Low Emission Zones (LEZ), public procurement and non-road mobile machinery;
- One category focusing on economic instruments;
- Three categories focusing on sustainable transport measures, i.e. traffic management, promotion of public transport and of cycling and walking;
- One category looking into reduction success; and
- One category focusing on information and participation.

Each measure was then evaluated for each city to give one of five grades (++, +, 0, - and --) these grades were then translated to corresponding points (5, 4, 3, 2 and 1). The number of points was then converted into the following grading system:

- Grade A if 100-90% of the maximum points were reached (grade A+ if ≥ 97% and grade A- if ≤ 92%);
- Grade B if 89-80% of the maximum points were reached;
- Grade C if 79-70% of the maximum points were reached;
- Grade D if 69-60% of the maximum points were reached; and
- Grade F (fail) if less than 59% of the maximum points were reached.

The aim of the project was not to provide a scientific assessment of the reduction potential of the different measures. Rather, the aim was to select relevant measures and evaluate whether they were planned and carried out in a meaningful and ambitious way.

Berlin finished top of the rankings with a grading of B (84%) closely followed by Copenhagen and Stockholm which both had a grading of B (82%). Of the 17 cities ranked, London finished joint 11th with Brussels, Madrid and Stuttgart, with a grade F (58%).

Advantages

- The method produced a clear final ranking system of the matters considered.

Disadvantages

- Data were gathered by questionnaire, but some cities that did not return the questionnaire were ranked;
- On most of the measures, e.g. reduction success, participation, information, there is no guarantee that the information supplied by the cities are comparable;
- A measure such as increasing public awareness carried the same weight as a measure such as the implementation of a LEZ such as the London LEZ, and the London LEZ that is rigorously enforced could be given the same weight as an LEZ that has no system of enforcement;
- Differences in governance between cities may account for differences in the responses;
- Of the nine measures used for calculating the grades, most relate to changes in policy rather than measuring improvement of present concentrations. A city can therefore gain a high ranking by showing willingness to improve regardless of whether air quality actually improves and regardless of the current levels of pollution;
- The single category relating to the reduction of measured concentrations only considers PM_{10}; and
- The method for calculating the rankings was somewhat over-complicated, with results from the nine measures converted from grades, to points, to totals, to percentages and then back to grades.

3.1.5 Perception of Air Quality 2009 - Urban Audit

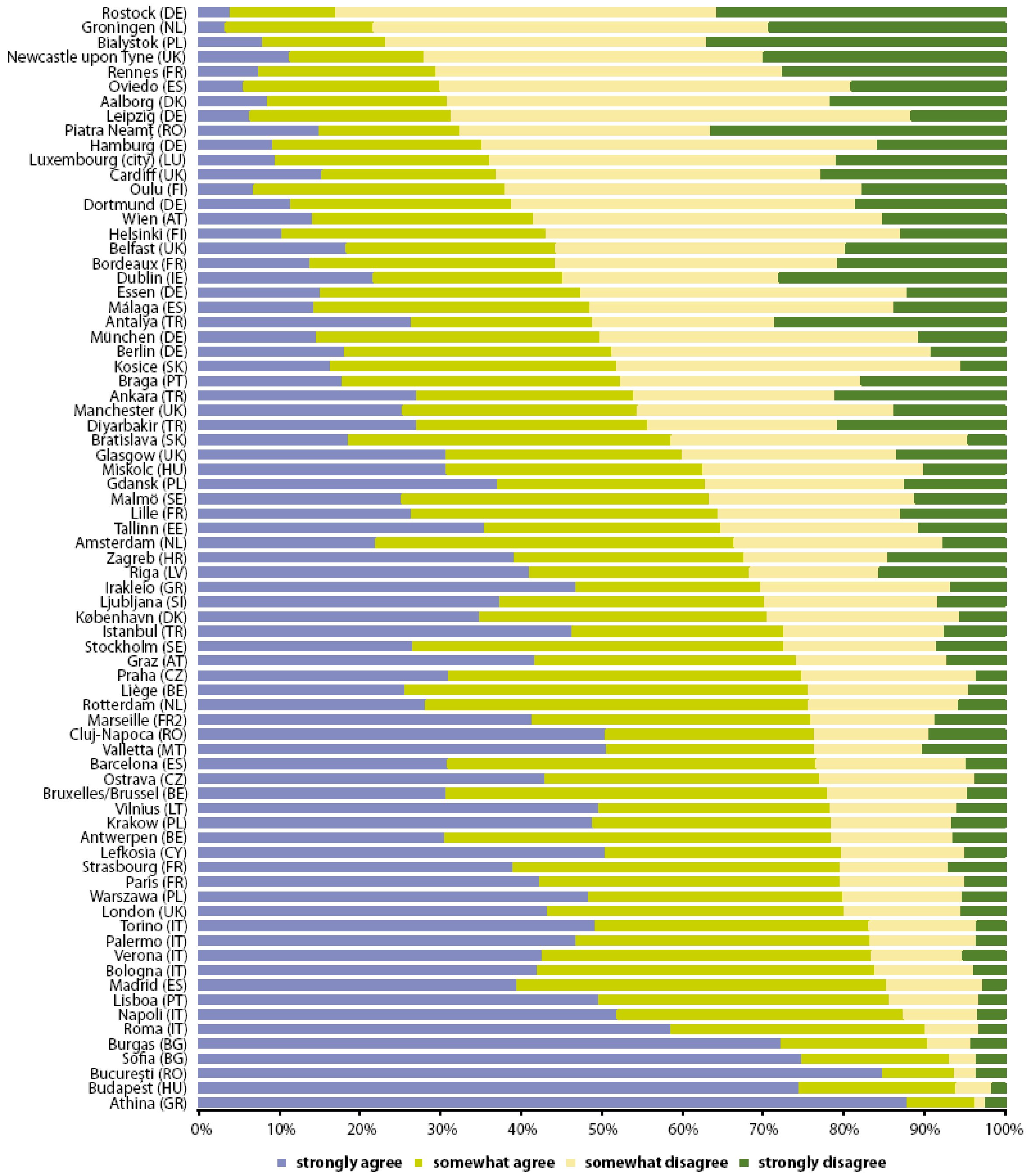
The Urban Audit perception survey[8] took place in 2009 and included 75 cities in the EU, Croatia and Turkey. It is a ranking based on the subjective assessment of air quality by residents of each city. Survey data were collected through telephone interviews of samples of 500 people per city. Respondents were asked for their perception of a wide variety of issues within their city, these included air quality and poverty. Figure 3.3 below shows results of the perception of air quality survey, respondents were asked to respond to the statement ‘in this city air pollution is a problem’.

According to the survey, air pollution appears to be a problem in most cities, with some exceptions. Respondents in Rostock (Germany), Groningen (Netherlands) and Białystok (Poland) mainly felt that air pollution was not a problem in their city. In Oviedo (Spain), Rennes (France), Newcastle (United Kingdom), Piatra Neamt (Romania), Leipzig (Germany) and Aalborg (Denmark), about two thirds of respondents somewhat or strongly disagreed that air pollution was an issue.

[8] European Cities – Demographic Challenges http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/European_cities_-_demographic_challenges#Perception_of_air_pollution

The size of the city seems to matter. Seventeen out of the 23 cities where the majority of respondents thought that air pollution was not a major problem have 500,000 or fewer inhabitants. Nine out of the 13 cities with the most unfavourable perception of air pollution have more than 500,000 inhabitants.

Figure 3.3 Perception of air quality in 75 Urban Audit cities, 2009 (Percentage of respondents who strongly agree, somewhat agree, somewhat disagree or strongly disagree with the statement that in this city air pollution is a problem), taken from European Cities - Demographic Challenges[8]



Advantages

- An interesting subjective survey from a large number of cities.

Disadvantages

- The obvious problem with this survey is that it does not measure air quality but people's perception of air quality. A person's perception of air quality within their city may be influenced more by other factors such as their personal feelings for the city or local media, rather than the level of air pollution.

3.2 WHO Urban Outdoor Air Pollution Database

The WHO Urban outdoor air pollution database can be found on the WHO website[9]. The database contains results of urban outdoor air pollution monitoring from almost 1100 cities in 91 countries. Air quality is represented by the annual mean concentration of fine particulate matter (PM_{10} and $PM_{2.5}$).

The WHO database makes no attempt to compare the different cities or different countries but merely presents the monitored annual averages. The monitored values are not all for the same year and no attempt has been made to update the database since 2011.

Despite the gaps in the data set, the WHO database has been used by several media sources to rank air pollution in different cities. In March of this year the Slate Group (a Division of the Washington Post Company) identified Ahwaz, a city in southwestern Iran and Mongolia's capital, Ulaanbaatar, as the top two polluted cities in the world on the basis of the WHO data.[10]

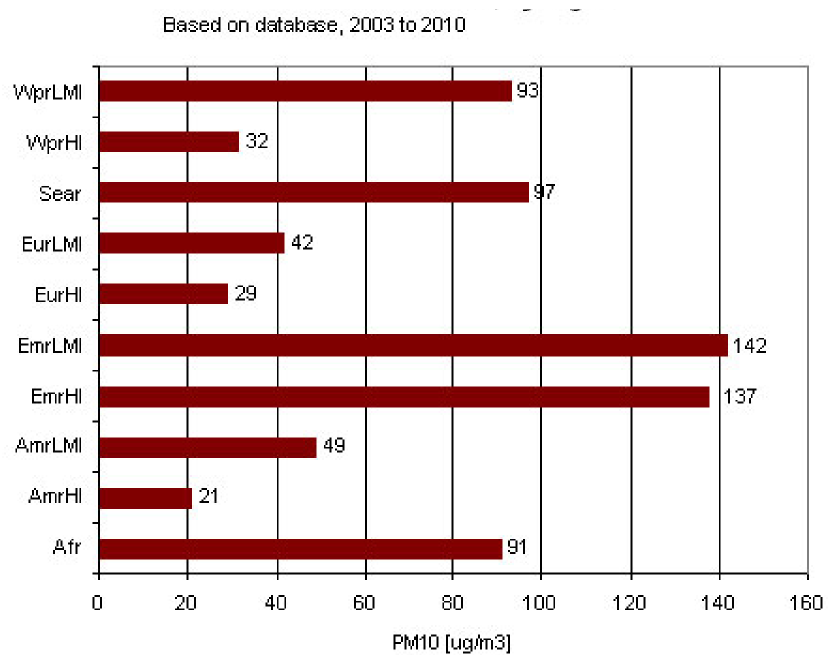
Figure 4.1 shows a WHO summary of PM_{10} data for 2010 averaged by region and low, middle and high categories. Concentrations are highest in the eastern Mediterranean region for both income categories, in south-east Asia (not distinguished by income), low and middle income areas of the western Pacific and in Africa (not distinguished by income). Where the classification is split by income, PM_{10} levels are higher (more polluted) in the low and middle income areas than in the high income areas.

Figure 3.5 shows similar information graphically, with exposure to PM_{10} on a city basis.

[9] WHO Urban outdoor air pollution database http://www.who.int/phe/health_topics/outdoorair/databases/en/

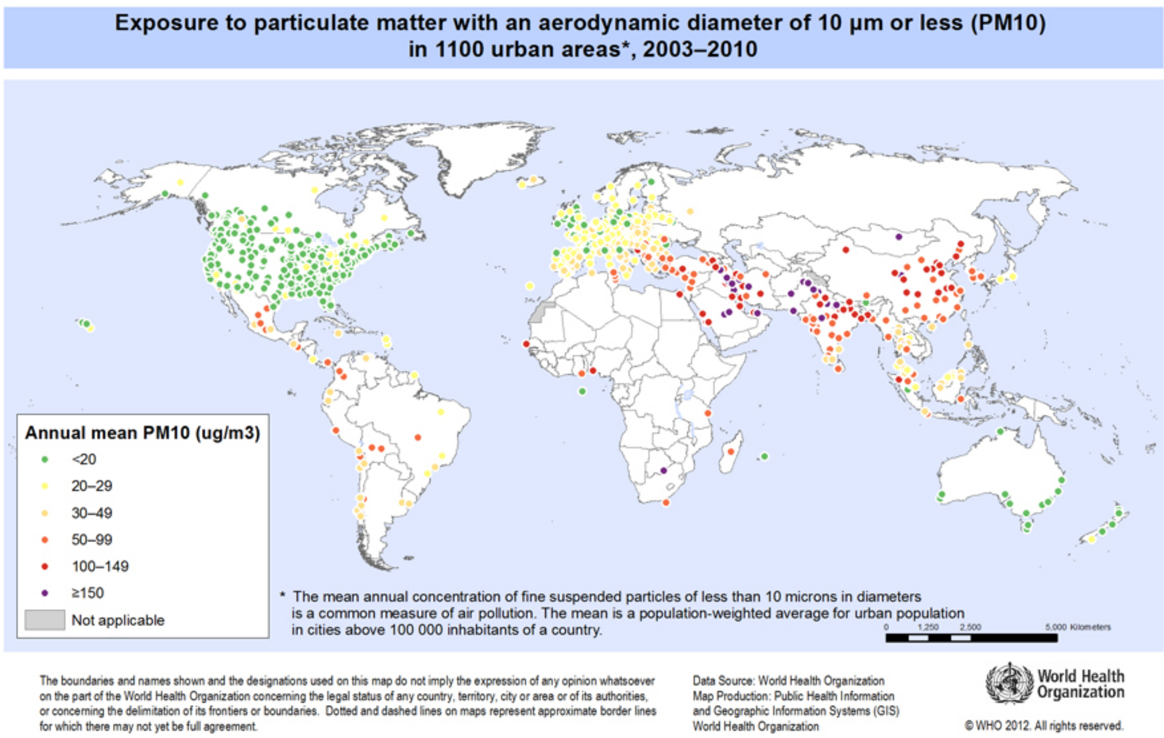
[10]http://www.slate.com/articles/health_and_science/medical_examiner/2013/03/worst_air_pollution_in_the_world_beijing_delhi_ahwaz_and_ulaanbaatar.html

Figure 3.4 Annual Mean PM_{10} in Cities, by World Region and Income



Afr: Sub-Saharan Africa; Amr: Americas; Emr: Eastern Mediterranean; Eur: Europe; Sear: South-East Asia; Wpr: Western Pacific; HI: High income; LMI: Low and middle income; PM10: Fine particulate matter of 10 microns or less.

Figure 3.5 Exposure to Particulate Matter (PM_{10})



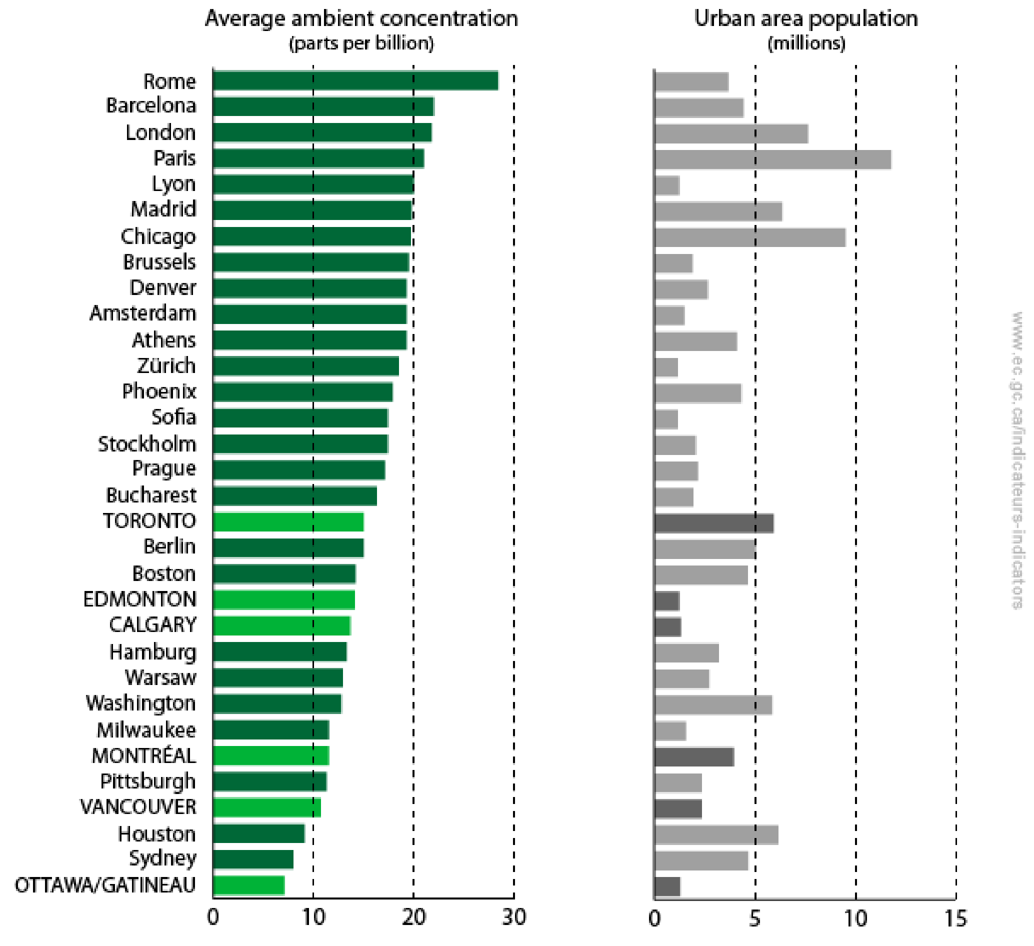
From the World Health Organization website: www.who.int.

3.3 Environment Canada

Environment Canada (Canada's Environment Agency) publishes international comparisons (Europe, USA, Canada and Australia) of urban air quality, based on the official locally produced data (e.g. USEPA, Airbase etc). It uses this to publish city comparisons on its website[11]. The comparator graphs are reproduced below. The webpage includes links to the source data, which are viewable online and downloadable. These webpages also contain links to the methodologies used to produce the data, charts and comparisons.

Figures 3.6 to 3.8 show the 2011 charts for NO_2, $PM_{2.5}$ and ozone. London appears in all the charts: for NO_2 only Rome and Barcelona are shown with a higher annual average concentration than London; for $PM_{2.5}$ London appears mid-table; and for ozone it has one of the lowest levels.

Figure 3.6 Data Charts: 2011 NO_2 Indicators



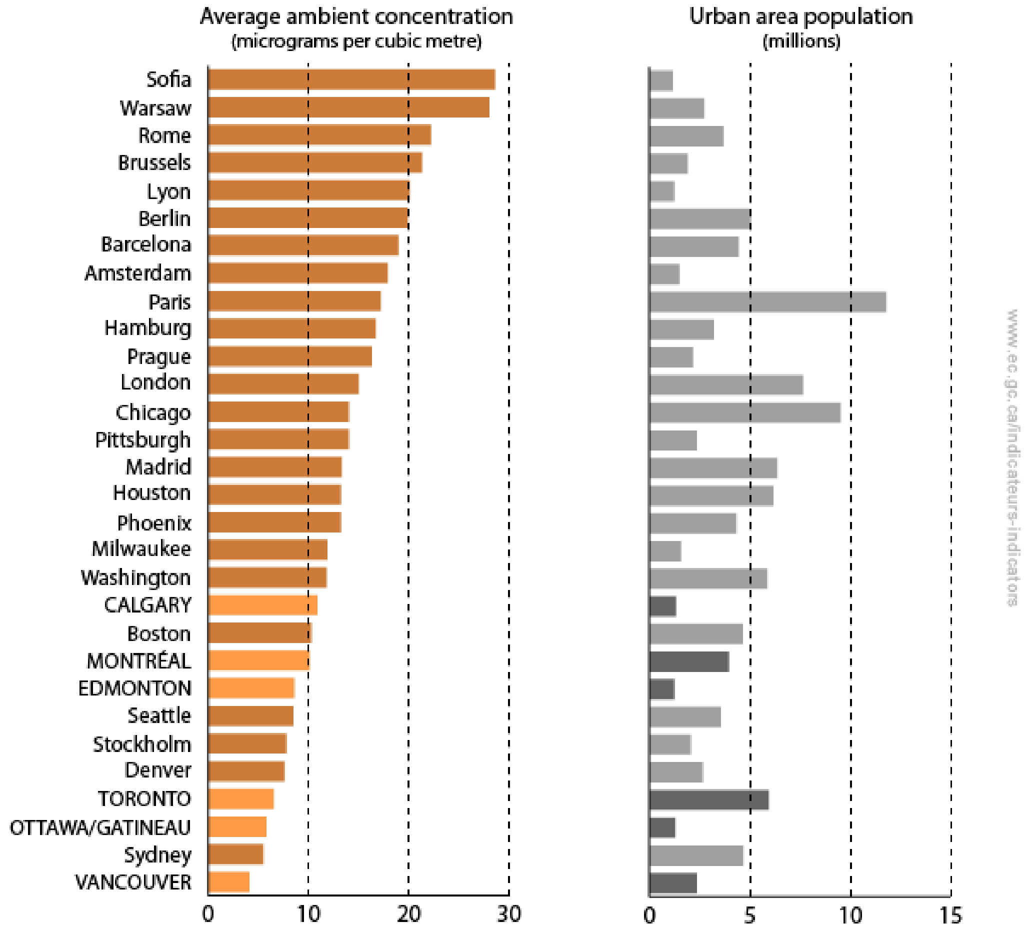
Notes:

The nitrogen dioxide (NO_2) indicators are based on the annual average of 24-hour daily average concentrations. Cities with populations comparable to Canadian cities (urban populations of over 1 million) with available data are included in this analysis.

Source: Environment Canada (2013) National Air Pollution Surveillance (NAPS) program; the European Environment Agency (2013) AIRBASE; the United States Environmental Protection Agency (2013) Air Quality System (AQS) Data; and the Office of Environment and Heritage, New South Wales (2013) Air Quality Data Search.

[11] https://www.ec.gc.ca/indicateurs-indicators/default.asp?lang=en&n=FDBB2779-1 – accessed September 2014

Figure 3.7 Data Charts: 2011 Fine Particulate Matter Indicators

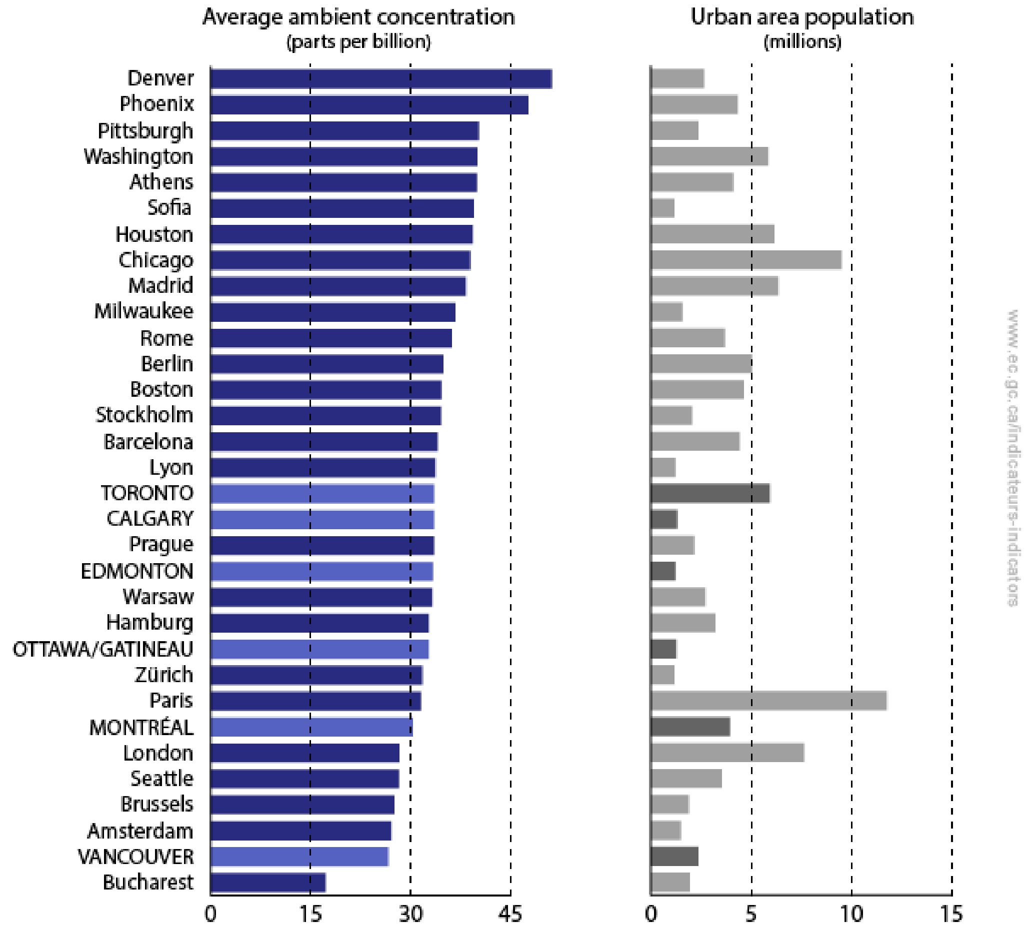


Notes

Note: The fine particulate matter ($PM_{2.5}$) indicator is based on the annual average of 24-hour daily average concentrations. Cities with populations comparable to Canadian cities (urban populations of over 1 million) and available data are included in this analysis.

Source: Environment Canada (2013) National Air Pollution Surveillance (NAPS) program; the European Environment Agency (2013) AIRBASE; the United States Environmental Protection Agency (2013) Air Quality System (AQS) Data; and the Office of Environment and Heritage, New South Wales (2013) Air Quality Data Search.

Figure 3.8 Data charts: 2011 O_3 Indicators



Notes:

Note: The fine particulate matter (PM2.5) indicator is based on the annual average of 24-hour daily average concentrations. Cities with populations comparable to Canadian cities (urban populations of over 1 million) and available data are included in this analysis.

Source: Environment Canada (2013) National Air Pollution Surveillance (NAPS) program; the European Environment Agency (2013) AIRBASE; the United States Environmental Protection Agency (2013) Air Quality System (AQS) Data; and the Office of Environment and Heritage, New South Wales (2013) Air Quality Data Search.

4. Review of Different Indices Reporting Air Pollution Levels

In this section, three schemes that have been used to categorise air quality levels, concentrations and exceedences, are described. Their advantages and disadvantages for potential use in this study are summarised.

4.1 UK Air Quality Index

In the UK, most air pollution information services reporting or forecasting daily air quality use the index and banding system recommended by the Committee on Medical Effects of Air Pollutants (COMEAP) and adopted by Defra[12,13]. The system uses an index numbered 1-10, divided into four bands to provide more detail about air pollution levels in a simple way. The four bands are detailed in Table 4.1 below.

Table 4.1 Health Advice to Accompany the Daily Air Quality Index (DAQI)[12]

Air Pollution Banding	Value	Accompanying health messages for at-risk groups and general population	
		At-risk individuals[a]	General Population
Low	1-3	**Enjoy** your usual outdoor activities.	**Enjoy** your usual outdoor activities.
Moderate	4-6	Adults and children with lung problems, and adults with heart problems, **who experience symptoms**, should **consider reducing** strenuous physical activity, particularly outdoors.	**Enjoy** your usual outdoor activities.
High	7-9	Adults and children with lung problems, and adults with heart problems, should **reduce** strenuous physical exertion, particularly outdoors, and particularly if they experience symptoms. People with asthma may find they need to use their reliever inhaler more often. Older people should also **reduce** physical exertion.	Anyone experiencing discomfort such as sore eyes, cough or sore throat should **consider reducing** activity, particularly outdoors.
Very High	10	Adults and children with lung problems, adults with heart problems, and older people, should **avoid** strenuous physical activity. People with asthma may find they need to use their reliever inhaler more often.	**Reduce** physical exertion, particularly outdoors, especially if you experience symptoms such as cough or sore throat.

[a] Adults and children with heart or lung problems are at greater risk of symptoms. Follow your doctor's usual advice about exercising and managing your condition.

[12] Defra, Daily Air Quality Index, http://uk-air.defra.gov.uk/air-pollution/daqi accessed 16 May 2013

[13] Committee on Medical Effects of Air Pollutants http://comeap.org.uk/ accessed 16 May 2013

The daily air quality index (DAQI) considers the following five pollutants:

- NO_2;
- SO_2;
- O_3;
- $PM_{2.5}$; and
- PM_{10}.

Table 4.2 below shows the bandings for each of the pollutants. The overall pollutant banding for a location is determined by the highest banding of the five pollutants. It is appropriate to use the maximum of the pollutants when forecasting pollution and issuing alerts. The advantage of the COMEAP banding system over other systems such as CITEAIR (section 4.2) is that having ten colour levels, the public will distinguish small changes in pollution levels from day to day whereas coarser systems may rarely show a change.

Table 4.2 DAQI Colour Coded Banding for Each Pollutant[12]

Pollutant	Measurement Period	Concentration (μg m^{-3})									
		1	2	3	4	5	6	7	8	9	10
		Low			Moderate			High		Very High	
NO_2	Hourly mean	0-66	67-133	134-199	200-267	268-334	335-399	400-467	468-534	535-599	600 or more
SO_2	15-minute mean	0-88	89-176	177-265	266-354	355-442	443-531	532-708	709-886	887-1063	1064 or more
O_3	Running 8-hourly mean	0-33	34-65	66-99	100-120	121-140	141-159	160-187	188-213	214-239	240 or more
$PM_{2.5}$	24 hour running mean	0-11	12-23	24-34	35-41	42-46	47-52	53-58	59-64	65-69	70 or more
PM_{10}	24 hour running mean	0-16	17-33	34-49	50-58	59-66	67-74	75-83	84-91	92-99	100 or more

Advantages

- The simple 1-10 number and colour index with the current banding thresholds is suitable for distinguishing daily changes in pollution in the UK.

Disadvantages

- The index is for daily pollution rather than long-term pollution; and

- Use of the maximum index of all the pollutants is suitable for forecasting and alerting but not for an assessment of ambient air quality.

4.2 CITEAIR

CITEAIR and CITEAIR II (Common Information to European Air, http://www.citeair.eu) were projects co-funded by the European Union's INTERREG IIIC and IVC Programmes. The projects started in March 2004 and ended in December 2011. Under CITEAIR an air quality index was developed with the purposing of easily comparing air quality in European cities in real time. It therefore has a particular interest in short-term concentrations and its scope is limited to the EU. Following the conclusion of the CITEAIR projects, the website hosted by CITEAIR[14] continues to provide an hourly updated index for up to six pollutants (NO_2, O_3, PM_{10}, $PM_{2.5}$, SO_2 and CO) for over a hundred European cities. The purpose is to give a dynamic picture of the air quality situation in each city, not for compliance checking.

To present air quality in European cities in a comparative and easily understandable way, the raw measured data are transformed into a single relative figure: the Common Air Quality Index (or CAQI[15]).

Three different indices have been developed to enable the comparison of three different timescales:

- An hourly index -which describes the air quality today, based on hourly values and updated every hour;
- A daily index - which stands for the general air quality situation of yesterday, based on daily values and updated once a day; and
- An annual index - which represents the city's general air quality conditions throughout the year compared to European air quality norms. This index is based on the annual average concentration compared to annual limit values, and is updated once a year.

The calculation method for the CAQI was developed following a review of a number of existing air quality indices, and it reflects the EU alert threshold levels or daily limit values as far as possible. In order to make cities more comparable and independent of the nature of their monitoring network, two types of monitoring locations are used and reported separately:

- Roadside, being representative of city streets with high traffic flows (based on roadside monitoring stations); and
- Background, representing the general situation of the given agglomeration (based on urban background monitoring sites).

The hourly and daily indices are calculated in the same way, using the sub-indices for each pollutant at roadside and background sites given in Table 4.3, differing only in the frequency with which they are updated. This use of a

[14] CITEAIR http://www.airqualitynow.eu/

[15] Van den Elshout S. et al, (2012) CAQI Air quality index, Comparing Urban Air Quality across Borders - 2012 http://www.airqualitynow.eu/download/CITEAIR-Comparing_Urban_Air_Quality_across_Borders.pdf

sub-index or index is a form of normalisation of the concentrations. In this case the normalisation results in a non-linear relationship between the concentration and the index (normalised concentration). The overall CAQI for a site is then the highest value of the sub-indices. The CAQI for a city is the highest of all the CAQIs for different monitoring site types.

The indices are based on the three pollutants of most concern in Europe (PM_{10}, NO_2, O_3), but also take into account three additional pollutants (CO, $PM_{2.5}$ and SO_2) where data are available. Ozone is only included in the urban background index as ozone concentrations at traffic stations will be lower due to the reaction with NO emitted from the traffic.

The indices have five colour-coded levels from Very Low to Very High, to give a relative measure of the amount of air pollution.

Table 4.3 CITEAIR Common Air Quality Index (CAQI) Calculation Grid[14]

Index Class	Grid	ROADSIDE INDEX						BACKGROUND INDEX							
		Mandatory pollutant			Auxiliary pollutant			Mandatory pollutant				Auxiliary pollutant			
		NO_2	PM_{10}		$PM_{2.5}$		CO	NO_2	PM_{10}		O_3	$PM_{2.5}$		CO	SO_2
			1 hour	24 hours	1 hour	24 hours			1 hour	24 hours		1 hour	24 hours		
Very High	>100	>400	>180	>100	>110	>60	>20000	>400	>180	>100	>240	>110	>60	>20000	>500
High	100	400	180	100	110	60	20000	400	180	100	240	110	60	20000	500
	75	200	90	50	55	30	10000	200	90	50	180	55	30	10000	350
Medium	75	200	90	50	55	30	10000	200	90	50	180	55	30	10000	350
	50	100	50	30	30	20	7500	100	50	30	120	30	20	7500	100
Low	50	100	50	30	30	20	7500	100	50	30	120	30	20	7500	100
	25	50	25	15	15	10	5000	50	25	15	60	15	10	5000	50
Very Low	25	50	25	15	15	10	5000	50	25	15	60	15	10	5000	50
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

- NO_2, O_3, SO_2: hourly value / maximum hourly value in $\mu g\ m^{-3}$
- PM_{10}, $PM_{2.5}$: hourly value / maximum hourly value or adjusted daily average in $\mu g\ m^{-3}$
- CO: 8 hours moving average / maximum 8 hours moving average in $\mu g\ m^{-3}$

CITEAIR also defined a year average common air quality index (YACAQI) that provides a general overview of the air quality situation in a given city throughout the year with regard to the European norms. Unlike the hourly and daily indices, the annual index is presented as a ratio of pollutants actual values divided by the EU target values (annual air quality standards plus the PM_{10} daily average and the 8-hourly ozone objectives). For annual averages this gives a linear relationship between concentration and the pollutant sub-index.

The sub-indices for each pollutant are averaged across the urban background and urban traffic sites separately. These are then averaged across the pollutants to give the citywide urban background and traffic YACAQI. NO_2, PM_{10} (annual) and PM_{10} (daily) are the pollutants averaged for the traffic sites. Ozone (8-hourly) is also included in the calculation at urban background sites.

- If the index is higher than 1: for one or more pollutants the limit values are not met.
- If the index is below 1: on average the limit values are met.

Table 4.4 below shows the pollutants considered in the annual air quality index and their relevant values.

Table 4.4 CITEAIR Common Annual Air Quality Index Calculation Scheme[15]

	NO_2	PM_{10} annual average	PM_{10} number days with daily average > 50µg m^{-3}	Ozone, number days with max 8-hour average > 120µg m^{-3}	$PM_{2.5}$	SO_2	Benzene
Target value (µg m^{-3})	40	40	-[a]	-[b]	20	20	5

Notes: [a] Evaluated as Log (number of days + 1)/Log (36)

[b] Evaluated as (number of days/ 25)

Although the CITEAIR site considers data from over 100 European cities participation in the site is voluntary at the decision of the local authority, consequently the locations listed do not always represent the most relevant locations. For example, of the ten locations listed in the United Kingdom, relatively small settlements such as Lewes, Eastbourne and Storrington are listed whilst major conurbations such as Manchester and Birmingham are not. Additionally, again due to the voluntary nature of the submission of data, the data set contains many gaps. No annual data are available for any of the UK sites for 2010, 2011 and 2012. The most recent annual data available for the London monitoring locations is 2008.

CITEAIR request that any group using the index establish a user agreement with them:

> *Potential users of the CAQI must notify the CITEAIR partners (at caqi@airqualitynow.eu) and establish a user agreement (www.airqualitynow.eu/about_copyright.php#legal_agreement).*
> *This way, users can be kept informed in case of further developments concerning the index.*
> *The use of the CAQI is free of charge for non commercial purposes.* [15]

Advantages

- The CITEAIR year average common air quality index (YACAQI) is a multi-pollutant index that has been developed as an output of a multi-year, multi-partner European project. The index methodology has, thus, been reviewed and tested, at least for the European context.

Disadvantages

- The CAQI was developed to give real time information on pollutant levels. It therefore has a particular interest in short-term concentrations. The annual index is a later extension;
- The need for a user agreement could tie an assessment to a methodology that may not be appropriate for the comparison of air quality in cites, in terms of the levels used and the treatment of short-term air quality;
- The cities chosen are not necessarily those with the highest air pollution levels; and
- The representativeness and suitability for comparison of reported monitoring sites is not considered.

4.3 WHO Air Quality Guidelines

The WHO air quality guidelines (AQGs) are designed to offer guidance in reducing the health impacts of air pollution. First produced in 1987, the latest update (2005[16]) of the AQGs relates to four common air pollutants: particulate matter (PM); ozone (O_3); nitrogen dioxide (NO_2); and sulphur dioxide (SO_2).

The AQGs are based on extensive scientific evidence relating to air pollution and its health consequences, and therefore offers a strong foundation for the recommended guidelines. They are intended for worldwide use but have been developed to support actions to achieve air quality that protects public health in different contexts, so in addition to guideline values, interim targets are given for some pollutants. These are proposed as incremental steps in a progressive reduction of air pollution and are intended for use in areas where pollution is high. These targets aim to promote a shift from high air pollutant concentrations, which have acute and serious health consequences, to lower air pollutant concentrations. Progress towards the guideline values should, however, be the ultimate objective of air quality management and health risk reduction in all areas.

Table 4.5 shows an example of the hierarchy of interim targets and air quality guidelines, in this case for annual average PM_{10} and $PM_{2.5}$.

[16] WHO (2005) WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global update 2005. Summary of risk assessment. WHO/SDE/PHE/OEH/06.02. http://whqlibdoc.who.int/hq/2006/WHO_SDE_PHE_OEH_06.02_eng.pdf

Table 4.5 WHO Air Quality Guidelines and Interim Targets for Particulate Matter: Annual Mean Concentrations[a] taken from the WHO Air Quality Guidelines[16].

	PM_{10} (μg m^{-3})	$PM_{2.5}$ (μg m^{-3})	Basis for the selected level
Interim target-1	70	35	These levels are associated with about a 15% higher long-term mortality risk relative to the AQG level.
Interim target-2	50	25	In addition to other health benefits, these levels lower the risk of premature mortality by approximately 6% [2–11%] relative to theIT-1 level.
Interim target-3	30	15	In addition to other health benefits, these levels reduce the mortality risk by approximately 6% [2-11%] relative to the -IT-2 level.
Air quality guideline (AQG)	20	10	These are the lowest levels at which total, cardiopulmonary and lung cancer mortality have been shown to increase with more than 95% confidence in response to long-term exposure to PM2.5.

Notes: [a] The use of $PM_{2.5}$ guideline value is preferred.

Advantages

- Internationally recognised, health-based objectives. The annual average values could be used in this study to normalise the concentrations;

Disadvantages

- The WHO has not set guideline values for all pollutants covered by the EU limit values, e.g. no WHO guideline is set for benzene.

5. Proposed Ranking Method

This section describes a ranking method for air quality in cities that can be tailored according to the data available and the pollutants of interest, but has, as an over-riding principle, that the data from all cities being compared is treated on the same basis.

5.1 Overview

The proposed ranking scheme will use annual average concentrations, normalised with respect to annual average objectives. It is proposed that short-term PM_{10} concentrations be excluded from the index for the reasons discussed in section 2.5.

Ozone, if reported, should be included in a separate index to address several of the issues with ozone: the short-term and variable nature of ozone pollution; the concentrations are beyond the control of the city, as ozone concentrations depend on factors such as latitude and meteorology; and the limited availability of data. The preference for ozone is to use the number of exceedences per annum of a threshold, such as the EU limit of 120 µg m^{-3} as an 8-hourly average, but the annual average would be an acceptable alternative basis for the ozone ranking,

The proposed index principle and calculation procedure are described below:

Overall Principles

- In any comparison the data from the cities must be treated consistently; and
- Indices for different site types (urban background, traffic, industrial) should be reported separately, where possible.

Calculation Procedure

- Annual average concentrations for each pollutant at each site, for one or more years, are normalised with respect to an annual average objective;
- A weighting factor applying a relative level of importance is applied to each pollutant so that the sub-indices are summed to give an overall index for each city; and
- For the ozone index the number of days on which the EU limit of 120 µg m^{-3} as an 8-hourly average is exceeded at urban background sites, is normalised by 25, the number of exceedences permitted by the EU.

Table 5.1 gives an example of annual average limits that can be used to normalise the concentrations and exceedences.

Figure 5.1 illustrates the calculation methodology. In calculating the overall weighted index, if a pollutant is absent, the weighting attributed to it is redistributed equally amongst the pollutants for which sub-indices do exist. This ensures that the sum of the individual pollutant weightings is always equal to 1.0 and that not measuring a pollutant does not result in a lower weighted index value. It does, however, alter the importance of the pollutants that are monitored in that city's weighted index value.

Table 5.1 Annual Statistics and Values for Normalisation for Each Pollutant

Pollutant	City annual value (background, traffic, industrial index)	Value for normalisation
NO_2	Annual average concentration	*40 μgm^{-3}
CO	Annual average concentration	5,000 μgm^{-3}
SO_2	Annual average concentration	**20 μgm^{-3}
PM_{10}	Annual average concentration	*40 μgm^{-3}
$PM_{2.5}$	Annual average concentration	*25 μgm^{-3}
Benzene	Annual average concentration	*5 μgm^{-3}
Pollutant	**City annual value (ozone index)**	**Value for normalisation**
Ozone	Number of exceedences of 120 μgm^{-3} by the maximum daily 8-hour average	*25 (exceedences)

Notes: *EU limit value for health; ** EU limit value for vegetation.

The features of the index are listed here as Basic and Advanced features and are described in more detail below.

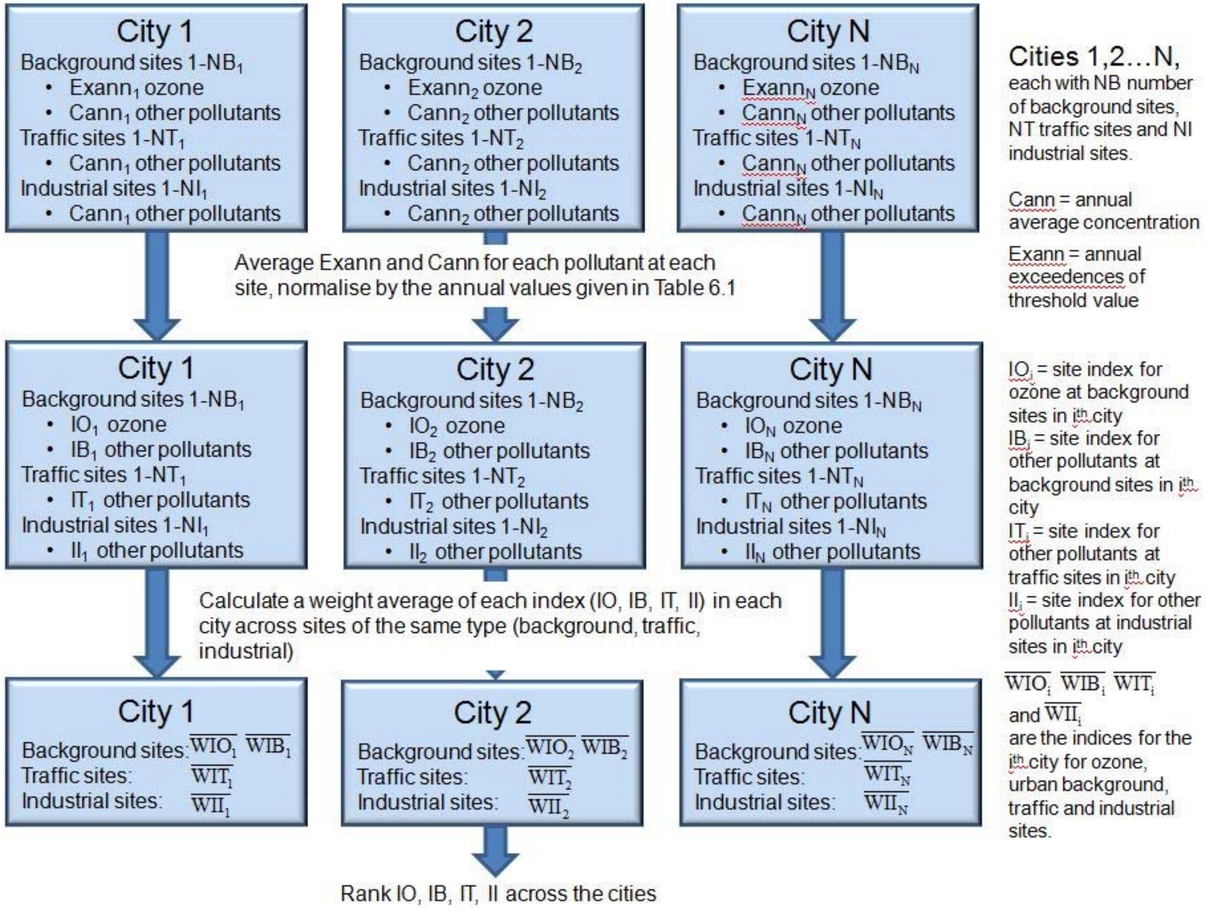
Basic Features

- Flexibility to use EU, WHO or other air quality standards for the calculation of the sub-indices and the overall ranking;
- Flexibility to decide the weight of each pollutant in the overall city index; and
- Flexibility to average over multiple years.

Advanced

- Includes the possibility of grouping cities to aid the presentation of results;
- A "Notes" field to be included as part of the comparison to prompt for the inclusion of key points such as data quality, lack of monitoring sites or abnormal events such as volcanic eruptions or regional fires; and
- Include a direction of travel indicator.

Figure 5.1 Flow Chart Illustrating the Calculation Methodology



5.1.1 Air Quality Standards

For each pollutant, the monitored annual mean values will be scaled against the concentrations that are set either by EU legislation, WHO guidelines or other standards. The normalisation with respect to the standards provides a sub-index for each pollutant which will be less than 1 if the standard is met and greater than 1 if the air quality limit is exceeded, but the index does not focus on whether the concentration is exceeded or not.

5.1.2 Pollutant Weighting

The methodology can accommodate all regulated pollutants but is also flexible enough to focus on specific pollutants. The reasons for considering weightings are as follows:

- Poor data availability: only consider NO_2 and PM_{10};
- Good data availability: consider all the pollutants for which there are EU annual average limit values to assess performance;
- Comparison of cities that are heavily industrialised: consider NO_2, SO_2, CO;
- Comparison of cities where industrial emissions are known to be low and emissions from traffic dominate: NO_2, PM_{10}, $PM_{2.5}$;
- Comparison of cities with heavy use of biofuels, e.g. Brazil: consider acetaldehyde, ethanol and NO_2; and
- The relative health impacts of the pollutants.

Individual pollutants will then be given different weightings in the calculation of the overall city index, based on their importance in terms of compliance, health impacts and the likelihood of reliable monitoring data being available. Table 6.2 shows chosen weightings for calculation of the Citywide, Citywide/ traffic focussed and Health Impacts indices.

The Health Impacts Index has been developed using damage costs produced by Defra[17] which include estimates of the heath impacts (both deaths and sickness) of PM_{10}, NO_X, SO_2 and ammonia (NH_3). The PM_{10} and SO_2 estimates also include the impact of building soiling and the impact on materials respectively. The latest damage costs published by Defra[18] give damage costs per tonne of £955 for NO_X, £1,633 for SO_X and £48,517 for PM ("transport average" value. The "PM transport central London" figure of £221,726 has not been used as the index would essentially replicate the index considering PM alone). The values reflect the evidence base on the severity of impacts for these pollutants. The WHO[19] has discussed the well-established link between particulate concentrations and health impacts and the health benefit of reducing particulate concentrations:

[17] Department for Environment, Food & Rural Affairs (2013) *Valuing impacts on air quality: Supplementary Green Book guidance*.

[18] https://www.gov.uk/air-quality-economic-analysis - accessed September 2014

[19] WHO Regional Office for Europe (2013) Review of evidence on health aspects of air pollution – REVIHAAP Project, Technical Report

"The adverse effects on health of particulate matter (PM) are especially well documented. There is no evidence of a safe level of exposure or a threshold below which no adverse health effects occur."

PM_{10} and $PM_{2.5}$ are more strongly associated with health impacts than NO_2 and the EU limit for $PM_{2.5}$ is formulated in terms of exposure reduction because any reduction in ambient $PM_{2.5}$ concentration will be beneficial in terms of health impacts for the whole population. Defra's Damage Cost Methodology for monetizing air quality impacts supports the greater value attached to reducing particulate concentrations. Defra's methodology gives the years of life lost[20] due to PM from traffic, in London, to be over seven times greater than that due to NO_X. Similarly, respiratory and cardiovascular hospital admissions per year due to PM from traffic are over five times greater than those due to NO_X[21].

Table 5.2 Pollutant Weightings for Calculation of the Weighted Indices

	Citywide Index	Citywide/Traffic Focussed Index	Health Impact Index
Pollutant	**Weighting**	**Weighting**	**Weighting**
NO_2	0.3	0.4	0.02
CO	0.0	0.0	0.00
SO_2	0.3	0.0	0.03
PM_{10}	0.3	0.4	0.71
$PM_{2.5}$	0.1	0.2	0.24
Benzene	0.0	0.0	0.00

Notes: $PM_{2.5}$ is given a reduced weighting in all indices due to anticipated lack of data.

CO is not given a weighting due to anticipated lack of data.

Ozone has not been assessed. The weighting has been applied to all sites equally, so there has been no distinction between background, traffic and industrial sites. Rural sites have been excluded. Annual average concentrations have been excluded if they are known to be based on a data capture of less than 75%.

5.1.3 Year Weighting

Where data exist for multiple years this is averaged to give an overall mean in order to reduce the influence of any anomalies or weather influenced 'bad years'.

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http://www.euro.who.int/__data/assets/pdf_file/0004/193108/REVIHAAP-Final-technical-report-final-version.pdf

[20] Years of life lost over a period of 100 years

[21] Defra (2011) Air Quality Appraisal – Damage Cost Methodology, Interdepartmental Group on Costs and Benefits, Air Quality Subject Group, February 2011
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/182391/air-quality-damage-cost-methodology-110211.pdf

5.1.4 Grouping City Results

Whilst cities must be compared using the same method, the results could be grouped according to cities that are similar, for instance in terms of population and/ or degree of industrialisation and widespread use of coal or density of the monitoring network. This would help the user separate out the effects of different factors.

5.1.5 Direction of Travel Indicator

A direction of travel indicator could be used to tie the assessment of monitored data to the assessment of policy measures, or to add more information on the monitored concentrations.

Considering the monitored concentrations, whilst it is proposed that the index can assess the air quality for a year or a number of years, it would also be useful to indicate whether the air quality is improving or worsening. The index could be based on calculations at each monitoring site:

- The difference between the annual average concentration in the first year and last year of the assessment, which is then normalised with respect to the annual average standard;
- The difference between the annual average concentration in the last year and the mean, which is then normalised with respect to the annual average standard; and
- The gradient of a (straight) line of best fit which is then normalised with respect to the annual average standard.

Or calculations on the final indices:

- The comparison between the overall indices for the final year and the whole period.

5.1.6 Notes Field

Including a Notes field as part of the index would prompt users to note external factors or questions of data quality. As a minimum the Notes field can be used to contextualise the number of monitoring sites in every city by providing an indicator such as number of monitoring sites per km^2 and/ or per population or monitors per km^2.

6. Selection of Cities

18 cities from the EU and 21 cities from outside the EU were selected for the ranking study. The selection was intended to be sufficiently large to be able to draw useful comparison whilst being manageable in terms of time and budget. The basis for the selection of cities was based on a combination of factors as follows:

- Population and area, to include major centres of population that are comparable to London in population and area;
- Importance, to include capital cities and major cities;
- Geographical spread across the world;
- At least one city from Brazil, Russia, India and China, the four large, developing countries known as the "BRIC" countries;
- Large cities from the "next 11"[22] developing countries after the BRIC countries;
- Countries that are part of the World Cities Culture Report 2012[23], a major global initiative on culture and the future of cities, established by the Mayor of London;
- Cities that are known to have launched initiatives or taken measures to address air quality issues;
- Cities where a need for air quality improvement is acknowledged; and
- Cities that compete with London economically or financially.

Table 6.1 below details the cities from the EU selected for the study and Table 6.2 shows the non-EU cities. Their population and size are given although it should be noted that there are different measures of what constitutes a city, whether the boundary is a strict government boundary or a broader community interpretation and, hence there are varying estimates of population and size. The city classification by the Globalization and World Cities Research Network[24], (GaWC), is also given. GaWC is a thinktank based at Loughborough University. The GaWC studies the relationships between World cities in the context of globalisation, categorizing cities into alpha, beta and gamma tiers based upon their international connectedness. The 2010 GaWC category for the cities selected in this study are also detailed in Table 6.1, all of which are in the alpha or beta categories. London and New York are the only cities in the world classified by GaWC as alpha++ cities. Paris is the only European city classified as alpha+, whereas there are several cities in the list classified as alpha.

The colour shading shows the ranking from highest population or area (darkest) to lowest population or area (lightest) of the cities in this study. The populations and areas are, where possible, those corresponding to the area

[22] Mexico, Vietnam, South Africa, Iran, Egypt, Turkey, Indonesia, Pakistan, Bangladesh, Nigeria

[23] http://www.worldcitiesculturereport.com/

[24] The Globalization and World Cities Research Network http://www.lboro.ac.uk/gawc/

from which monitoring data have been gathered. The "Population rank amongst all cities" gives the population for the city proper that was one of the factors in the city selection, but may differ from the population in the area of monitoring data.

Table 6.1 EU Cities Selected for Ranking

City	Population [a]	Population Rank [a]	Area (km^2) [b]	2010 GaWC Category [c]	Additional Information
Amsterdam	755,605	16	219	Alpha	-
Barcelona	1,611,013	10	101	Alpha-	Major refit of buses
Berlin	3,460,725	3	892	Beta+	World city, tackling NRMM[d]. LEZ[e]
Brussels	1,136,778	14	161	Alpha	Air quality challenges, capital & European Community centre
Bucharest	1,924,229	6	228	Beta	-
Budapest	1,712,210	8	525	Beta	-
Frankfurt	679,664	17	248	Alpha	Major financial centre
London	8,173,941	1	1,572	Alpha++	LEZ, major financial centre
Madrid	3,198,645	4	606	Alpha	-
Milan	1,307,495	12	182	Alpha	Air quality challenges
Munich	1,353,186	11	310	Alpha-	-
Paris	6,507,783	2	762	Alpha+	Major financial centre
Prague	1,241,664	13	496	Beta+	-
Rome	2,743,796	5	1,285	Beta+	-
Stockholm	864,324	15	209	Beta+	2010 European green capital, aim to be fossil fuel free
Stuttgart	606,588	18	207	Beta-	Air quality challenges
Vienna	1,687,271	9	415	Alpha-	-
Warsaw	1,714,446	7	517	Alpha-	-

Notes:

[a]Population data taken from European Commission Eurostat http://epp.eurostat.ec.europa.eu/ - accessed September 2014

[b]City area data taken from the Wikipedia page of the respective city e.g. London : http://en.wikipedia.org/wiki/London

[c]The Globalization and World Cities Research Network http://www.lboro.ac.uk/gawc/

[d]NRMM: non-road mobile machinery

[e]Low Emission Zone

Table 6.2 Non-EU Cities Selected for Ranking, and London

City	Population (millions)[a]	Population Rank[b]	Area (km^2) [c]	2010 GaWC Category [d]
Beijing	27.71	5	1,378	Alpha
Cairo	24.50	7	453	Beta +
Chicago	8.75	Not Ranked	606	Alpha +
Dubai	2.42	Not Ranked	4114	Alpha +
Hong Kong	7.31	Not Ranked	1,154	Alpha +
Istanbul	16.69	20	5,343	Alpha -
Jakarta	13.81	25	740	Alpha
Johannesburg	9.40	Not Ranked	1,644	Alpha -
Lagos	24.24	9	999.6	Beta -
Los Angeles	3.82[e]	Not Ranked	1,302	Alpha
London	8.17	Not Ranked	1,572	Alpha ++
Mexico City	23.86	10	1,485	Alpha
Moscow	12.17	Not Ranked	2,511	Alpha
Mumbai	27.80	4	4,355	Alpha
New York-Newark	18.59	14	1,123	Alpha ++
Rio de Janeiro	14.17	23	4,557	Beta -
São Paolo	23.44	11	2,139	Alpha
Shanghai	30.75	3	2,606	Alpha +
Singapore	5.62	Not Ranked	710	Alpha +
Sydney	4.51	Not Ranked	12,145	Alpha +
Tokyo	37.19	1	2,187	Alpha +
Vancouver	0.60[f]	Not Ranked	115	Beta +

Notes:
[a] Population data were taken from the United Nations population division - http://esa.un.org/unpd/wup/CD-ROM/Default.aspx - accessed September 2014. The colour shading shows the ranking from highest population (darkest) to lowest population (lightest) of the cities in this study.
[b] Population ranking amongst cities in the United Nations list of the 30 Largest Urban Agglomerations Ranked by Population Size
[c] City area data taken from the Wikipedia page of the respective city e.g. London : http://en.wikipedia.org/wiki/London
[d] The Globalization and World Cities Research Network http://www.lboro.ac.uk/gawc/
[e] Data refers to the metropolitan area of Los Angeles in which there are 4 monitoring sites. The greater conurbation has a population of circa 12,828,837 habitants and an area of 2,519km^2
[f] http://vancouver.ca – accessed September 2014.

7. Meteorological and Local Factors

The selected cities are in both the northern and southern hemispheres, and are located in a great range of latitudes, from Sydney at 33.8°S to Moscow at 55.8°N. Several of the cities lie in the tropics (between 23.5°S and 23.5°N) with Singapore and Jakarta lying close to the Equator. The difference in latitude and the effect of seas, ocean, lakes, hills and mountains contribute to large variations in climate. Air quality is closely linked to climate. The EU cities all lie in a fairly narrow band from Madrid at 40.4°N to Stockholm at 59.3°N where the general atmospheric circulation leads to predominant westerly winds. There are however variations in climate and local effects such as hills, mountains, sea and ocean that produce differences. The broad classification of the cities by climate is given in Table 7.1

Tables A.1 and A.2 in Appendix A contain a summary of meteorological conditions and local climatic factors for each of the selected cities. An indicative windrose based on the year 2012 is also included for each city, taken from the Enviroware website[25].

The windroses reveal where the climate is strongly influenced by hills or mountains: Bucharest, Budapest, Milan, Munich, Rome and Vienna; and by proximity to the sea: Barcelona and Rome, amongst the EU cities. In Munich the proximity to Alps not only affects wind direction but increases the incidence of rain and snow and gives rise to warm downhill winds from the Alps. Milan is notable amongst the cities for its lower average wind speed, due to its position in the Po river valley, seen as the predominance of green in the wind rose.

Amongst the non-EU cities several of the windroses also show a very dominant wind direction: Hong Kong, Los Angeles and Vancouver due to the impact of mountains or proximity to oceans. Mexico City, Lagos and Singapore have very low average wind speeds, whilst Sydney and Tokyo have the highest average wind speeds amongst the cities considered.

[25] www.enviroware.com/metar-wind-roses-for-year-2012/

Table 7.1 Variations in Climate between Cities

Climate	Cities
Continental climate: cold winters and warm summers	Berlin (cool continental), Stockholm (humid continental), Warsaw (humid continental).
Humid continental climate: cold winters and warm summers.	Beijing, Chicago, Moscow
Hot desert climate: hot, in some cases exceptionally hot, summers and mild to warm winters.	Cairo, Dubai
Humid subtropical: hot, humid summer and mild to cool winters.	Hong Kong, New York City (borderline humid continental), São Paulo, Tokyo
Mediterranean climate: mild, humid winters and warm, dry summers	Barcelona, Madrid (Mediterranean with cool winters due to its elevation), Milan, Rome
Temperate Oceanic/Subtropical highland: mild winters and moderately warm summers.	Johannesburg, Mexico City
Temperate Oceanic: mild winters and moderately warm summers.	Amsterdam, Brussels, Frankfurt, London, Munich (oceanic/humid continental), Paris, Prague (borderline oceanic climate), Stuttgart, Sydney, Vancouver
Subtropical Mediterranean: Warm summers and relatively mild winters.	Los Angeles, Istanbul
Transitional climate: both continental and subtropical/humid influences	Bucharest, Budapest, Vienna
Tropical Monsoon: Results from monsoon winds, which change direction according to seasons. Has a driest month in mid-winter. Temperature remains fairly stable throughout the year.	Jakarta
Tropical Wet and Dry Savanna: Have pronounced wet and dry season. Temperature remains fairly stable throughout the year.	Lagos, Mumbai, Rio de Janeiro
Tropical Rainforest: High precipitation and has no natural seasons. Temperature remains fairly stable throughout the year.	Singapore

8. Availability of Monitoring Data

Ambient concentration monitoring data were sought from city, national and multi-national sources. Sections 8.1 to 8.4 describe the multi-national sources of data and section 8.4 summarises the data found for each city.

8.1 World Health Organization

The most comprehensive source of international comparisons in urban air quality worldwide is provided by the WHO. In particular, it produces the *urban outdoor air pollution database*[26], the latest version of which is from 2011, using data from 2003-2010. It aggregates $PM_{2.5}$ and PM_{10} measurements for almost 1,100 cities in 91 countries.

The database covers the period from 2003 to 2010, with the majority of values present being for 2008 and 2009. The primary sources of data include publicly available national/ sub-national reports and websites, regional networks such as the Asian Clean Air Initiative and the European AirBase, and selected publications. The database aims to be representative for human exposure and therefore primarily captures measurements from monitoring stations located in urban background, urban traffic, residential, commercial and mixed areas.

8.2 Clean Air Asia

Clean Air Asia is a very useful source of air pollution information for Asia. It acts as a depository/ online library of articles, links, downloads, pictures and videos related to air quality, climate change, and sustainable transport and describes itself thus:

> *Clean Air Asia was established in 2001 as the premier air quality network for Asia by the Asian Development Bank, World Bank, and USAID. Its mission is to promote better air quality and liveable cities by translating knowledge to policies and actions that reduce air pollution and greenhouse gas emissions from transport, energy and other sectors.*
>
> *Since 2007, Clean Air Asia is a UN recognized partnership of almost 250 organizations in Asia and worldwide and 8 Country Networks (China, India, Indonesia, Nepal, Pakistan, Philippines, Sri Lanka, and Vietnam), and is supervised by a Partnership Council.*[27]

For some cities/countries, all measurements are reported directly to it, instead of or as well as via the municipal/regional/national institutions. Clean Air Asia uses this information to produce a number of publications[28], including a Strategy for 2009-2012, Factsheets (including Asian status and trends of PM, SO_2, NO_2,

[26] http://www.who.int/phe/health_topics/outdoorair/databases/en/

[27] http://cleanairinitiative.org/portal/aboutus

[28] http://cleanairinitiative.org/portal/knowledgebase/publications

O_3 and CO), and annual reports for countries and sectors, and descriptions of air quality management programmes in Asian countries. An example of a Factsheet is shown in Figure 8.1.

Figure 8.1 Factsheet 3 – PM Status and Trends PM Status and Trends, from Clean Air Asia

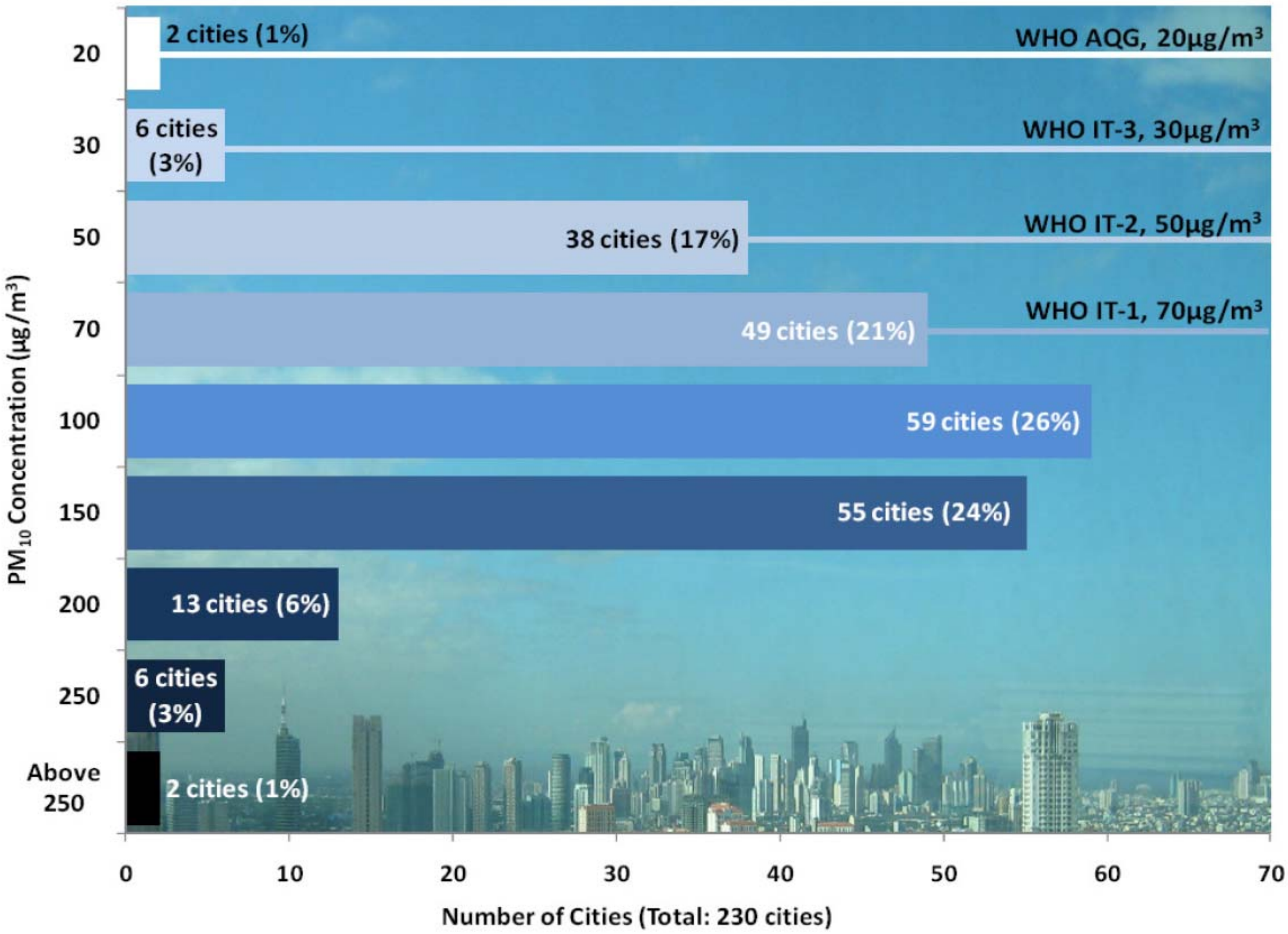


Figure 8.2 plots annual average PM_{10} concentrations in 230 Asian cities.

Figure 8.2 Annual PM_{10} Concentrations in 230 Cities in Asia (2008), from Clean Air Asia

Figure 2. Distribution of Asian Cities relative to PM_{10} Concentration (2008
Source: CAI-Asia, 2010.

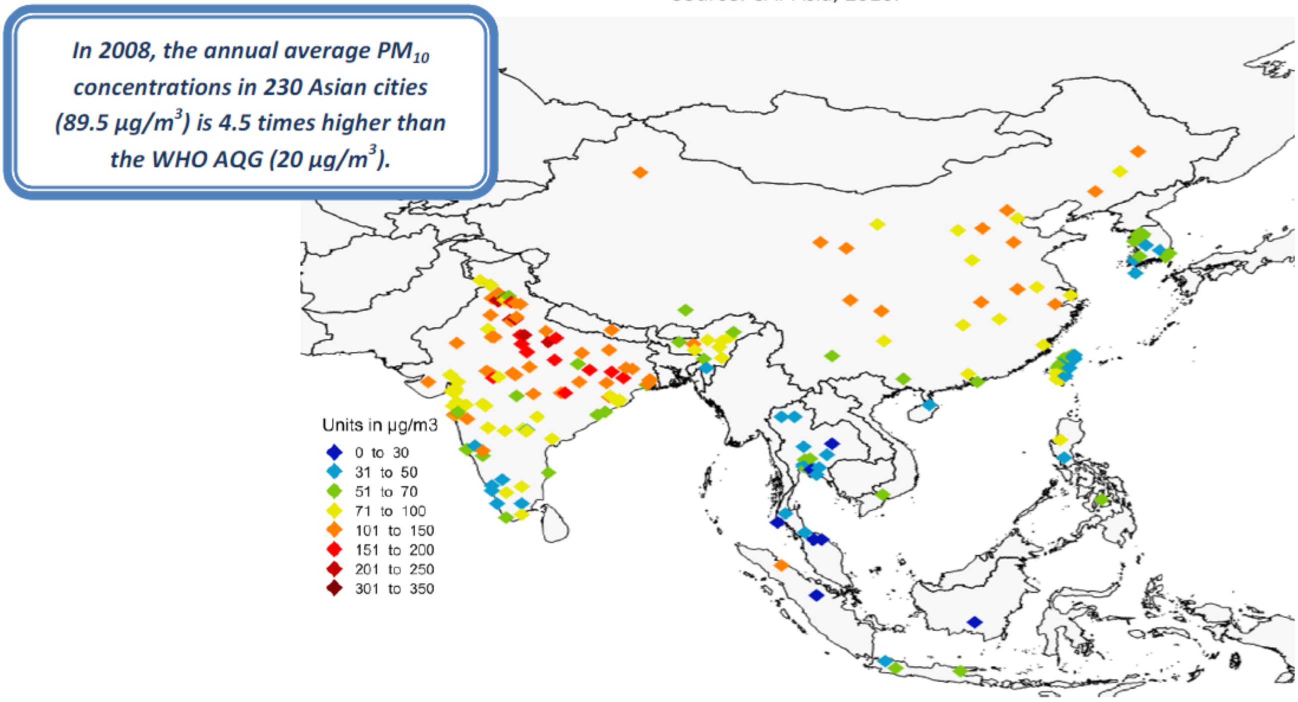


Figure 3. Annual PM_{10} concentrations in 230 cities in Asia (2008)
Source: CAI-Asia, 2010.

8.2.1 CitiesACT Database

Clean Air Asia maintains the CitiesACT Database[29], which is an online database providing access to air quality, climate change, transport and energy data and indicators for Asian cities and countries. It was developed by Clean Air Asia with support from partners including the Asian Development Bank, the World Bank and the Global Atmospheric Pollution Forum. It should be noted that CitiesACT does not provide data for specific measuring stations. Rather, it presents city-wide averages. These need to be individually downloaded for a particular city and pollutant (PM_{10}, SO_2 an NO_2 only) for comparisons to be drawn. The latest year for which data are available currently is 2010. Data from CitiesACT have been used to obtain data for Beijing, Jakarta, Shanghai and Singapore.

8.3 AirBase Database

AirBase is the public air quality database system of the European Economic Area. It is maintained through the European Topic Centre on Air Pollution and Climate Change Mitigation and contains air quality monitoring data

[29] http://citiesact.org/ CitiesACT Database, Clean Air Asia, accessed 10 December 2013

and metadata submitted by the participating countries throughout Europe. AirBase contains annual time series of air quality data and their statistics for a number of pollutants monitored at a selection of sites. It covers about 35 European countries, 140 pollutants, more than 6,000 monitoring stations and 25,000 time series with hourly and daily data covering more than 30 years. Having a Europe-wide geographical scope, AirBase covers all countries in the EEA-EFTA plus some EEA potential candidate countries (Croatia, Albania, Andorra, Bosnia-Herzegovina, Macedonia, Montenegro, Serbia, and Turkey).

AirBase became available in 1997 following the Exchange of Information Council Decision (97/101/EC). This Decision requires EU Member States to report data on ambient air quality annually, and it is made publicly available on AirBase. Non-EU members can do so by implementing these requirements into national legislation as their own commitment or adapting their monitoring and reporting infrastructure to these criteria. Submitted data are subject to quality control, data aggregation, calculation and statistical analysis.

For the preparation of this report, air quality data for the relevant cities was downloaded from the European Environmental Agency website[1]. Within each country dataset, stations located within the selected cities were identified using the station descriptions provided by each submitting country. In some cases, such as London or Paris, stations located outside the strict administrative boundaries but within the metropolitan area were also identified and considered. Once all the stations were identified, annual average concentrations during the period 2008-2011 for the selected pollutants (PM_{10}, $PM_{2.5}$, NO_2 and SO_2) were extracted. The number of days per year exceeding 120µg m^{-3} O_3 was also recorded.

For NO_2 and SO_2, annual averages were calculated using hourly values. However, for PM_{10} and $PM_{2.5}$ hourly averages were not available, annual averages were therefore calculated using daily values. In order to maintain data quality standards, records with less than 75% capture were excluded.

8.4 Summary of Data for each City

Information on the cities' monitoring sites and monitoring data for the years 2008 to 2012 were sought initially from city sources, from web sites and by requests to relevant organisations. Table 8.1 shows the level of detail of data obtained.

For 30 cities annual average data were available on a monitoring site basis and, for all the EU cities and several other cities, hourly data or exceedence statistics of 24 hour PM_{10} and 8 hour ozone concentrations were also available. The site type of each monitoring site was given for the EU cities but for the non-EU cities was often not available. Istanbul, although not a member of the EU, reports its monitoring data annually to the EU's AirBase database, so the nature of the sites is described as for the European cities and the data are subject to quality control. For three cities citywide average data were available from local sources, although for Lagos the data were from a 10 month monitoring campaign in 2005. Lagos was the only city in the study for which there was no evidence of routine ambient monitoring. For a further four cities, citywide average data were available from CitiesACT, part of Clean Air Asia, described in section 8.2. For all the cities, if information on data capture were given, annual averages based on a data capture of less than 75% were excluded. No data have been obtained for Johannesburg or Dubai. Johannesburg has maintained a good network of monitoring stations, but as a consequence of budget pressures, monitoring has not been carried out since 2011 and the archived data are no longer readily available and has not been obtained. Dubai maintains a network of monitors with real-time information, but the annual summaries found are of short-term maximum concentrations. They report that some areas have high levels of benzene and volatile organic compounds, as well as particulate matter.

Most of the cities displayed pollution indices or concentrations at multiple locations across the city in near real time as a public service but archived concentration data were much harder to obtain. Beijing, Shanghai, Singapore and Dubai all displayed near real time indices or concentration although only citywide or, in the case of Dubai not even citywide, archived data were obtained.

Table 8.2 shows the sources of data on ambient monitoring.

Table 8.1 Data Obtained for Each City

Data available by monitoring site from local sources	Citywide average data from local source	Citywide average data from CitiesACT	No data obtained
All EU cities	Lagos[2]	Beijing	Dubai
Cairo	Rio de Janeiro	Jakarta	Johannesburg-Gauteng
Chicago	Tokyo	Shanghai	
Hong Kong		Singapore	
Istanbul			
Los Angeles			
Mexico City			
Moscow[1]			
Mumbai			
New York			
São Paolo			
Sydney			
Vancouver			

Notes:

[1] 2012 data only obtained

[2] 2005 data only obtained, limited period monitoring campaigns

Table 8.2 Ambient Monitoring Data Sources

City	Source of Data
EU Cities	European Environment Agency, AirBase – The European air quality database http://www.eea.europa.eu/data-and-maps/data/airbase-the-european-air-quality-database-7, accessed 21 May 2013.
London	UK Defra: http://uk-air.defra.gov.uk/networks/ London Air Quality Network (LAQN): http://www.londonair.org.uk/LondonAir/Default.aspx Web sites of the 33 London Boroughs
Non-EU Cities	
Beijing	CitiesACT: http://citiesact.org/
Cairo	Egyptian Environmental Affairs Agency (EEAA): http://www.eeaa.gov.eg/eimp/air.html and http://www.eeaa.gov.eg/eimp/airreports.html
Chicago	Illinois State: http://www.epa.state.il.us/air/air-quality-report/index.html http://www.stateoftheair.org/2013/states/illinois/cook-17031.html
Dubai	None obtained UAE Ministry of Environment: http://www.uae-airquality.com/
Hong Kong	Hong Kong Environmental Protection Department http://epic.epd.gov.hk/ca/uid/airdata/p/1
Istanbul	European Environment Agency, AirBase – The European air quality database http://www.ibb.gov.tr/sites/CevreKoruma/HavaKalitesi/Sayfalar/HavaKalitesiAgimiz.aspx http://application2.ibb.gov.tr/IBBWC/HavaKalitesi.aspx
Jakarta	CitiesACT: http://citiesact.org/
Johannesburg-Gauteng	None obtained
Lagos	Taiwo (2005): http://www.docstoc.com/docs/43066096/The-state-of-urban-air-pollution-in-Lagos
Los Angeles	Request form at www.aqmd.gov http://www.stateoftheair.org/
Mexico City	http://www.calidadaire.df.gob.mx/calidadaire/index.php Air quality reports: http://www.calidadaire.df.gob.mx/calidadaire/index.php?opcion=2&opcioninfoproductos=12
Moscow	http://www.mosecom.ru/air/air-today/ State Environmental Organisation: http://www.mosecom.ru/air/ Moscow City Government on air quality: http://www.mos.ru/en/authority/activity/ecology/index.php?id_14=22254 Trends in air pollution: http://www.mosecom.ru/air/air-dinamic/
Mumbai	http://mpcb.gov.in/envtdata/envtair.php http://mpcb.gov.in/envtdata/demoPage1.php#station1 http://mpcb.gov.in/envtdata/airstrengthing.php http://mpcb.gov.in/air%20quality/air_caaqms_01.php

City	Source of Data
New York City	http://www.dec.ny.gov/chemical/27442.html http://www.dec.ny.gov/chemical/65574.html http://www.dec.ny.gov/chemical/8541.html http://www.dec.ny.gov/chemical/29310.html http://www.stateoftheair.org/
Rio de Janeiro	Instituto Estadual do Ambiente (INEA) (State Institute of the Environment, Government of Rio de Janeiro) http://www.inea.rj.gov.br/fma/images/estacoes-ar.jpg http://www.inea.rj.gov.br/fma/qualidade-ar-rapido.asp?cat=65
São Paulo	CETESB webpage: http://www.cetesb.sp.gov.br/ar/Informa??es-B?sicas/24-Configura??es-da-Rede-Autom?tica Relatório de qualidade do ar no Estado de São Paulo 2008-2011 http://www.cetesb.sp.gov.br/ar/qualidade-do-ar/31-publicacoes-e-relatorios#
Shanghai	CitiesACT: http://citiesact.org/
Singapore	CitiesACT: http://citiesact.org/
Sydney	Monitoring data: http://www.environment.nsw.gov.au/AQMS/hourlydata.htm Action for Air (AQMP), which covers Sydney, the Lower Hunter and Illawara: http://www.environment.nsw.gov.au/air/actionforair/index.htm
Tokyo	http://www.kankyo.metro.tokyo.jp/en/attachement/Air%20Pollution%20Monitoring%20System.pdf Environment of Tokyo: http://www.kankyo.metro.tokyo.jp/en/index.html
Vancouver	Data request to National Air Pollution Surveillance (NAPS) for Vancouver: http://www.ec.gc.ca/rnspa-naps/default.asp?lang=En&n=D11B2A90-1 http://www.metrovancouver.org/about/publications/Publications/ LowerFraserValleyAirQualityMonitoringNetwork2012StationInformation.pdf

9. Monitoring Sites

9.1 Monitoring Site Classification

A monitoring site is a facility to measure systematically concentrations of pollutants in the air. There are different classifications of site[30]and in the EU these are, namely:

- Traffic: Located such that its pollution level is determined predominantly by the emissions from nearby traffic (roads, motorways, highways). Air sampled at traffic sites must be representative of air quality for a street segment no less than 100 m in length. They can be divided into the following categories:
  - Kerbside: Sites with sample inlets within 1m of the kerb of a busy road. Sampling heights are within 2-3m of the ground.
  - Roadside: Sites with sample inlets between 1m and 5m of the kerbside. Sampling heights are within 2-3m of the ground.
- Urban Background: Urban locations away from major sources and broadly representative of town/ city-wide background concentrations, e.g. urban residential areas.
- Suburban: Sites typical of residential areas on the outskirts of a town or city.
- Rural: Distanced from major population centres, roads, industrial areas or other pollution sources.
- Industrial: Sites where industrial emissions make a significant contribution to pollution levels.

Not all pollutants are measured at all sites. For example, SO_2 is rarely measured at traffic stations. Although this classification system is standardised in Europe, the system changes when the scope is worldwide. Some cities classify the stations differently, whereas others do not classify them at all (officially).

Monitoring sites across cities are not always evenly distributed geographically or according to the size and population of the city. Types are also not equally represented. Table 9.1 shows the number of sites in each EU city in 2011 and their type. 10 of the 18 cities have more background than traffic monitoring stations. The number of industrial monitoring stations is always the lowest or joint lowest. The data have been obtained from publicly available data published by the cities and from AirBase. Only automatic monitoring sites considered to be maintained to a high standard have been included. The stations that are reported to the EU and appear in the AirBase directory and the non-AirBase stations are shown separately in Table 9.1.

It can be seen that London is by far, the city with the highest number of stations, albeit it does also have the highest population and area. It is also the city with the most non-AirBase stations, with 139, corresponding to 84% of

[30] Defra (2011) *Site environment types*. Department for environment, food and rural affairs. Available from: http://uk-air.defra.gov.uk/networks/site-types

urban/ suburban/ rural background, 90% of traffic and 89% of industrial background stations. For half the cities there are no sites other than those reported to the EU. After London, the maximum number of non-AirBase sites is 4 (Paris – for which there are other monitoring results available from monitoring stations that are periodically moved around the city and therefore do not allow assessment of long-term trends making the results unsuitable for this study). The calculation of air quality index included AirBase and non-AirBase stations for London, but for all other cities only the AirBase stations have been analysed. The inclusion of all monitoring sites for London sites is likely to result in a conservative ranking London as monitoring stations operated by local authorities for Local Air Quality Management (LAQM) purposes are included. The UK's LAQM guidelines on the siting of monitors[31] advise that authorities should:

> *"Try to site the monitors as near to the point of public exposure as possible".*

The AirBase monitors are those used for reporting air quality to the EU and therefore have siting requirements detailed in the EU Directive[32]. For example, a roadside monitor must be at a location representative of air quality for a street segment no less than 100m in length and it must not be positioned in the immediate vicinity of sources:

> *"Sampling points shall in general be sited in such a way as to avoid measuring very small micro-environments in their immediate vicinity, which means that a sampling point must be sited in such a way that the air sampled is representative of air quality for a street segment no less than 100m length at traffic-orientated sites";*
>
> *"The inlet probe shall not be positioned in the immediate vicinity of sources in order to avoid the direct intake of emissions unmixed with ambient air".*

[31] Defra (2009). Local Air Quality Management Technical Guidance LAQM.TG (09).

[32] DIRECTIVE 2008/50/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 21 May 2008 on ambient air quality and cleaner air for Europe, Official Journal of the European Union, L 152/1
http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0050&from=EN

Table 9.1 Monitoring Sites in the Selected EU Cities (2011)

City	Population	Area (km^2)	Monitoring Sites (2011)	Of which: Background	Of which: Traffic	Of which: Industrial	Of which: Other
Amsterdam	755,605	219	**19**	10	8	1	-
Barcelona	1,611,013	101	**14**	6	6	2	-
Berlin	3,460,725	892	**17**	9	7	1	-
Brussels	1,136,778	161	**20(2)**	6	9	3	(2*)
Bucharest	1,924,229	228	**8**	3	2	3	-
Budapest	1,712,210	525	**9(3)**	4	2	-	(3*)
Frankfurt	679,664	248	**6(2)**	2 (2*)	2	-	-
London	8,173,941	1572	**157(139)**	9 (49*)	8 (73*)	1 (8*)	(9*)
Madrid^	3,198,645	606	**24**	15	9	-	-
Milan	1,307,495	182	**8**	3	5	-	-
Munich	1,353,186	310	**6**	2	4	-	-
Paris	6,507,783	762	**32(4)**	21 (1*)	7 (3*)	-	**
Prague	1,241,664	496	**21**	12	8	1	-
Rome	2,743,796	1285	**13(1)**	7(1*)	4	-	1
Stockholm	864,324	209	**7**	2	4	-	(1*)
Stuttgart	606,588	207	**6(1)**	1(1*)	4	-	-
Vienna	1,687,271	415	**17**	7	9	1	-
Warsaw	1,714,446	517	**9**	7	1	-	(1*)

Notes:

* refers to monitoring stations not included in AirBase (2011).

** the site on the third floor of the Eiffel Tower classified as an “Observation” site has not been included.

^ Madrid is a very particular case among the selected EU cities: Due to a significant number of monitoring sites substitutions in the years 2009 and 2010, the total number of stations present in the studied period (2008-2012) is 35, with a variable number of simultaneously operating stations (~25 in a given year)

Table 9.2 shows the number of sites and their type in the non-EU cities and London in 2011.

Table 9.2 Monitoring Sites in the Selected Non-EU Cities and London (2011)

City	Population (millions)	Area (km^2)	Monitoring Sites	Of which: Background	Of which: Traffic	Of which: Industrial	Of which: Other
Beijing	27.71	1,378	9	N/C	N/C	N/C	
Cairo	24.50	453	41	24	3	14	
Chicago	8.75	606	13	N/C	N/C	N/C	
Dubai	2.42	4,114	8	N/C	N/C	N/C	
Hong Kong	7.31	1,154	14	9	5	0	
Istanbul	16.69	5,343	10	5	2	3	
Jakarta	13.81	740	25	N/C	N/C	N/C	
Johannesburg	9.40	1,644	11	N/C	N/C	N/C	
Lagos	24.24	999.6	12	0	6	3	3[1]
London	8.17	1,572	157	58	81	9	
Los Angeles	12.31	1,302	4	N/C	N/C	N/C	
Mexico City	23.86	1,485	24	N/C	N/C	N/C	
Moscow	12.17	2,511	28	16	3	4	
Mumbai	27.80	4,355	23	N/C	N/C	8	
New York City	18.59	1,123	25	N/C	N/C	N/C	
Rio de Janeiro	14.17	4,557	26	N/C	N/C	N/C	
São Paolo	23.44	2,139	32	N/C	N/C	N/C	
Shanghai	30.75	2,606	10	N/C	N/C	N/C	
Singapore	5.62	710	5	N/C	N/C	N/C	
Sydney	4.51	12,145	15	N/C	N/C	N/C	
Tokyo	37.19	2,187	82	47	35	0	
Vancouver	0.60	115	42	N/C	N/C	N/C	

Notes: N/C: Not officially classified

[1] Located at dumpsites

[2] It is stated that roadside and background concentrations are monitored but it is not clear how many sites there are of each type.

9.2 Monitoring Site Distribution

The density of monitoring stations in terms of population and area is presented in Table 9.3 and shown in Figures 9.1 and 9.2 for the EU cities. Table 9.4 and Figures 9.3 and 9.4 show the corresponding data for the non-EU cities and London.

Table 9.3 Air Quality Stations Resolution Compared To Habitants and City Area, EU cities

City	Stations per 100,000 Inhabitants	Stations per km^2
Amsterdam	2.51	0.087
Barcelona	0.87	0.138
Berlin	0.49	0.019
Brussels	1.76	0.124
Bucharest	0.42	0.035
Budapest	0.53	0.017
Frankfurt	0.88	0.024
London	1.92	0.100
Madrid	0.75	0.040
Milan	0.61	0.044
Munich	0.44	0.019
Paris	0.49	0.042
Prague	1.69	0.042
Rome	0.47	0.010
Stockholm	0.81	0.033
Stuttgart	0.99	0.029
Vienna	1.01	0.041
Warsaw	0.52	0.017

It can be seen from Table 9.3 that, for the EU cities, the density of stations per city area and number of inhabitants covered varies significantly. In terms of monitoring stations per area, Barcelona has the highest number of stations per km^2 (over 1 station per 10 km^2), followed by Brussels and then London. As stated above, however, only 10% of London monitoring stations are officially reported to the EU.

Paris, the other alpha city with a population comparable to that of London, but a smaller city area, is 14th in terms of density of monitors. The worst performing city in this aspect is Rome, with an area of 1285 km^2, but only 13 measuring stations.

As for the density of monitoring station per inhabitant, Amsterdam is the top city (approximately 1 for every 40,000 inhabitants), followed by London and Brussels. Paris is 14th and Bucharest is the city with the lowest monitoring density per habitant, with only 8 stations for the more than 1.9 million population. Barcelona is the best city per km^2 it is only the 8th city per inhabitant.

Figure 9.1 Number of Monitoring Stations per 100,000 Population (2011), EU Cities

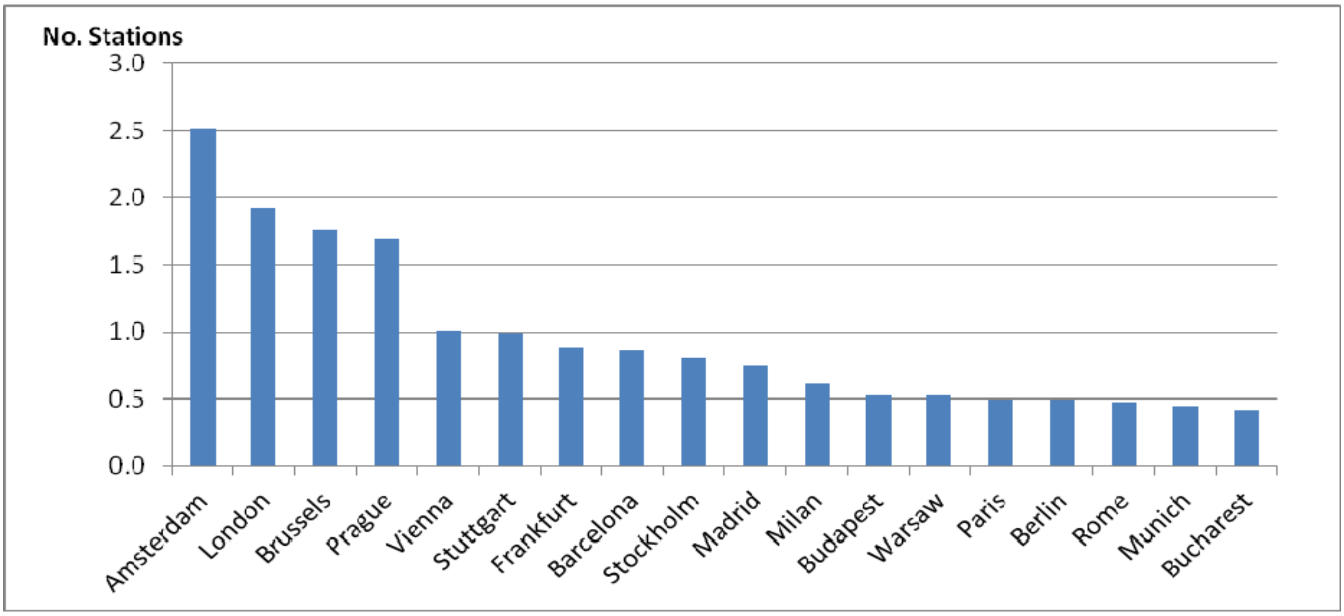


Figure 9.2 Number of Monitoring Stations per Unit of Area (Km^2), EU Cities

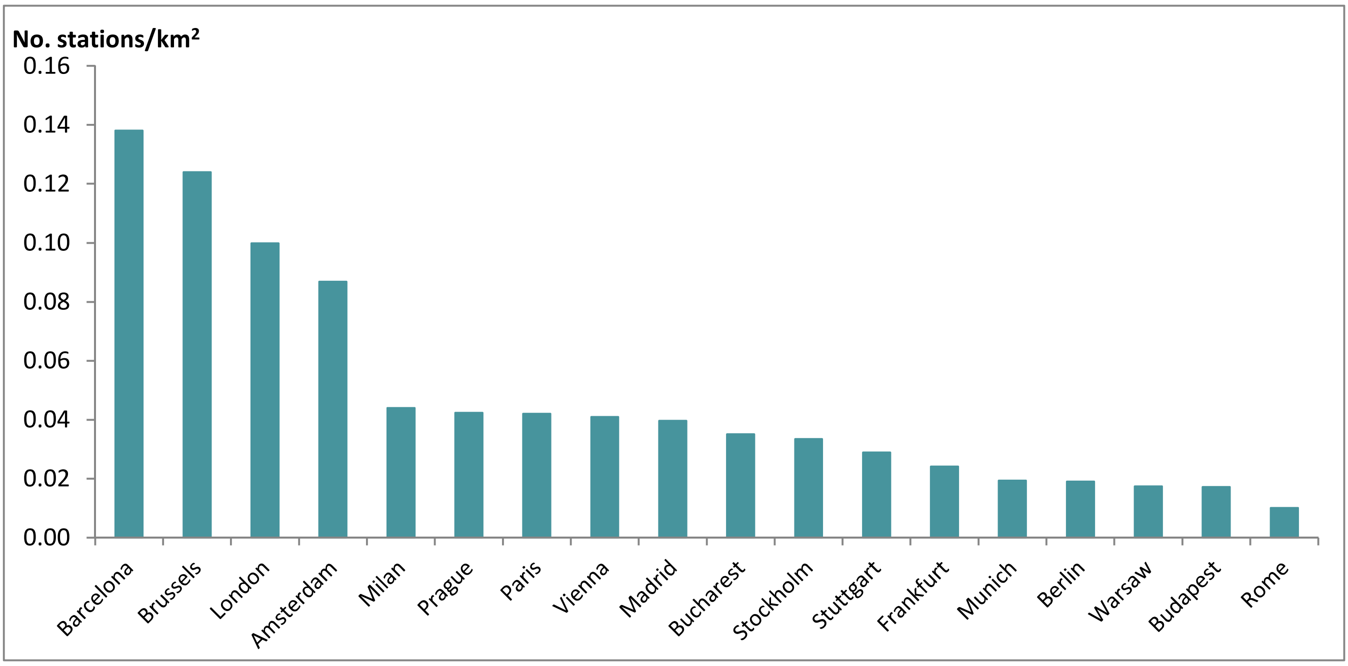


Table 9.4 Air Quality Stations Resolution Compared To Habitants and City Area, London and non-EU Cities

City	Stations per 100,000 Inhabitants	Stations per km^2
Beijing	0.03	0.01
Cairo	0.17	0.09
Chicago	0.15	0.02
Dubai	0.33	<0.01
Hong Kong	0.19	0.01
Istanbul	0.06	<0.01
Jakarta	0.18	0.03
Johannesburg	0.12	0.01
Lagos	0.05	0.01
London	1.92	0.1
Los Angeles	0.03	<0.01
Mexico City	0.10	0.02
Moscow	0.23	0.01
Mumbai	0.08	0.01
New York City	0.13	0.02
Rio de Janeiro	0.18	0.01
Sao Paulo	0.14	0.01
Shanghai	0.03	<0.01
Singapore	0.09	0.01
Sydney	0.33	<0.01
Tokyo	0.22	0.04
Vancouver	6.97	0.37

Table 9.4 shows that, for the non-EU cities, the range of monitoring stations per km^2 and per 100,000 inhabitants is greater than for the EU cities. For instance, Vancouver, despite having the smallest population of all the cities, has the most monitoring stations both per number of inhabitants (6.97 stations per 100,000 inhabitants) and per area of the city (0.37 stations per km^2). Shanghai, with a very large population, has the fewest monitoring stations per inhabitant with 0.03 stations per 100,000 inhabitants. Sydney, with a large area and small population, has the least per area with less than 0.01 monitoring station per km^2. London has the second highest number of monitoring stations both per number of inhabitants (1.92 per 100,000 inhabitants) and per area (0.10 per km^2).

Figure 9.3 Number of Monitoring Stations per 100,000 Population (2011), London and Non-EU Cities

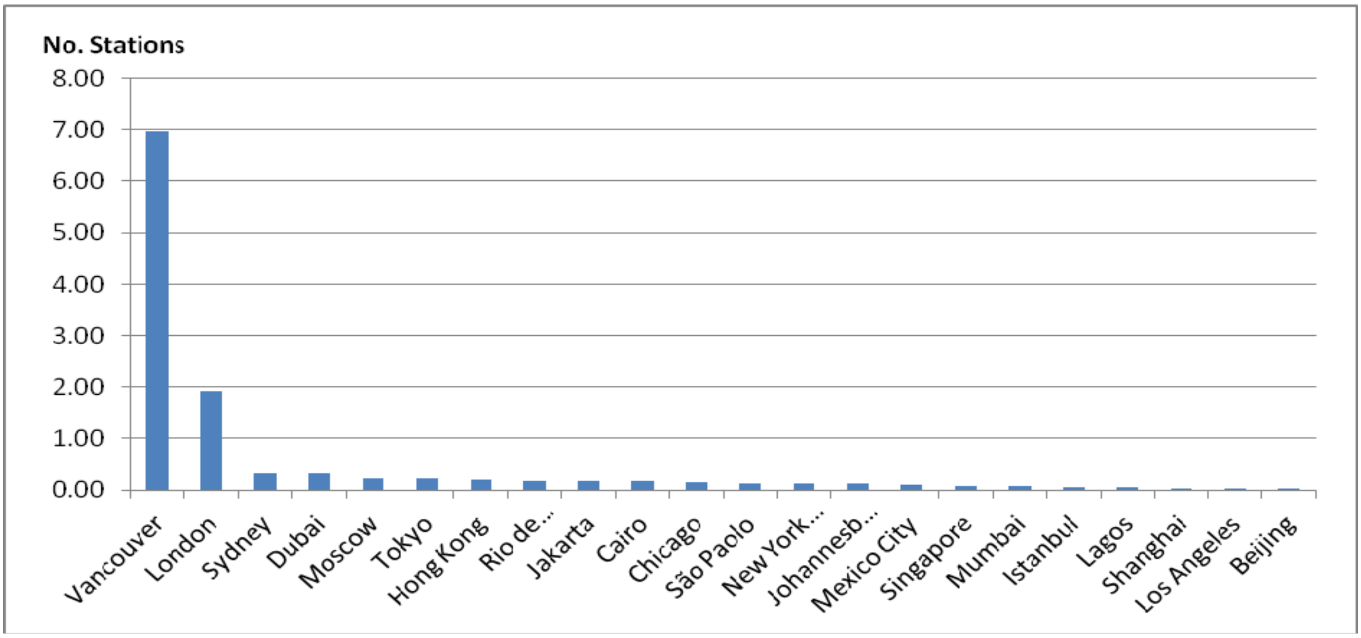
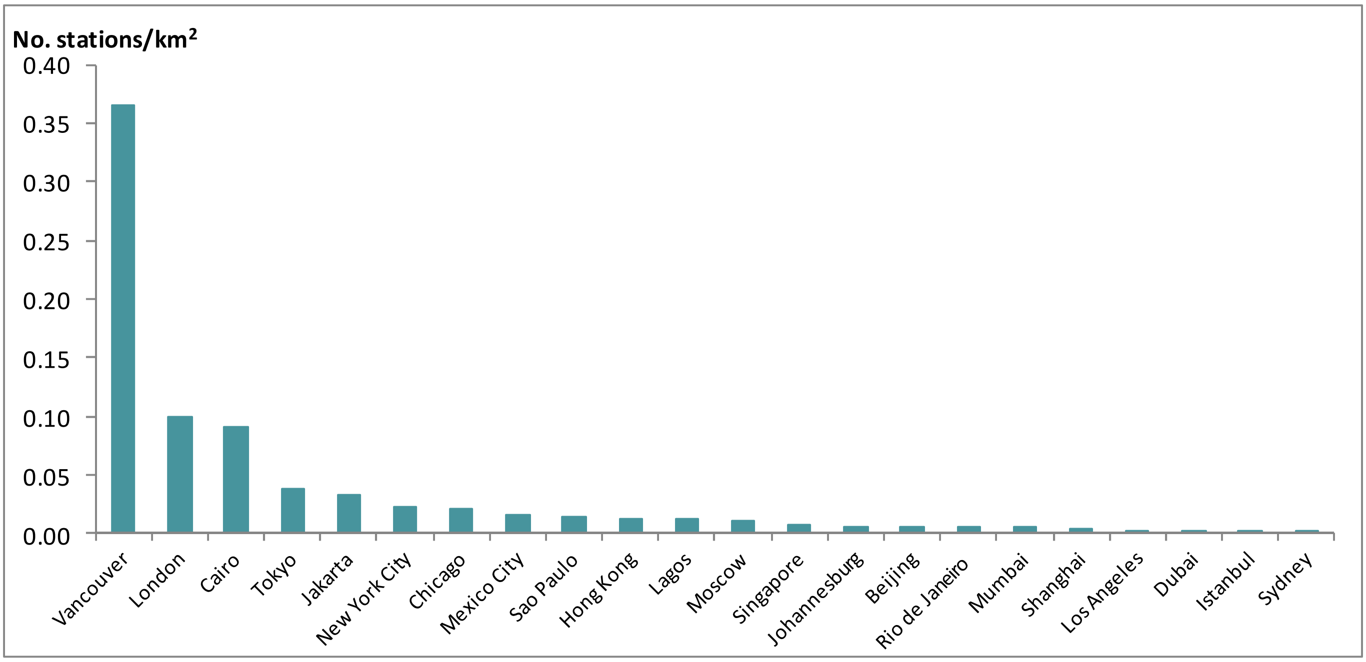


Figure 9.4 Number of Monitoring Stations per Unit of Area (km^2), London and Non-EU Cities



9.3 Limitations in Monitored Data

When monitored data was collected for this study, the following limitations in data were indentified which have affected the way that the ranking of cities was carried out:

- Monitoring site classifications are not available for many of the cities outside of the EU that were considered. Consequently, it has not been possible to create ranking based on different monitoring site types;
- Publication of data following formal ratification processes can take some time. For this reason, there is reduced data availability in 2012; and
- Some pollutants are not monitored in some of the cities. This is accounted for in the ranking method which will redistribute the overall score according to the pollutants that are monitored.

10. Ranking of Air Quality

10.1 Individual Pollutants

The method described in section 5.2 has been applied to monitored data for the selected cities to calculate indices, to rank the cities by concentrations of individual pollutants. Of the 39 selected cities, three do not appear in the tables due to lack of data, these are: Dubai, Johannesburg-Gauteng and Lagos. The indices for NO_2, SO_2, PM_{10} and $PM_{2.5}$ are shown in the tables below. These tables show, that of the 36 cities ranked, Sydney has the lowest monitored NO_2 concentrations, Stockholm has the lowest SO_2 concentrations and Vancouver has the lowest PM_{10} and $PM_{2.5}$ concentrations. London is ranked 27th, 13th, 9th and 7th for NO_2, SO_2, PM_{10} and $PM_{2.5}$ respectively.

Table 10.1 City Index for NO_2 for Each Year (2008-2012) and the 5-Year Average

City	2008	2009	2010	2011	2012	Average
Amsterdam	1.06	0.96	0.94	0.91		0.97
Barcelona	1.28	1.21	1.17	1.20	1.10	1.19
Beijing	1.23	1.33	1.43			1.33
Berlin	0.80	0.86	0.85	0.86		0.84
Brussels	0.98	0.98	0.97	0.92		0.96
Bucharest	1.16	1.27	0.90	0.66		1.00
Budapest	0.88	0.77	0.86	0.91		0.86
Cairo	1.60	0.90	1.10			1.20
Chicago	1.13	0.99	0.99	0.87		0.99
Frankfurt	1.12	1.13	1.07	1.08		1.10
Hong Kong	1.62	1.69	1.86	1.59	1.82	1.72
Istanbul	1.69	1.69	1.63	1.51	1.68	1.64
Jakarta	0.45	0.55	0.50	0.93		0.61
London	**1.27**	**1.31**	**1.34**	**1.33**	**1.30**	**1.31**
Los Angeles	1.22	1.05	1.05	0.96	0.99	1.05
Madrid	1.38	1.39	1.11	1.12	0.98	1.20
Mexico City	2.72	2.57	2.57	2.48		2.58
Milan	1.59	1.55	1.46	1.53	1.37	1.50
Moscow					1.04	1.04
Mumbai						
Munich	1.43	1.45	1.42	1.32		1.40
New York	1.10	1.07	1.34	0.98		1.12
Paris	1.04	1.06	1.10	1.09	1.12	1.08
Prague	0.89	0.85	0.91	0.87	0.81	0.87
Rio de Janeiro	1.63	1.45	0.55			1.21
Rome	1.30	1.36	1.27	1.38	1.21	1.30
Sao Paulo	1.22	1.11	1.14	1.02		1.12
Shanghai	1.40	1.33	1.25			1.33
Singapore	0.55	0.55	0.58	0.63		0.58
Stockholm	0.88	0.82	0.95	0.82	0.75	0.84
Stuttgart	1.77	1.89	1.68	1.77		1.78
Sydney	0.47	0.46	0.48	0.46	0.44	0.46
Tokyo	1.25	1.22	1.15	1.08		1.18
Vancouver	0.63	0.63	0.53	0.52	0.55	0.57
Vienna	0.79	0.77	0.78	0.76	0.72	0.76
Warsaw	0.73	0.73	0.82	0.87	0.78	0.79

Table 10.2 City Index for SO_2 for Each Year (2008-2012) and the 5-Year Average

City	2008	2009	2010	2011	2012	Average
Amsterdam	0.12	0.11	0.09			0.11
Barcelona	0.20	0.14	0.12	0.21	0.14	0.16
Beijing	1.80	1.70	1.60			1.70
Berlin	0.14	0.13	0.17	0.13		0.14
Brussels	0.22	0.21	0.21	0.20	0.19	0.21
Bucharest	0.48	0.30	0.72	0.40		0.48
Budapest	0.24	0.39	0.31	0.31	0.33	0.32
Cairo	1.95	1.40	1.35			1.57
Chicago	0.22	0.26	0.00	0.00		0.24
Frankfurt	0.20	0.14	0.13	0.16		0.16
Hong Kong	1.76	1.10	0.76	0.85	0.70	1.03
Istanbul	0.38	0.49	0.32	0.45	0.25	0.38
Jakarta	2.65	2.90	2.30			2.62
London	**0.18**	**0.16**	**0.18**	**0.19**	**0.25**	**0.19**
Los Angeles	0.06	0.05	0.05	0.06		0.05
Madrid	0.53	0.51	0.49	0.35	0.22	0.42
Mexico City	0.83	0.76	0.74	0.73		0.77
Milan	0.20	0.22	0.14	0.14	0.11	0.16
Moscow						
Mumbai	0.97	0.76	0.92	0.86	1.10	0.92
Munich	0.24	0.18	0.26	0.24		0.23
New York	0.75	0.65	0.50	0.48		0.59
Paris	0.15	0.13	0.12	0.08	0.06	0.11
Prague	0.21	0.24	0.27	0.17	0.21	0.22
Rio de Janeiro	0.25	0.00	0.00			0.25
Rome	0.07	0.06	0.04	0.06	0.06	0.06
Sao Paulo	0.40	0.42	0.29	0.36		0.37
Shanghai	2.55	1.75	1.45			1.92
Singapore	0.55	0.45	0.55	0.50		0.51
Stockholm	0.04	0.05	0.06	0.04	0.04	0.05
Stuttgart	0.16	0.14	0.08	0.08		0.11
Sydney						
Tokyo	0.26	0.26	0.26	0.26		0.26
Vancouver	0.18	0.19	0.15	0.14	0.15	0.16
Vienna	0.14	0.14	0.17	0.16	0.17	0.16
Warsaw	0.44	0.39	0.34	0.29	0.38	0.37

Table 10.3 City Index for PM_{10} for Each Year (2008-2012) and the 5-Year Average

City	2008	2009	2010	2011	2012	Average
Amsterdam	0.70	0.67	0.63	0.64		0.66
Barcelona			0.69	0.75	0.80	0.74
Beijing	3.08	3.03	3.03			3.04
Berlin	0.62	0.69	0.72	0.68		0.68
Brussels	0.73	0.76	0.70	0.73	0.65	0.71
Bucharest	1.23		0.85	0.94		1.01
Budapest	0.81	0.82	0.84	0.88	0.76	0.82
Cairo	3.63	3.73	3.15			3.50
Chicago	0.58	0.59	0.60	0.53		0.57
Frankfurt	0.56	0.63	0.57	0.58		0.58
Hong Kong	1.35	1.19	1.19	1.23	1.08	1.21
Istanbul	1.47	1.33	1.26	1.21	1.31	1.32
Jakarta	1.08	1.30	1.20	1.75		1.33
London	0.63	0.64	0.62	0.67	0.62	0.64
Los Angeles	1.08	1.10	0.88	0.85	0.93	0.97
Madrid	0.67	0.62	0.54	0.58	0.54	0.59
Mexico City	1.29	1.49	1.38	1.48		1.41
Milan	1.11	1.10	0.99	1.25	1.08	1.10
Moscow					0.58	0.58
Mumbai	2.99	2.43	2.48	2.53	2.44	2.58
Munich	0.66	0.70	0.72	0.67		0.69
New York	0.50	0.50	0.55	0.48		0.51
Paris	0.73	0.84	0.78	0.80	0.79	0.79
Prague	0.65	0.65	0.72	0.72	0.67	0.68
Rio de Janeiro	1.25	1.23	1.68			1.38
Rome	0.88	0.86	0.73	0.82	0.77	0.81
Sao Paulo	0.95	0.84	0.97	0.94		0.93
Shanghai	2.10	2.03	1.98			2.03
Singapore		0.73	0.65	0.68		0.68
Stockholm	0.71	0.63	0.57	0.64	0.56	0.62
Stuttgart	0.77	0.73	0.77	0.77		0.76
Sydney	0.43	0.63	0.40	0.41	0.44	0.46
Tokyo						
Vancouver	0.29	0.30	0.26	0.26	0.26	0.27
Vienna	0.61	0.63	0.75	0.76	0.59	0.67
Warsaw	0.82	0.89	0.95	0.94	0.93	0.91

Table 10.4 City Index for $PM_{2.5}$ for Each Year (2008-2012) and the 5-Year Average

City	2008	2009	2010	2011	2012	Average
Amsterdam	0.00	0.66	0.71	0.68		0.68
Barcelona	0.74	0.82	0.69	0.78	0.76	0.76
Beijing						
Berlin	0.83	0.77	0.85	0.83		0.82
Brussels	0.77	0.84	0.80	0.85	0.75	0.80
Bucharest	0.00	0.00	0.94	0.83		0.88
Budapest	0.00	0.64	0.90	1.07		0.87
Cairo						
Chicago	0.48	0.46	0.51	0.48		0.48
Frankfurt	0.65	0.74	0.79	0.75		0.73
Hong Kong	1.63	1.37	1.36	1.50	1.22	1.42
Istanbul						
Jakarta						
London	0.62	0.59	0.59	0.65	0.59	0.61
Los Angeles	0.00	0.76	0.72	0.68	0.88	0.76
Madrid	0.57	0.52	0.49	0.49	0.47	0.51
Mexico City	0.87	0.85	0.77	0.80		0.82
Milan	1.27	1.13	1.01	1.33	1.35	1.22
Moscow					0.80	0.80
Mumbai						
Munich	0.60	0.77	0.74	0.68		0.70
New York	0.00	0.43	0.41	0.43		0.42
Paris	0.62	0.75	0.74	0.85	0.83	0.76
Prague	0.69	0.65	0.76	0.72		0.70
Rio de Janeiro						
Rome	0.79	0.80	0.75	0.84	0.74	0.78
Sao Paulo	0.68	0.60	0.71	0.83		0.71
Shanghai	0.00	0.00	0.00			0.00
Singapore	0.64	0.76	0.68	0.68		0.69
Stockholm	0.43	0.25	0.32	0.31	0.26	0.31
Stuttgart	0.62	0.81	0.84	0.76		0.76
Sydney	0.24	0.31	0.24	0.23	0.27	0.26
Tokyo						
Vancouver	0.18	0.19	0.16	0.16	0.16	0.17
Vienna	0.70	0.78	0.86	0.82	0.68	0.77
Warsaw	0.00	0.94	1.22	1.12	1.06	1.09

10.2 Overall City Ranking Index

The Citywide index is considered to be the most appropriate for the ranking of air quality in the cities assessed as it takes account of the range of likely pollution problems (SO_2/ PM for industrial source s and NO_2/ PM for traffic sources). The index and ranking produced using the Citywide index are shown in Tables 10.5 and 10.6. Of the 36 ranked cities, 8 have a 5-year index value greater than or equal to 1.00, indicating a weighted pollutant score showing annual average concentrations greater than the concentrations used for the normalisation. The 8 cities are: Beijing, Cairo, Hong Kong, Istanbul, Jakarta, Mexico City, Mumbai and Shanghai. Cairo has the highest 5-year average with a value of 2.09 and Vancouver the lowest value of 0.32. London has a 5-year average value of 0.70.

The city ranked 1 is judged to have the best air quality (least polluted) and the city ranked 36 is judged to have the worst air quality (most polluted) according to this index. Vancouver is ranked the most favourably for monitored air pollution for every single year between 2008 and 2012. Cairo is ranked the worst over five years, followed by Beijing and then Shanghai. London is ranked 15th in terms of the best air quality out of the 36 cities (10th out of the 18 EU cities). This index gives SO_2 a relatively high priority to produce the ranking, with the result that industrialised cities in developing countries are ranked lowest for air quality. This is a pollutant that still requires action in these countries. Cities with the lowest industry and fossil fuel burning within the urban area have the highest ranking.

The rankings obtained using the other indices are shown in Appendix C. These demonstrate the sensitivity of the method to considerations of the relative importance of pollutants. London is ranked 17th in terms of the best air quality out of the 36 cities (11th out of the 18 EU cities) using the Citywide/ Traffic Focussed Index which prioritises the traffic related pollutants for which the objective concentrations are most commonly exceeded in Europe, NO_2 and PM_{10}. London is ranked 9th in terms of the best air quality out of the 36 cities (4th out of the 18 EU cities) using the Health Impacts Index which gives a high priority to PM, reflecting the evidence base on the severity of impacts for this pollutant relative to the other pollutants included. The relatively high ranking of London in the EU cities may well result from policies designed to reduce particulate emissions in recent years.

Table 10.5 Citywide Index for Each Year (2008-2012) and the 5-Year Average

City	2008	2009	2010	2011	2012	Average
Amsterdam	0.62	0.59	0.57	0.76		0.59
Barcelona	0.74	0.69	0.66	0.73	0.69	0.71
Beijing	2.03	2.02	2.02			2.02
Berlin	0.55	0.58	0.61	0.58		0.58
Brussels	0.65	0.67	0.64	0.64	0.47	0.64
Bucharest	0.96	0.79	0.84	0.68		0.83
Budapest	0.64	0.66	0.69	0.74	0.54	0.69
Cairo	2.39	2.01	1.87			2.09
Chicago	0.62	0.60	0.75	0.67		0.59
Frankfurt	0.63	0.65	0.61	0.62		0.63
Hong Kong	1.58	1.33	1.28	1.25	1.20	1.33
Istanbul	1.18	1.17	1.07	1.06	1.08	1.11
Jakarta	1.39	1.58	1.33	1.34		1.52
London	0.69	0.69	0.70	0.72	0.71	0.70
Los Angeles	0.78	0.74	0.66	0.63	0.95	0.70
Madrid	0.83	0.81	0.69	0.66	0.57	0.71
Mexico city	1.54	1.53	1.48	1.49		1.51
Milan	1.00	0.98	0.88	1.01	0.90	0.95
Moscow					0.81	0.81
Mumbai	1.98	1.60	1.70	1.69	1.77	1.75
Munich	0.76	0.77	0.80	0.74		0.77
New York	0.78	0.71	0.76	0.62		0.71
Paris	0.64	0.69	0.68	0.67	0.68	0.67
Prague	0.59	0.59	0.65	0.60	0.56	0.60
Rio de Janeiro	1.04	1.34	1.11			0.95
Rome	0.75	0.76	0.69	0.76	0.69	0.73
Sao Paulo	0.84	0.77	0.79	0.78		0.79
Shanghai	2.02	1.70	1.56			1.76
Singapore	0.56	0.59	0.60	0.61		0.60
Stockholm	0.53	0.48	0.51	0.48	0.43	0.49
Stuttgart	0.87	0.91	0.84	0.86		0.87
Sydney	0.42	0.51	0.41	0.40	0.42	0.43
Tokyo	0.75	0.74	0.71	0.67		0.72
Vancouver	0.35	0.35	0.30	0.29	0.30	0.32
Vienna	0.53	0.54	0.60	0.59	0.51	0.55
Warsaw	0.66	0.70	0.75	0.74	0.73	0.73

Table 10.6 Citywide Ranking for Each Year (2008-2012) and the 5-year Average

City	2008	2009	2010	2011	2012	Average
Amsterdam	8	7	4	23	-	6
Barcelona	16	15	12	18	11	16
Beijing	34	35	35	-	-	35
Berlin	5	5	7	4	-	5
Brussels	13	12	9	11	4	11
Bucharest	25	23	24	16	-	25
Budapest	12	11	16	20	6	13
Cairo	35	34	34	-	-	36
Chicago	9	9	19	13	-	7
Frankfurt	10	10	8	8	-	10
Hong Kong	31	28	29	28	18	30
Istanbul	28	27	27	27	17	29
Jakarta	29	31	30	29	-	32
London	**15**	**14**	**17**	**17**	**12**	**15**
Los Angeles	21	18	11	10	16	14
Madrid	22	24	15	12	8	18
Mexico City	30	30	31	30	-	31
Milan	26	26	26	26	15	28
Moscow	-	-	-	-	14	24
Mumbai	32	32	33	31	19	33
Munich	19	22	23	19	-	22
New York	20	17	21	9	-	17
Paris	11	13	13	15	9	12
Prague	7	6	10	6	7	9
Rio de Janeiro	27	29	28	-	-	27
Rome	17	20	14	22	10	21
Sao Paulo	23	21	22	24	-	23
Shanghai	33	33	32	-	-	34
Singapore	6	8	6	7	-	8
Stockholm	4	2	3	3	3	3
Stuttgart	24	25	25	25	-	26
Sydney	2	3	2	2	2	2
Tokyo	18	19	18	14	-	19
Vancouver	1	1	1	1	1	1
Vienna	3	4	5	5	5	4
Warsaw	14	16	20	21	13	20

11. Conclusions

The aim of this study was to develop a method to rank cities based on their *monitored* air quality and to use that method to rank air quality in selected international cities. The ranking scheme adopted was required to be a robust and technically sound method for the comparison and ranking of outdoor air quality in different European and world cities. It should be a methodology that can be understood by an interested member of the public, not just by air quality professionals.

Ranking Methodology

This report reviewed existing ranking methodologies and indices and, building on these schemes, developed a method that allows selection of cities and/ or types of monitoring stations, based on pre-determined criteria. However, in any comparison the overriding principle is that data from all cities be treated on the same basis.

The ranking method uses a multi-pollutant weighted index of annual average concentrations normalised with respect to an annual average value such as the EU limit values. Three index schemes considered in this report using the following pollutants and weightings:

- Citywide - NO_2: 0.3; SO_2:0.3; PM_{10}: 0.3; $PM_{2.5}$: 0.1;
- Citywide/Traffic Focussed - NO_2: 0.4; PM_{10}: 0.4; $PM_{2.5}$: 0.2; and
- Health Impacts - NO_2: 0.02; SO_2:0.03; PM_{10}: 0.71; $PM_{2.5}$: 0.24.

The weighting was applied to data from all monitoring sites equally, so there has been no distinction between background, traffic and industrial sites. Rural sites have been excluded. Annual average concentrations have been excluded if they are known to be based on a data capture of less than 75%. The Citywide index is considered to be most appropriate for this study as it takes into account important pollutants from traffic and industrial sources that affect cities around the world.

The method recommends that ozone, if considered, should be reported as a separate index to address several of its characteristics: the short-term variable nature of the ozone concentrations; the impact of effects that are beyond the control of a city, as ozone concentrations depend on factors such as solar radiation, temperature and atmospheric mixing depth, which vary with latitude; and the non-availability of data. It is recommended that for ozone the index would not be based on annual average concentrations, but instead the number of days on which the EU limit of 120 $\mu g\ m^{-3}$ as an 8-hourly average is exceeded at urban background sites, normalised by 25, the number of exceedences permitted by the EU. In this study ozone was not assessed due to the lack of data outside the EU.

City Selection

The selection of cities was based on the following: population and area; significance, to include capital cities and major European cities; geographical spread across the EU and the world; representation of the “BRIC” countries and other large developing countries; countries that are part of the World Cities Culture Report 2012, established by the Mayor of London; cities that have launched initiatives or taken measures to address air quality issues; cities where a need for air quality improvement is acknowledged; and cities that compete with London economically and financially.

The cities considered include cities in the northern and southern hemispheres, covering a great range of latitudes, from Sydney at 33.8°S to Moscow at 55.8°N. Meteorological and local factors such as the effect of sea, ocean, hills and mountains are presented in section 7.

Monitoring Data

Data were gathered from the EEA's AirBase database for EU Cities, the CleanAir Asia database and from publicly available data sources published by the cities or regions, such as the LAQN. Data for Los Angeles and Vancouver were sent on request, the Vancouver data being supplied with a disclaimer.

Amongst the EU cities, London had the highest number of monitoring sites with 157 and it was the only city with a significant number of high quality monitoring data from sites not in AirBase (139 sites). The ranking has, therefore, been carried out for AirBase sites only for the EU cities, except for London, where all available sites were included.

The number of monitoring stations are not equally distributed according to the city area or number of inhabitants. Vancouver, despite having the smallest population of all the cities considered in the study, has the most monitoring stations both per number of inhabitants (6.97 stations per 100,000 inhabitants) and per area of the city (0.37 stations per km^2). Beijing, with a very large population, is observed to have the least number of monitoring stations per inhabitant with just 0.03 stations per 100,000 people. Sydney, with a large area and small population, has the least per area with less than 0.01 monitoring station per km^2.

Compared with all the non-EU cities London has the second highest number of monitoring stations both per number of inhabitants (1.92 per 100,000 inhabitants) and per area (0.10 per km^2). Compared with EU cities London has the third highest number of stations per km^2, behind Barcelona and Brussels. The lowest performing city in this aspect is Rome, with an area of 1285 km^2, but only 13 measuring stations. In terms of stations per inhabitant London is second, behind Amsterdam. Bucharest is the city with the lowest monitoring density per habitant, with only 8 stations for the more than 1.8 million population.

City Ranking

Table 11.1 shows the city rankings based on five years data (2008-2012). Three cities do not appear in the tables due to lack of data, these are: Dubai, Johannesburg-Gauteng and Lagos. The city with the best air quality (least polluted) is Vancouver and the city with the worst air quality (most polluted), using these indices, is. London is ranked 15th. The EU city with the best air quality is Stockholm. The EU city with the worst air quality is Milan.

Broadly, cities from emerging markets which are currently in the process of rapid growth and industrialisation are observed to be ranked less favourably, whilst cities from 'developed' nations are ranked higher.

The data gathered by AMEC on air quality in various cities, whilst obtained from publicly available sources (with the exception of Los Angeles and Vancouver) may, nonetheless, require explicit permission from the originators of the data for GLA to publish it.

Table 11.1 Overall 5-Year Ranking for City Air Quality (36 Cities)

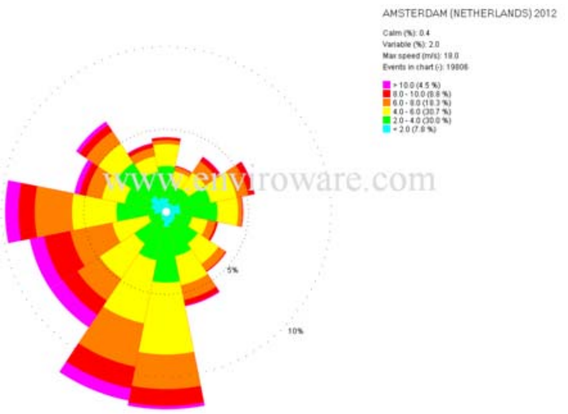
City	Ranking	Descriptor
Vancouver	1	Best Air Quality
Sydney	2	
Stockholm	3	
Vienna	4	
Berlin	5	
Amsterdam	6	
Chicago	7	
Singapore	8	
Prague	9	
Frankfurt	10	
Brussels	11	
Paris	12	
Budapest	13	
Los Angeles	14	
London	15	
Barcelona	16	
New York	17	
Madrid	18	
Tokyo	19	
Warsaw	20	
Rome	21	
Munich	22	
Sao Paulo	23	
Moscow	24	
Bucharest	25	
Stuttgart	26	
Rio de Janeiro	27	
Milan	28	
Istanbul	29	
Hong Kong	30	
Mexico city	31	
Jakarta	32	
Mumbai	33	
Shanghai	34	
Beijing	35	
Cairo	36	Worst Air Quality

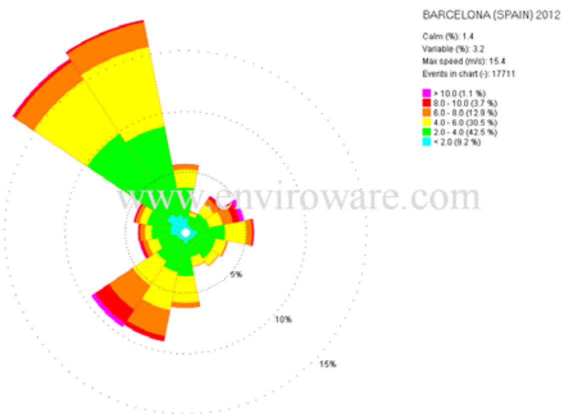
Appendix A
Windroses for Each City

EU Cities

Table A.1 shows the windroses for each EU city and a summary of the climate. The windroses have been taken from www.envirocare.com

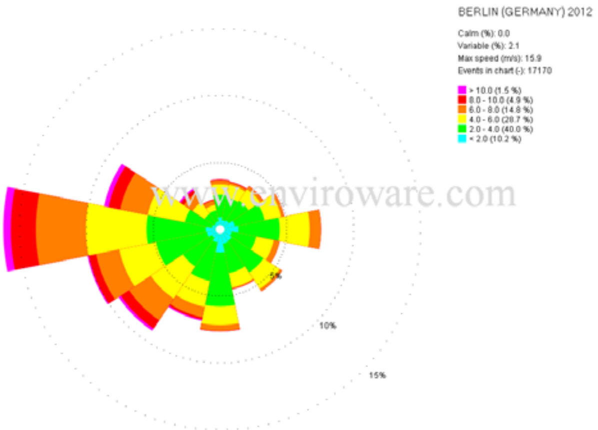
Table A.11.2 EU Cities: Summary of Meteorology and Local Factors

<table>
<tr><th>City and Windrose</th><th>Summary of Climate</th></tr>
<tr><td>Amsterdam

</td><td>Amsterdam has an oceanic climate strongly influenced by its proximity to the North Sea to the west, with prevailing westerly winds.

The city has mainly mild winters with frosts mainly occurring during spells of easterly or north easterly winds from the inner European continent. Temperatures in Amsterdam rarely fall below −5 °C due to it being surrounded on three sides by large bodies of water, as well as having a significant heat-island effect. Summers are moderately warm but rarely hot, again due to the city being surrounded by water, with temperatures rarely recorded above 30 °C. Days with measurable precipitation are common, on average 187 days per year.</td></tr>
<tr><td>Barcelona

</td><td>Barcelona has a Mediterranean climate with mild, humid winters and warm, dry summers.

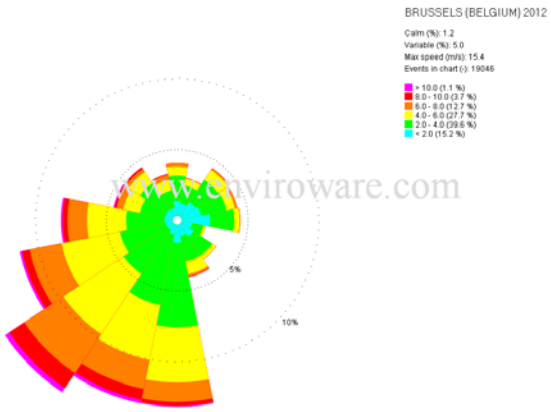
Barcelona's average annual temperature is 20 °C during the day and 11 °C at night. In winter the temperature is not likely to fall below 8 °C during the day and 4°C at night. In the warmest month – August, the typical temperature ranges from 25 to 31 °C.

Barcelona has several rainy days per month although the volume of precipitation which falls is small.</td></tr>
</table>

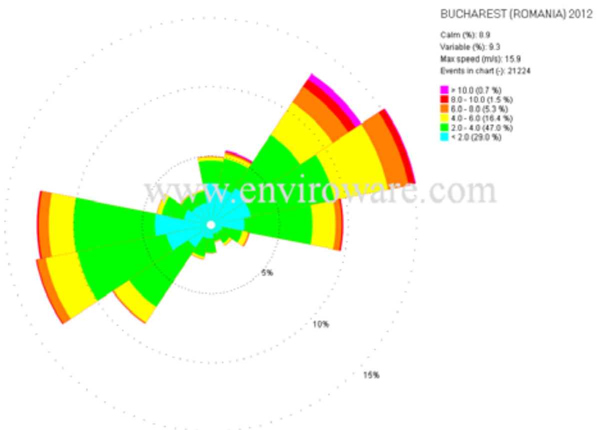
<table>
<tr><th>City and Windrose</th><th>Summary of Climate</th></tr>
<tr><td>Berlin

</td><td>Berlin has a temperate oceanic climate or cool continental climate.

Summers are warm and sometimes humid with average high temperatures of 22–25 °C and lows of 12–14 °C. Winters are relatively cold with average high temperatures of 3 °C and lows of -2 to 0 °C. Spring and autumn are generally chilly to mild.

Berlin's built-up area creates a strong urban heat island effect. Temperatures can therefore be 4 °C higher in the city than in the surrounding areas.

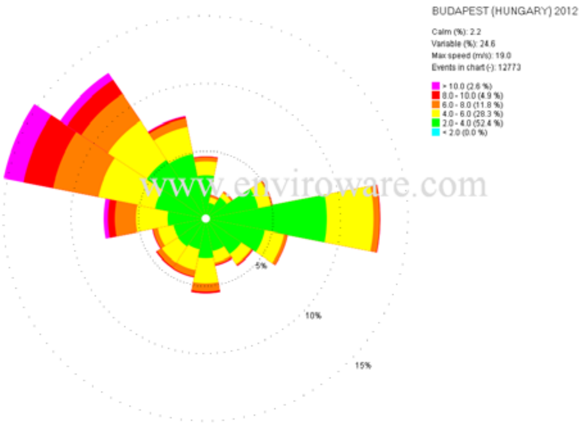
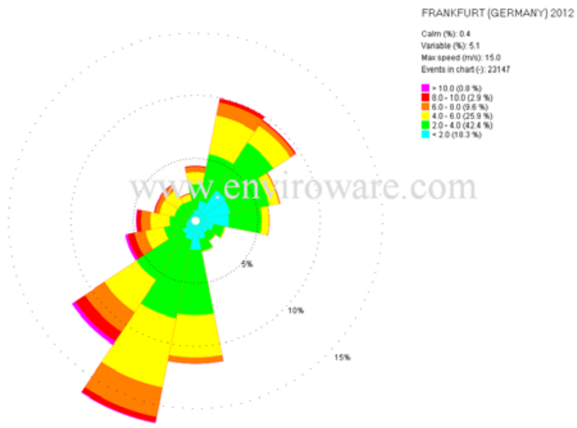
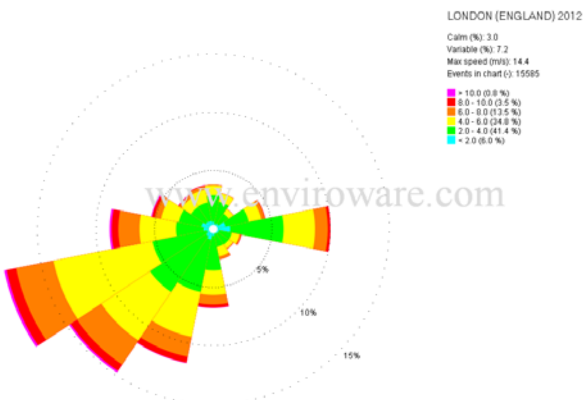
Annual precipitation is 570 millimetres with moderate rainfall throughout the year. Light snowfall mainly occurs from December through March.</td></tr>
<tr><td>Brussels

</td><td>Brussels experiences an oceanic climate.

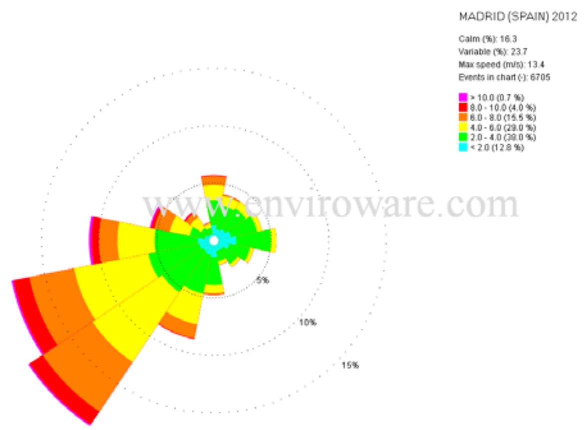
Brussels' proximity to coastal areas influences the area's climate by sending marine air masses from the Atlantic Ocean. Nearby wetlands also ensure a maritime temperate climate.

On average, there are approximately 200 days of rain per year in the Brussels-Capital Region. Snowfall occurs every year between October and April.</td></tr>
<tr><td>Bucharest

</td><td>Bucharest has a transitional climate, with both continental and subtropical influences. Due to its position on the Romanian Plain, the city experiences windy winters.

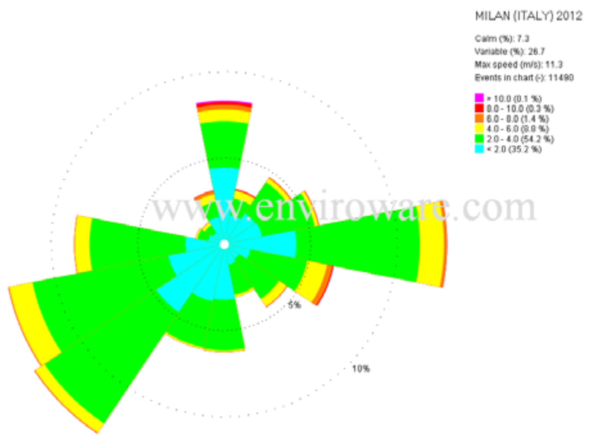
Winter temperatures regularly dip below 0 °C, and can fall as low as −20 °C. Average summer temperatures are around 23°C although the city centre can frequently reach 35 °C in mid-summer.

Precipitation and humidity during summer is low, although the city experiences occasional heavy storms.</td></tr>
</table>

<table>
<tr><th>City and Windrose</th><th>Summary of Climate</th></tr>
<tr><td>Budapest

</td><td>Budapest experiences a humid continental, transitional climate.
Historically the climate of Budapest was more rigid and cold during the winter and warm during the summer, however this trend seems to have become more unstable recently.
During the spring the weather is agreeable at day and fresh at night. The summer temperatures are warm which combined with the humidity can cause sudden heavy showers. The spring and autumn are characterised by little rain and long sunny days. Snow in winter is rare and lasts only a few days.</td></tr>
<tr><td>Frankfurt

</td><td>Frankfurt has a temperate-oceanic climate with relatively cold winters and warm summers.
The average annual temperature is 10.6 °C, with monthly mean temperatures ranging from 1.6 °C in January to 20.0 °C in July.</td></tr>
<tr><td>London

</td><td>London has a temperate oceanic climate, similar to much of southern Britain.
Winters are generally cold with frost usually occurring in the suburbs on average twice a week from November to March. Snow usually occurs about four or five times a year mostly from December to February. Winter temperatures seldom fall below −4 °C or rise above 14 °C.
Summers are generally warm, the heat being boosted by the urban heat island effect making the centre of London at times 5 °C warmer than the suburbs and outskirts. London's summer average is 24 °C.</td></tr>
</table>

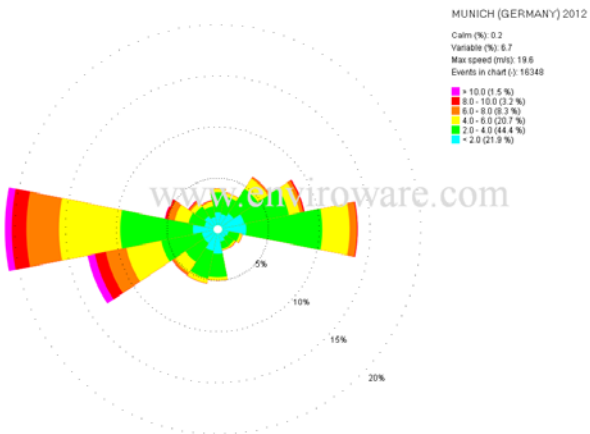
<table>
<tr><th>City and Windrose</th><th>Summary of Climate</th></tr>
<tr><td>Madrid
</td><td>The Madrid region features a Mediterranean climate with cool winters, caused by it elevation.

Summers are warm to hot with temperatures that consistently surpass 30°C. Due to Madrid's altitude and dry climate, diurnal ranges are often significant during the summer.

Precipitation is concentrated in the autumn and spring. It is particularly sparse during the summer, taking the form of about two showers and/or thunderstorms a month.</td></tr>
<tr><td>Milan
</td><td>Milan has a humid subtropical climate, similar to much of northern Italy's. The Alps and Apennines mountains form a natural barrier that protects the city from the major circulations coming from northern Europe and the sea.

During winter, average temperatures can fall below freezing levels and significant accumulations of snow can occur. The city receives an average of seven days of snow per year.

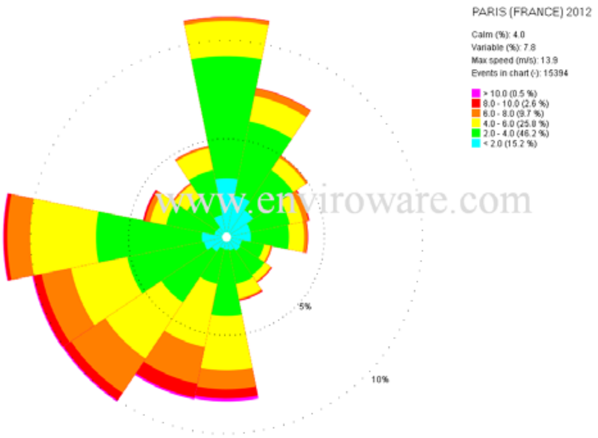
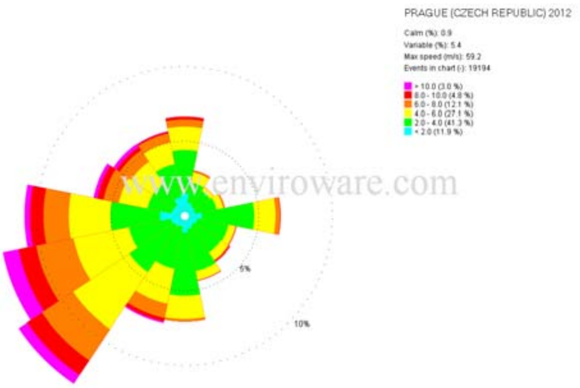
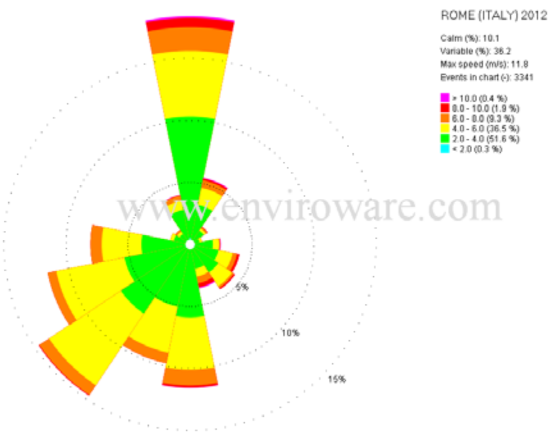
Summers can be quite sultry, when humidity levels are high and peak temperatures can reach 34 °C.

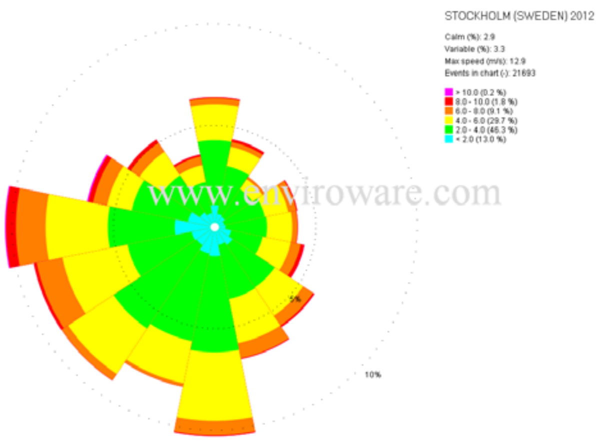
Relative humidity typically ranges between 45% (comfortable) and 95% (very humid) throughout the year, rarely dropping below 27% (dry) and reaching as high as 100%.</td></tr>
<tr><td>Munich
</td><td>The city of Munich experiences an oceanic/humid continental climate.

The elevation of Munich and the proximity of the Alps play a significant role on the climate, causing the city to have more rain and snow than many other parts of Germany. The Alps also cause 'föhn wind' (warm downhill wind from the Alps), which can raise temperatures sharply within a few hours, even in the winter.

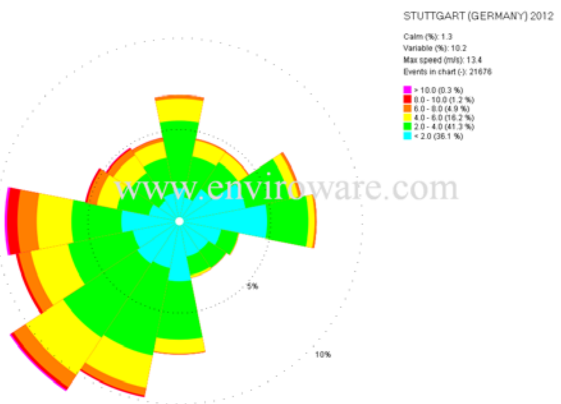
The warmest month of the year, on average, is July. The coolest month of the year, on average, is January.

Showers and thunderstorms bring the highest average monthly precipitation totals in late spring and throughout the summer. June, on average, records the most precipitation of any month. The winter months tend to bring lower precipitation, on average, and February averages the least amount of monthly precipitation for the year.</td></tr>
</table>

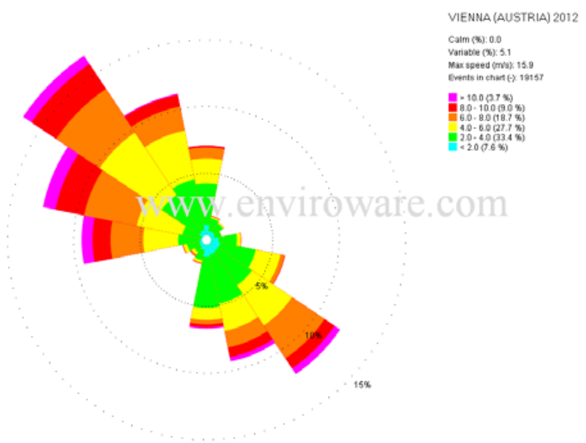
City and Windrose	Summary of Climate
Paris  	Paris has the typical Western European oceanic climate. Paris' climate can be described as mild and moderately wet. Summer days are usually warm and pleasant with average temperatures hovering between 15 °C and 25 °C. In winter, sunshine is scarce; days are cold but generally above freezing with temperatures around 7 °C. Snowfall is rare, but the city sometimes sees light snow or flurries with or without accumulation. Rain falls throughout the year.
Prague  	The city of Prague has borderline oceanic climate. The winters are relatively cold with very little sunshine. Snow cover can be common between mid-November to late March. Summers usually bring fine sunny days with highs being around 25 °C. Nights can be quite cool even in summer, though. Precipitation in Prague is rather low due to the shadow of the Ore Mountains and the Czech Central Highlands.
Rome  	Rome enjoys a Mediterranean climate with mild, humid winters and warm, dry summers. Its average annual temperature is above 20 °C during the day and 10 °C at night. In January, the average temperature is 12 °C during the day and 3 °C at night. In the warmest months, the average temperature is 30 °C during the day and 18 °C at night. Snowfall is rare but not unheard of, with light snow or flurries occurring almost every winter.

<table>
<tr><th>City and Windrose</th><th>Summary of Climate</th></tr>
<tr><td>Stockholm

</td><td>Stockholm has a humid continental climate. Due to the city's high northerly latitude, daylight varies widely from more than 18 hours around midsummer, to only around 6 hours in late December. Despite its northern location, Stockholm has relatively mild weather compared to other locations at similar latitude.

Summers average daytime high temperatures of 20–25 °C and lows of around 13 °C. Winters are sometimes snowy with average temperatures ranging from -5 to 1 °C, and sometimes drop below −15 °C. Spring and autumn are generally cool to mild.

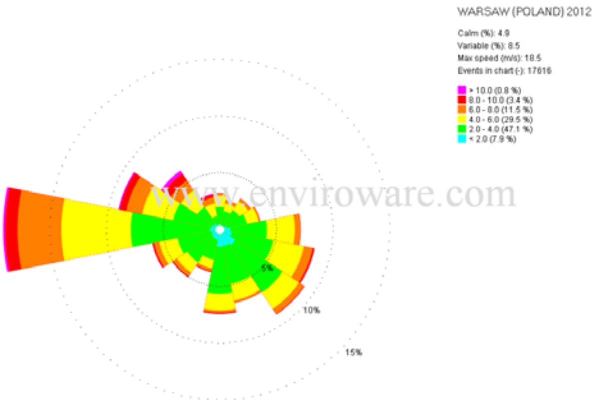
Annual precipitation is 539 mm with around 170 wet days and light to moderate rainfall throughout the year. Snowfall occurs mainly from December through March.</td></tr>
<tr><td>Stuttgart

</td><td>Stuttgart experiences an oceanic climate. The nearby Black Forest and Swabian Alb hills act as a shield during the summer months from harsh weather.

The centre of the city is referred to by locals as the "Kessel" (kettle) as it experiences severe heat in the summer and less snow in the winter than the suburbs. Lying as it does at the centre of the European continent, the temperature range between day and night or summer and winter can be extreme.

Winters last from December to March. The coldest month is January with an average temperature of 0 °C. Snow cover tends to last no longer than a few days. The summers are warm with an average temperature of 20 °C in the hottest months of July and August. The summers last from May until September.</td></tr>
<tr><td>Vienna

</td><td>Vienna lies within a transition of oceanic climate and humid continental climate

The city has warm summers with average high temperatures of 22 to 26 °C and lows of around 15 °C.

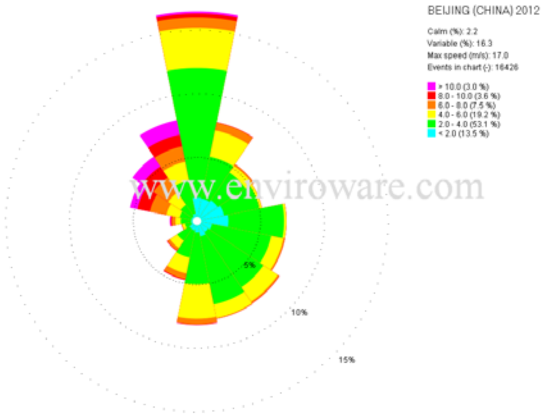
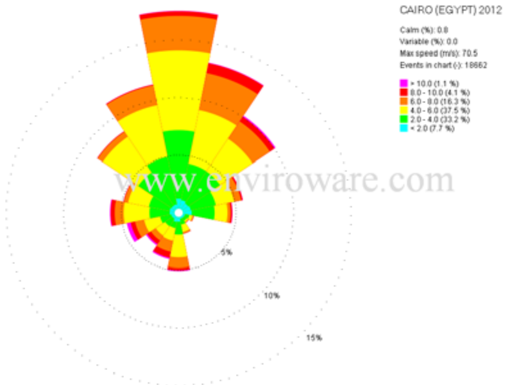
Winters are relatively cold with average temperatures at about freezing point, and snowfall occurring mainly from December through March. Spring and autumn are cool to mild. Precipitation is generally moderate throughout the year.</td></tr>
</table>

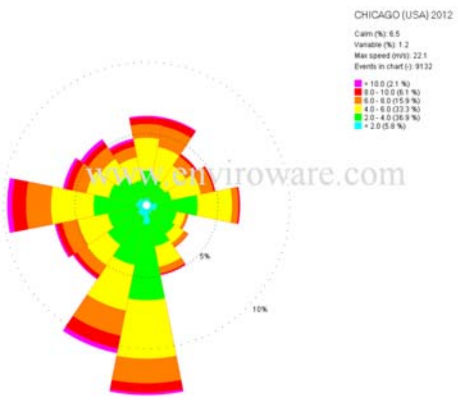
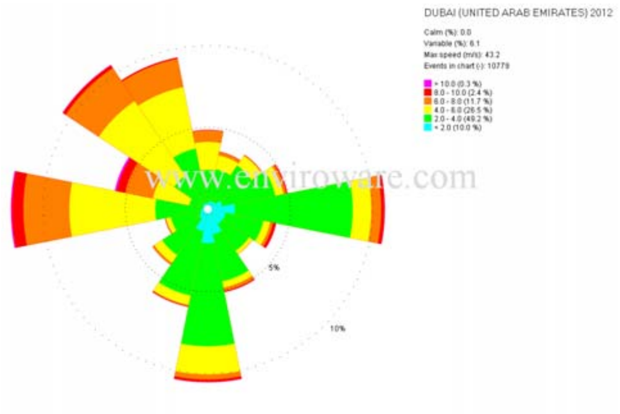
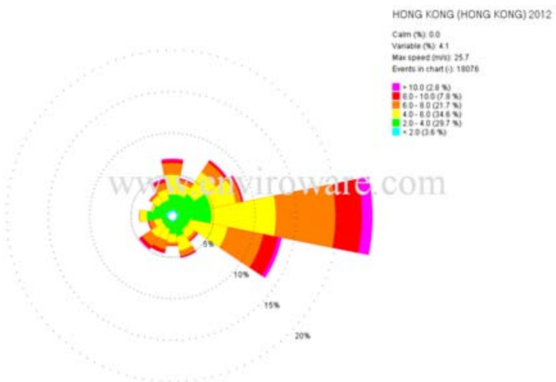
City and Windrose	Summary of Climate
Warsaw  	Warsaw's climate is humid continental with cold winters and warm summers, on the border with an oceanic climate. The average temperature is −3 °C in January and 19.3 °C in July. Yearly rainfall averages 495 millimetres (19.5 in), with the wettest month being July.

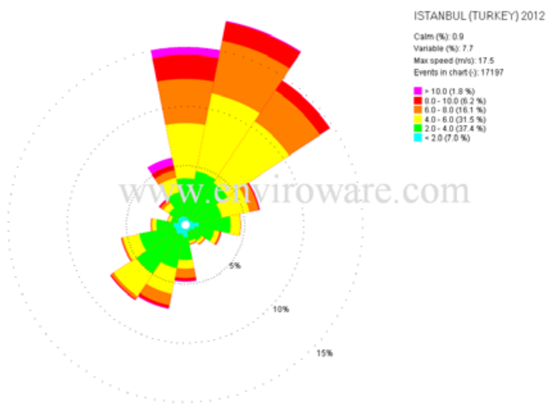
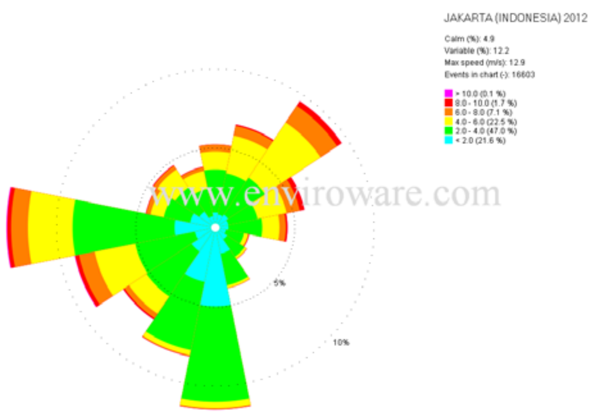
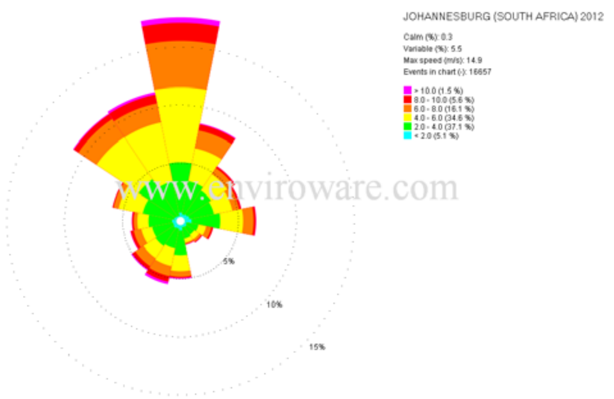
Non-EU Cities

Table A.2 shows the windroses for each non-EU city and a summary of the climate. The windroses have been taken from www.envirocare.com

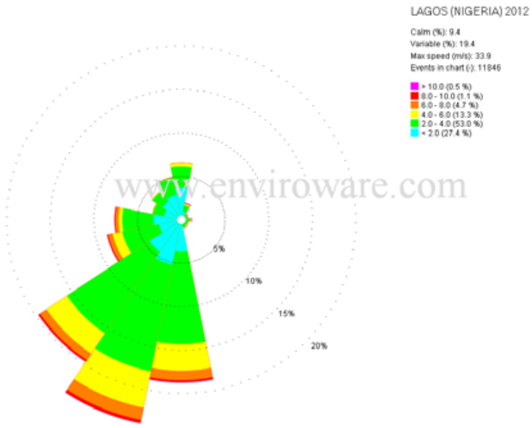
Table A.11.3 Non-EU Cities Summary of Meteorology and Local Factors

City and Windrose	Summary of Climate
Beijing  	Beijing has a dry humid continental climate which is influenced by monsoons. Summers tend to be hot and humid and winters are generally cold, windy and dry reflecting the influence of the Siberian anticyclone. The average temperature is January is -3.7ºC while in July the average temperature is 26.2ºC. Precipitation averages around 570 mm per year, with most rainfall occurring in between June and August.
Cairo  	Cairo has a hot desert climate with high humidity. During March and April wind storms can be frequent, bringing Saharan dust into the city. High temperatures in winter range from 19 °C to 29 °C, while lows drop to below 11 °C (52 °F). In summer, the highs rarely surpass 45°C and lows drop to about 20 °C. There is very little precipitation (~25 mm per year on average), most of which tends to occur in the winter months.

City and Windrose	Summary of Climate
Chicago 	Chicago lies within the humid continental zone and experiences four distinct seasons. Summers are hot and humid with highs of approximately 30°C whereas spring and autumn are mild with low humidity. Average lows in the winter are between -5°C and -8°C. However, the city can experience some extreme winter cold waves.
Dubai 	Dubai has a hot desert climate. In the summer, weather conditions tend to be extremely hot, windy and humid, with an average high of approximately 42°C and overnight lows of around 29°C. Temperatures remain high throughout the year. The average winter high is 23°C and overnight lows of around 14°C. Dubai has an annual average precipitation of 94.3 mm.
Hong Kong 	Hong Kong has a humid subtropical climate. Summers are hot and humid with showers and thunderstorms; the average rainfall in June is around 450 mm. Summer highs average around 31°C. Winters in Hong Kong are mild; average lows are approximately 15°C.

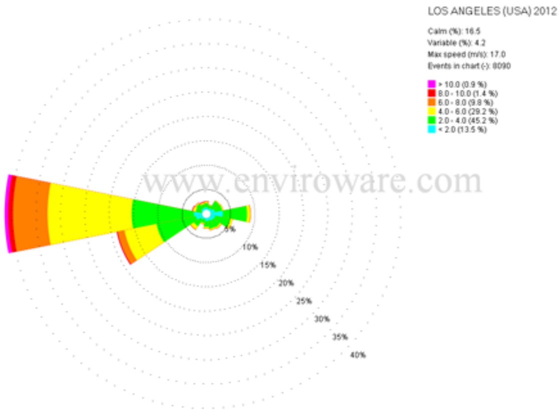
City and Windrose	Summary of Climate
Istanbul  	Istanbul has a particularly high humidity, more so in the northern parts of the city, which are closer to the Black Sea. Due to these humid conditions, fog is very common. During summer months, temperatures average around 29°C and there is very little rainfall. Winter months are colder than in most Mediterranean Basin cities. Indeed, low temperatures average between 4°C and 5°C. Spring and autumn are mild, but often wet. Average annual precipitation is 852 mm.
Jakarta  	Jakarta is located relatively close to the Equator, yet has distinct wet and dry seasons. The wet season runs from November through to June and the remaining four months of the year is the city's dry season. The wettest month tends to be January, when there is an average of 390 mm of rainfall. Jakarta's climate is hot and humid with little variation in temperature throughout the year. Average highs for each month are between 31°C and 33°C. Average lows for each month are between 24°C and 26°C.
Johannesburg  	Johannesburg's climate is defined as subtropical highland. Summer is characterised by hot days, afternoon thunderstorms and cool evenings. Average highs in the winter are around 25°C. In winter conditions are usually sunny and temperatures are fairly mild. However, the average low drops to about 4°C. The annual average rainfall is 713 mm, most of which falls in the summer, with January usually being the wettest month.

<table>
<tr><th>City and Windrose</th><th>Summary of Climate</th></tr>
<tr><td>Lagos



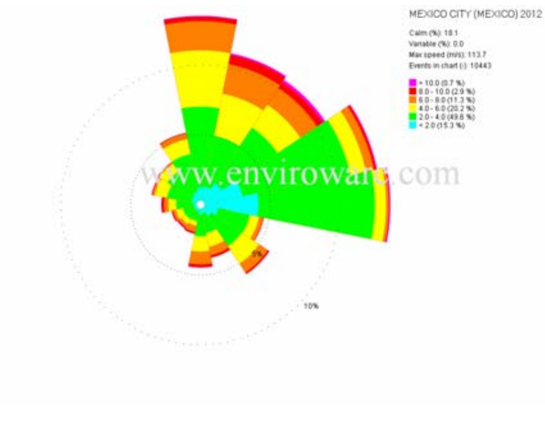
</td><td>Lagos has a tropical climate with two rainy seasons. The heaviest rain falls between April and July and the second rainy season occurs in October and November.

Average highs for each month are between 28°C and 33°C. Average lows for each month are between 21°C and 24°C.</td></tr>
<tr><td>Los Angeles



</td><td>The average annual temperature in Los Angeles is around 24°C during the day and 14°C at night. January is the coldest month with average lows of around 7-8°C. August is the city's warmest month, when daytime temperatures average 29°C.

Los Angeles averages around 385 mm of precipitation. This occurs mainly in the winter and spring months.</td></tr>
<tr><td>Mexico City

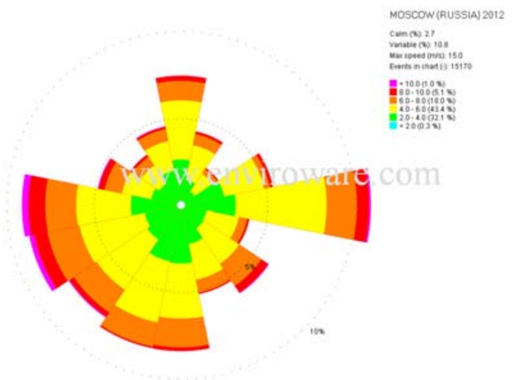
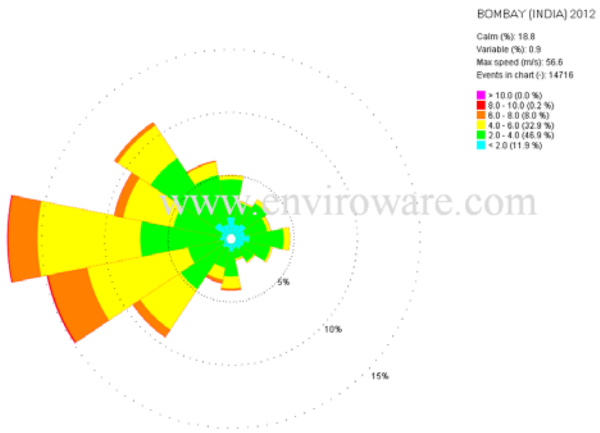
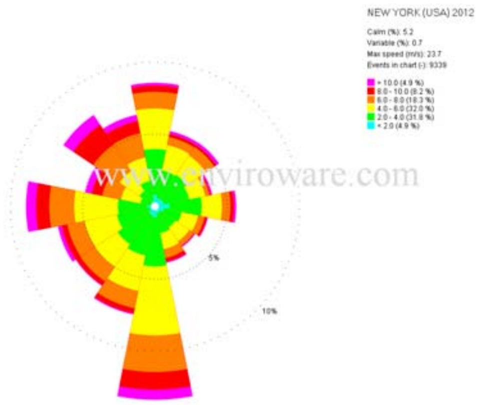


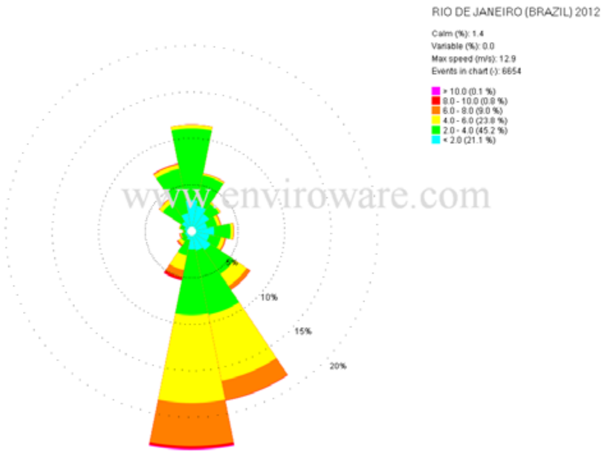
</td><td>Mexico City has a subtropical highland climate due to its tropical location and high elevation.

The average annual temperature varies from 12°C to 16°C, depending on altitude. The lowest temperatures, which are usually registered in January and February, can be around -5°C to -2°C.

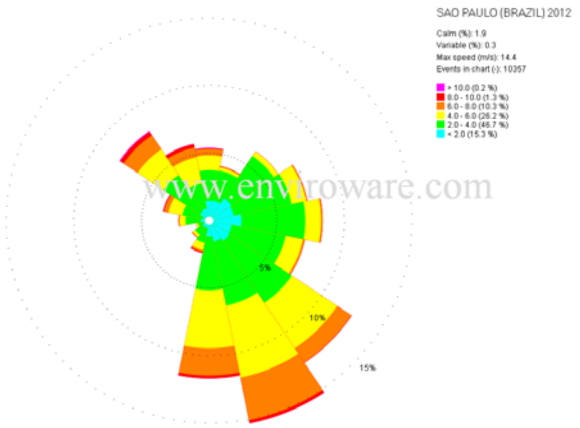
Precipitation is heavily concentrated in the summer months and includes dense hail. Overall the city receives around 820 mm of annual rainfall.

Whilst at high elevation, Mexico City is surrounded by mountains and volcanoes, in the Valley or Basin of Mexico. The region of the Valley of Mexico receives anti-cyclonic systems. The weak winds in this area do not allow for effective dispersion of air quality pollutants.</td></tr>
</table>

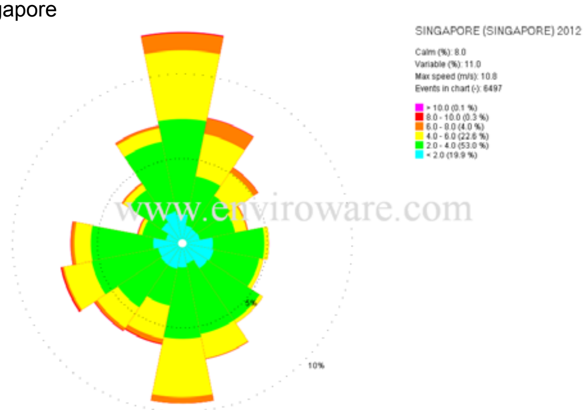
City and Windrose	Summary of Climate
Moscow  	Moscow has warm humid summers but long and cold winters. Average temperatures in the warm months of June, July and August are around 20°C. In the winter, night-time temperatures normally drop to around -10°C. The city's average annual rainfall is 707 mm, with June, July and August being the wettest months of the year.
Mumbai  	Mumbai has a tropical climate, with distinct wet and dry seasons. The wet season runs from June through to September, caused by the south west monsoon. The average rainfall is July is approximately 868 mm, whereas the average rainfall in March is only 0.1 mm. Mumbai's average annual precipitation is 2,167 mm. The average annual temperature in Mumbai is 27°C. Daily mean temperatures for each month are between 24°C and 31°C.
New York City  	New York City experiences a humid subtropical climate. Winters are cold and damp and the wind that blows offshore minimises the moderating effects of the Atlantic Ocean. The average temperature in January is around 0.1°C. Summers are typically hot and humid with average temperatures of around 24°C. New York City receives an average annual rainfall of 1,260 mm.

<table>
<tr><th>City and Windrose</th><th>Summary of Climate</th></tr>
<tr><td>Rio de Janeiro

</td><td>Rio has a tropical savannah climate. The city has long periods of rain during the summer, from December through to March. During these months, in inland areas of the city, temperatures can reach above 40°C, but are moderated by winds blowing both onshore and offshore.

Temperatures are lower in June through to September, yet they are still warm with daily average temperatures between 21°C and 22°C.

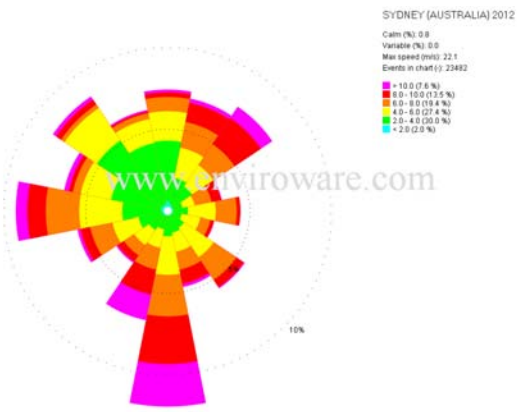
The average annual rainfall in Rio is 1,172mm, with December being the wettest month.</td></tr>
<tr><td>São Paulo

</td><td>São Paulo has a humid subtropical climate, influenced by monsoons. In the summer, average high temperatures are approximately 28°C and in winter the temperatures tend to range between 11°C and 23°C.

During the late winter the city experiences the phenomenon known as ‘veranico’ (‘little summer’) which consists of hot and dry weather. Relatively cool days in the summer are fairly common, owing to the winds from offshore.

São Paulo receives a high amount of rainfall, annually averaging 1,454 mm. Precipitation is especially common in the summer months.</td></tr>
<tr><td>Singapore

</td><td>Owing to its tropical climate, Singapore has no distinct seasons. Singapore experiences uniform temperatures throughout the year and very high humidity. Average high temperatures for each month are between 30°C and 31°C.

Rainfall is abundant; there is an annual average annual rainfall of 2,342 mm, with each month averaging at least 158 mm. November, December and January are the wettest months of the year.</td></tr>
</table>

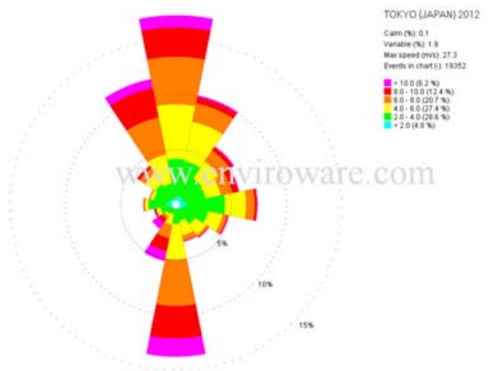
<table>
<tr><th>City and Windrose</th><th>Summary of Climate</th></tr>
<tr><td>Sydney



</td><td>Sydney has a temperate climate, with hot summer and mild winters. The weather is moderated by the proximity to the ocean. January is Sydney's warmest month, with average highs of 25°C. In the winter temperatures rarely drop below 5°C.

The annual average rainfall is 1,214 mm, with the wettest month being June, which, on average, receives 131mm.

The city can be affect by the El Niño–Southern Oscillation. It can bring about droughts and bush-fires as well as storms and floods.</td></tr>
<tr><td>Tokyo

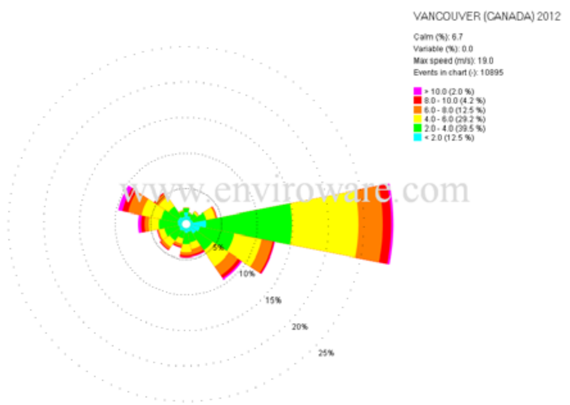


</td><td>Tokyo experiences hot and humid summers and mild winters with cool spells.

The warmest month is August, with a daily mean temperature of 27°C, and the coolest month is January, with a daily mean temperature of 6°C.

Annual rainfall averages around 1530 mm, with a wetter summer and a drier winter.

Whilst few are strong, Tokyo often experiences typhoons each year.</td></tr>
<tr><td>Vancouver



</td><td>Summer months in Vancouver are typically dry but, in contrast, precipitation falls every other day on average between November and March.

In the downtown area of Vancouver, average annual rainfall is 1,588mm.

Daily mean temperatures in the summer months of Jun and July are around 18°C. Whereas the mean temperatures in the winter months of December and January are between 4°C and 5°C.</td></tr>
</table>

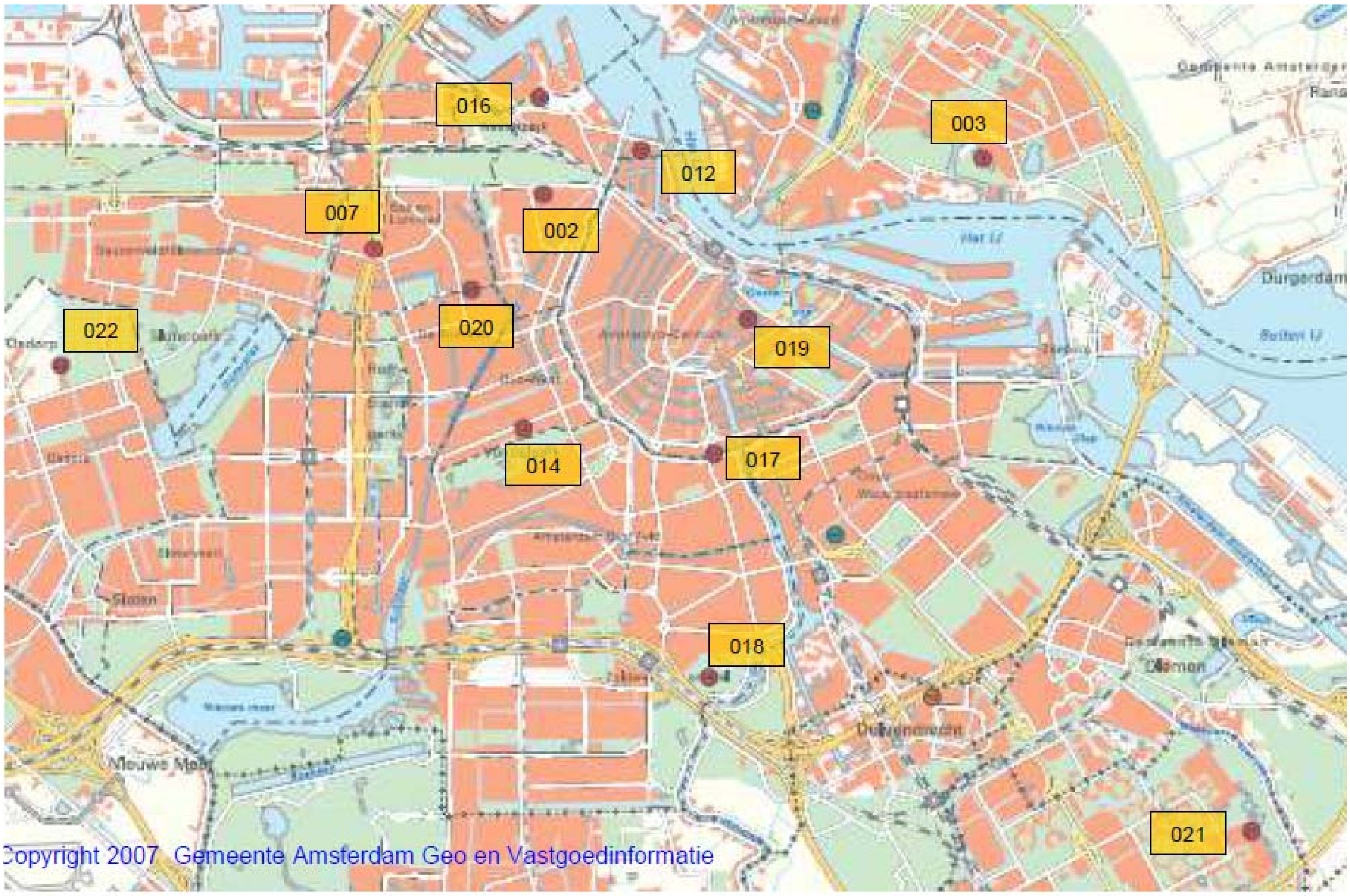
Appendix B
Map and Characteristics of Monitoring Stations

Note that the maps are not all presented with north-south aligned vertically.

EU Cities

Amsterdam

Figure B.1 Map of Monitoring Stations in Amsterdam (Gemeente Amsterdam Geo En Vastgoedinformatie, 2007)



Available at http://www.luchtmetingen.amsterdam.nl/Default.aspx

Table B.1 Monitoring Stations in Amsterdam

Site	Period	Location Longitude	Location Latitude	Type
Amsterdam - Kantershof (Zuid Oost)	07/02/2007-now	4.99	52.32	Background
Amsterdam-A10 west	01/04/2007-now	4.84	52.34	Traffic
Amsterdam-A10zuid	01/12/2003- now	4.90	52.33	Traffic
Amsterdam-Cabeliaustraat	02/04/1976- now	4.80	52.38	Background
Amsterdam-Einsteinweg	01/01/1999- now	4.85	52.38	Traffic
Amsterdam-Florapark	02/02/1976- now	4.92	52.39	Background
Amsterdam-Haarlemmerweg	01/01/1997- now	4.88	52.39	Traffic
Amsterdam-Hoogtij	01/01/2009- now	4.77	52.43	Industrial
Amsterdam-Jan van Galenstraat	01/01/2007- now	4.86	52.38	Traffic
Amsterdam-Nieuwendammerdijk	01/01/1987- now	4.94	52.39	Background
Amsterdam-Oude Schans	03/01/2007- now	4.91	52.37	Background
Amsterdam-Overtoom	01/01/1990- now	4.81	52.36	Background
Amsterdam-Overtoom RIVM	26/10/2007- now	4.87	52.36	Background
Amsterdam-Prins Bernhardplein	22/12/2004- 27/12/2011	4.92	52.35	Traffic
Amsterdam-Spaarnwoude	01/12/2008- now	4.73	52.40	Background
Amsterdam-Sportpark Ookmeer (Osdorp)	20/01/2007- now	4.79	52.38	Background
Amsterdam-Stadhouderskade	01/01/1999- now	4.90	52.36	Traffic
Amsterdam-Van Diemenstraat	01/01/1990- now	4.89	52.39	Traffic
Amsterdam-Westerpark	01/01/1999- now	4.87	52.39	Background

Barcelona

Figure B.2 Map of Monitoring Stations in Barcelona (Catalonian Regional Department for Territory and Sustainability, 2011)

Notes: Red circles refer to active stations. Grey circles refer to stations closed in the period 2008-2012

Available at http://www.mediambient.bcn.es/cas/web/cont_bcn_aire_xarxa.htm

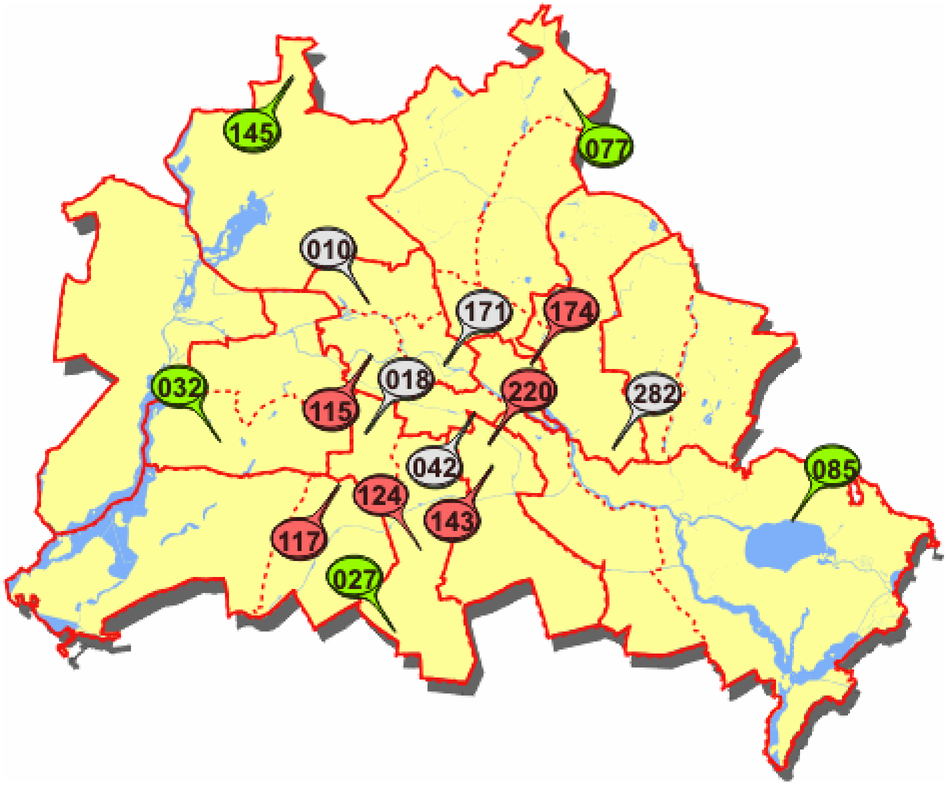
Table B.2 Monitoring Stations in Barcelona

Site	Period	Location Longitude	Location Latitude	Type
Ciutadella	2004- now	2° 11' 15" E	41° 23' 17" N	Urban background
IES Verdaguer*	2009- now	2° 11' 16" E	41° 23' 18" N	Urban background
Vall d'Hebron	2008- now	2° 08' 53" E	41° 25' 34" N	Urban background
Zona Universitària*	1984- now	2° 07' 18" E	41° 23' 10" N	Urban background
IES Goya*	2007- now	2° 10' 11" E	41° 25' 16" N	Urban background
Torre Girona*	2009-2011	2° 06' 57" E	41° 23' 25" N	Urban background
Eixample	1984- now	2° 09' 16" E	41° 23' 07" N	Urban traffic (very intense)
Gràcia-St. Gervasi	1984- now	2° 09' 09" E	41°23' 57" N	Urban traffic (very intense)
Poblenou	1982- now	2° 12' 19" E	41° 24' 15" N	Urban traffic (moderate)
Sants	1986- now	2° 07' 57" E	41° 22' 43" N	Urban traffic (moderate)
Plaça Universitat*	1984- now	2° 09' 59" E	41° 23' 19" N	Urban traffic (very intense)
Palau Reial	2011- now	2° 06' 55" E	41° 23' 15" N	Urban traffic (moderate)
Lluís Solé i Sabarís	2005-2008	2° 07' 09" E	41° 23' 05" N	Urban background
Port Vell	2006- now	2° 11' 17" E	41° 22' 36" N	industrial suburban

Notes: * Manual stations

Berlin

Figure B.3 Maps of Monitoring Stations in Berlin (BLUME, 2010)



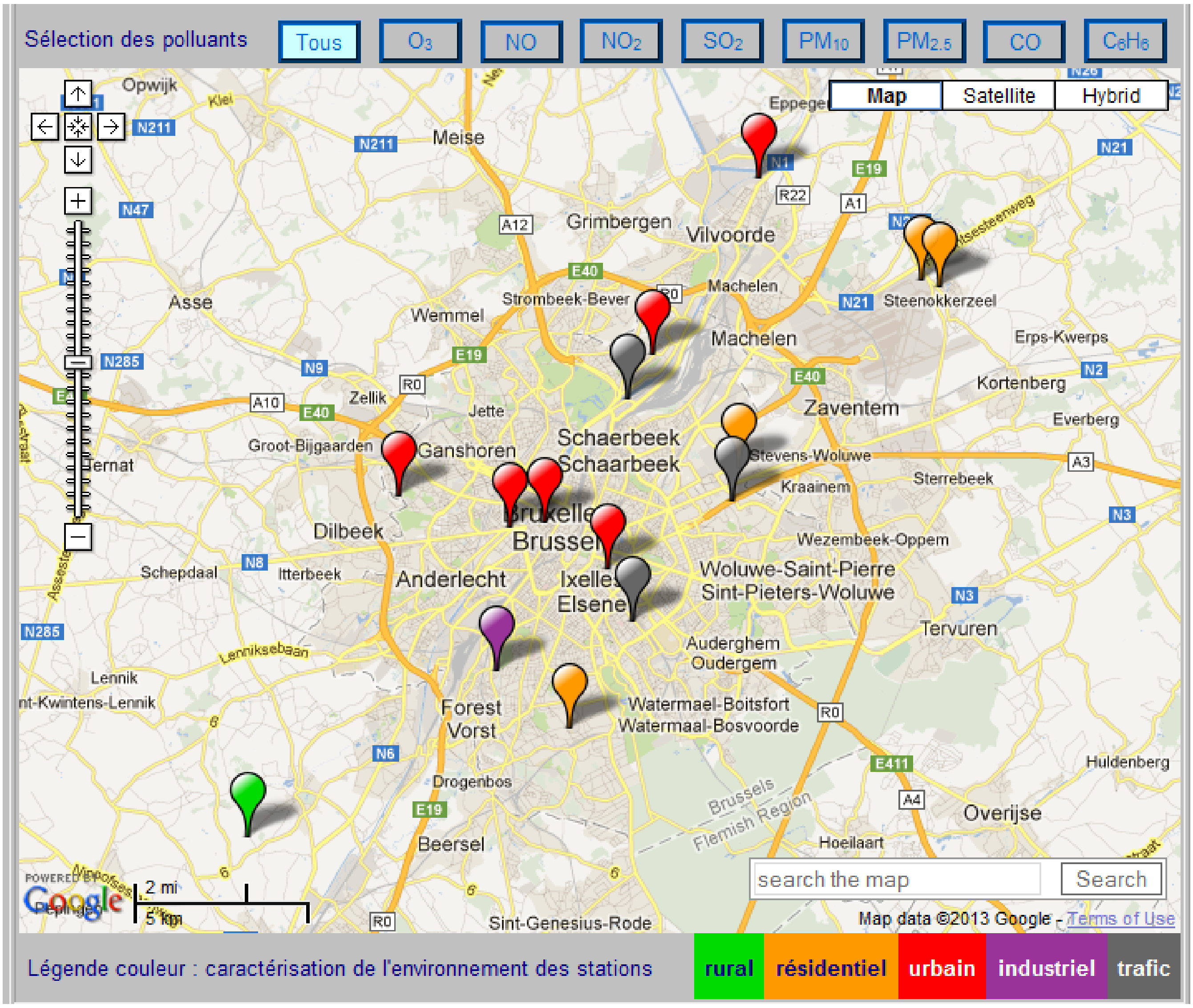
Available at http://www.stadtentwicklung.berlin.de/geoinformation/fis-broker/index_en.shtml

Table B.3 Monitoring Stations in Berlin

Site	Period	Location longitude	Location latitude	Type
Funkturm Frohnau' Berlin	1996- now	13°17'45,89"	52°39'11,77"	Background rural
Klinikum Buch' Berlin	1993- now	13°29'22,31"	52°38'36,39"	Suburban background
Beuth Hochschule fuer Technik', Amrumer	1984- now	13° 20' 57,48"	52° 32' 32,58"	Urban background
Brueckenstrasse 6	2003- now	13° 25' 7,80"	52° 30' 48,98"	Urban background
Friedichschain-Kreuzberg	1993- now	13° 28' 11,75"	52° 30' 50,66"	Urban traffic
Waldstation 3m Hoehe', Forst Grunewald, Jagen 91, Charlottenburg-Wilbersdorf	1986- now	13° 13' 30,52"	52° 28' 23,49"	Rural background
Waldstation 27m Hoehe', Forst Grunewald, Jagen 91, Charlottenburg-	1986- now	13° 13' 30,52"	52° 28' 23,49"	Rural background
Hardenbergplatz	2004- now	13° 19' 58,70	52° 30' 23,76"	Urban traffic
Gelaende des Senatfuhrtparks, Belziger Strasse 52	1986- now	13° 20' 55,59"	52° 29' 8,93"	Urban background
Amtsgericht, Karl-Marx Strasse 77	1993- now	13° 26' 2,28"	52° 28' 54,01"	Urban traffic
Johanna-und-Willy-Brauer-Platz, Karlshorst-Lichtenberg	1999- now	13° 31' 46,21"	52° 29' 6,94"	Suburban background
Schildhornstrasse 76	1991- now	13° 19' 5,70"	52° 27' 49,00"	Urban traffic
Mariendorfter Damm 148, Tempelhof-Schoeneberg	2009- now	13° 23' 15"	52° 26' 17"	Urban traffic
Nansenstrasse 10, Berlin	1986- now	13° 25' 51,08"	52° 29' 21,98"	Urban background
Versuchsfeld Merienfeld des UBA	1989- now	13° 22' 5,17"	52° 23' 54,26"	Industrial rural
Silbersteinstrasse 1	1996- now	13° 26' 29,94"	52° 28' 3,04"	Urban traffic
Wasserwerksgelaende	1994- now	13° 38' 49,38"	52° 26' 51,71"	Rural background

Brussels

Figure B.4 Map of Monitoring Stations in Brussels (Google Maps and Irceline, 2013)



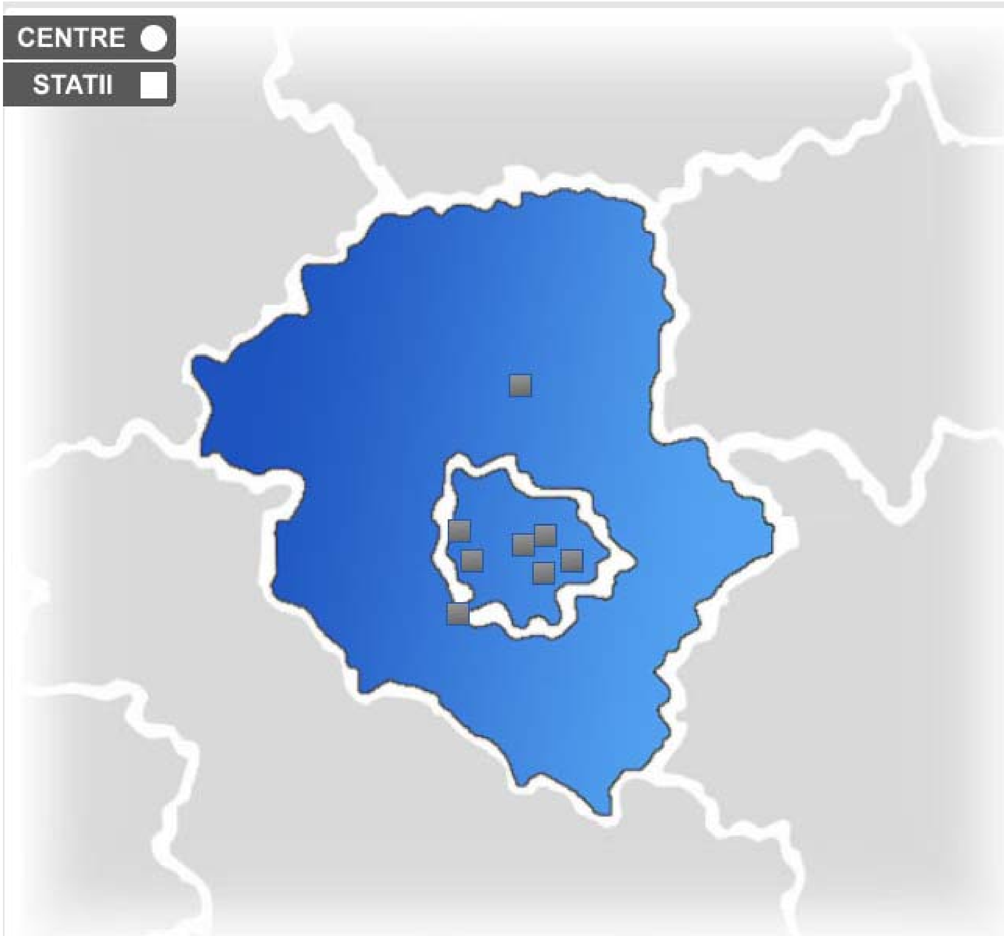
Available at http://www.irceline.be/~celinair/maps/stations/stations.php?lan=fr&pol=&tab=&sta=BRU

Table B.4 Monitoring Stations in Brussels

Site	Period	Location Longitude	Location Latitude	Type
Bruxelles – Arts - Loi	N/A	N/A	N/A	N/A
41B004 - STE.CATHERI	01/01/2000- now	4.347322	50.851353	Traffic urban
41B005 - BELLIARD	01/01/2001- now	4.377467	50.840668	Traffic urban
41B006 - PARL.EUROPE	01/01/2001- now	4.373122	50.839172	Background urban
Eastman Belliard	N/A	N/A	N/A	N/A
41B011 - BERCHEM S.A	01/01/1992- now	4.287072	50.858574	Background suburban
41MEU1 - MEUDON	01/03/1998- now	4.39145	50.895645	Background suburban
41N043 - HAREN	01/01/1976- now	4.381697	50.884106	Industrial suburban
41R001 - MOLENBEEK	01/01/1976- now	4.332555	50.850208	Traffic urban
41R002 - IXELLES	01/01/1990- now	4.383452	50.825672	Traffic suburban
41R012 - UCCLE	01/01/1976- now	4.357275	50.797178	Background suburban
41WOL1 - WOL.ST.L.	01/01/1994- now	4.424436	50.857121	Traffic suburban
41WOL2 - WOL.ST.L.	01/01/1999- now	4.424436	50.857121	Traffic suburban
47E013 - VORST	01/01/1997- now	4.327119	50.812248	Industrial urban
61MEU1 - MEUDON	01/01/1998- now	4.39145	50.895645	Background suburban
61N043 - HAREN	01/01/2009- now	4.381697	50.884106	Industrial suburban
61R002 - IXELLES	01/01/1998- now	4.383452	50.825672	Traffic suburban
61R112 - UCCLE	01/01/2009- now	4.357275	50.797178	Background suburban
61WOL1 - WOL.ST.L.	01/01/1997- now	4.424436	50.857121	Traffic suburban
61WOL2 - WOL.ST.L.	01/07/2006- now	4.424436	50.857121	Traffic suburban

Bucharest

Figure B.5 Map of Monitoring Stations in Bucharest (Romanian National Agency of Environmental Protection, 2013)



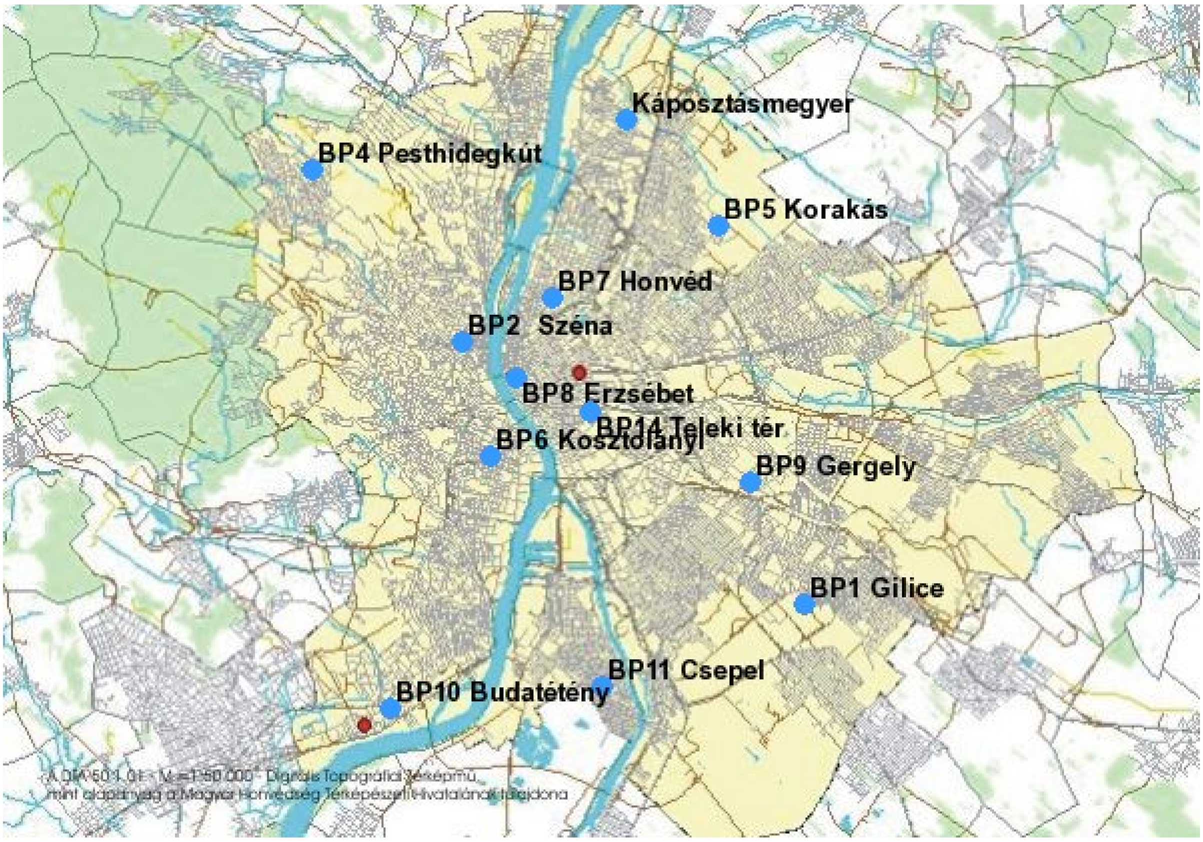
Available at http://www.calitateaer.ro/index.php

Table B.5 Monitoring Stations in Bucharest

Site	Period	Location Longitude	Location Latitude	Type
B1 Lacul Morii	01/01/2004- now	26.036831	44.447071	Background
B2 Titan	01/01/2004- now	26.184734	44.411114	Industrial
B3 Mihai Bravu	01/01/2004- now	26.151121	44.440556	Traffic
B4 Berceni	01/01/2004- now	26.148348	44.395836	Industrial
B5 Drumul Taberei	01/01/2004- now	26.052244	44.411667	Industrial
B6 Cercul Militar	01/01/2004- now	26.120836	44.42889	Traffic
B7 Magurele	01/01/2004- now	26.033613	44.348888	Background
B8 Balotesti	01/01/2004- now	26.116667	44.616665	Background

Budapest

Figure B.6 Map of Monitoring Stations in Budapest (Hungarian Air Quality Network, 2013)



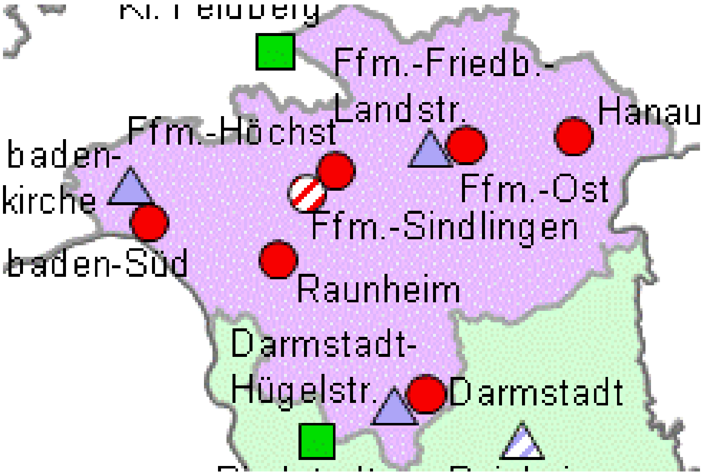
Available at http://www.kvvm.hu/olm/map.php

Table B.6 Monitoring Stations in Budapest

Site	Period	Location Longitude	Location Latitude	Type
Budapest Gilice	01/01/2003- now	19.18	47.43	Background
Budapest Honved	01/01/2009- now	19.07	47.52	Background
Budapest Korakas	07/01/2003- now	19.15	47.54	Background
Budapest Pesthidegkut	07/01/2003- now	18.96	47.56	Background
Budapest Szena	01/01/1994- now	19.03	47.51	Traffic
Budapest Teleki	23/08/2007- now	19.09	47.49	Traffic
Gergely u. 85.				
Káposztásmegyer				
Budatétény				

Frankfurt

Figure B.7 Map of Monitoring Stations in Frankfurt (Hessischen Landesamt fur Umwelt und Geologie, 2013)



Available at http://www.hlug.de/fileadmin/scripts/recherche/info/FrankfurtHoechst.pdf

Table B.7 Monitoring Stations in Frankfurt

Site	Period	Location Longitude	Location Latitude	Type
Lerchesberg Kleingartenkolonie		8°40'58.82	50°4'53.28	Suburban background
Raunheim				Suburban background
Friedberger Landstrasse	1993- now	8°41'34.8	50°07'32.4	Urban traffic
Hoechstrasse	1979- now	8.542053	50.101871	Urban traffic
Frankfurt Ost	1984- now	8°44'54.9	50°07'36.9	Urban background
Sindlingen	1977- now	8°30'56.00	50°4'50.00	Urban background

London

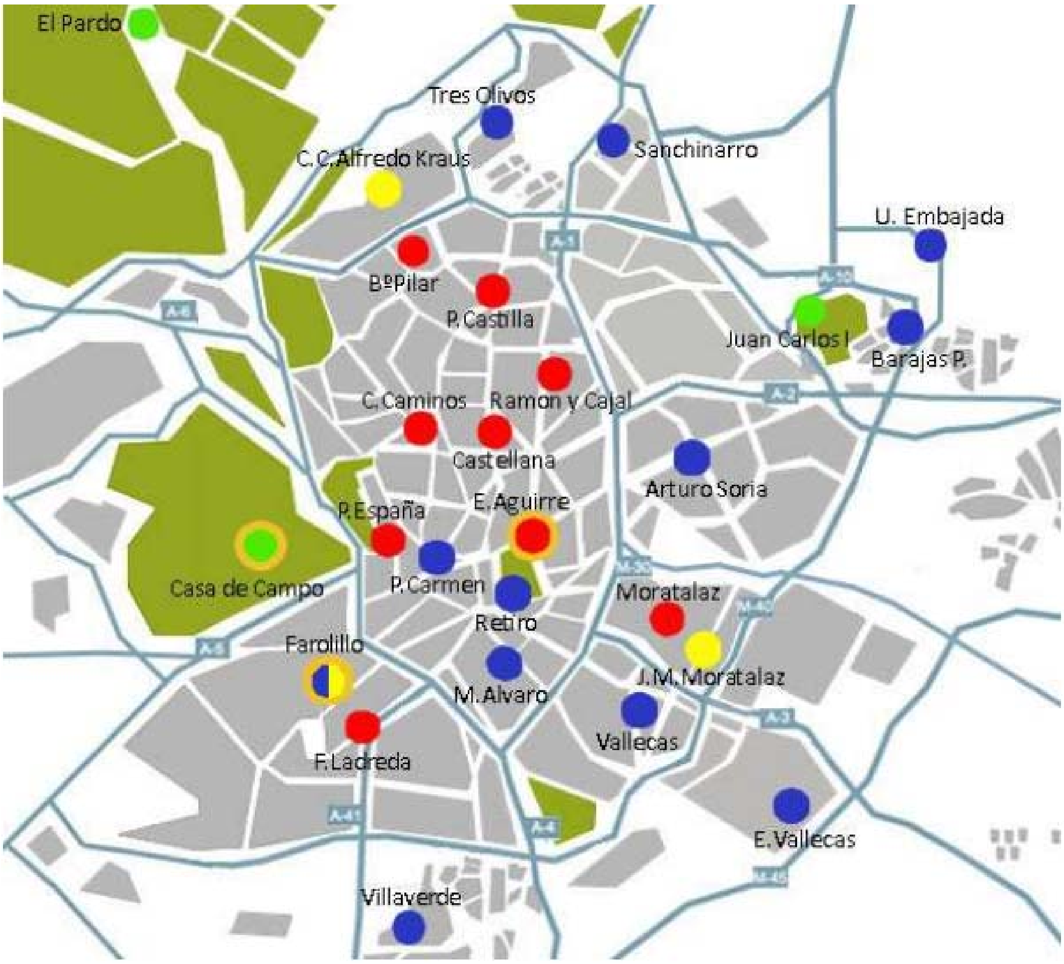
2008-12 monitoring data have been obtained from the following sources:

- UK Defra: http://uk-air.defra.gov.uk/networks/;
- London Air Quality Network (LAQN): http://www.londonair.org.uk/LondonAir/Default.aspx; and
- Web sites of the 33 London Boroughs.

An interactive map of monitoring sites is available at: http://www.londonair.org.uk/

Madrid

Figure B.8 Map of Monitoring Stations in Madrid (Madrid City Hall, 2012)



Notes: Green circles: Suburban background. Red circles: Traffic. Blue circles: Urban background. PM 2.5 measurements from the National Institute of Meteorology

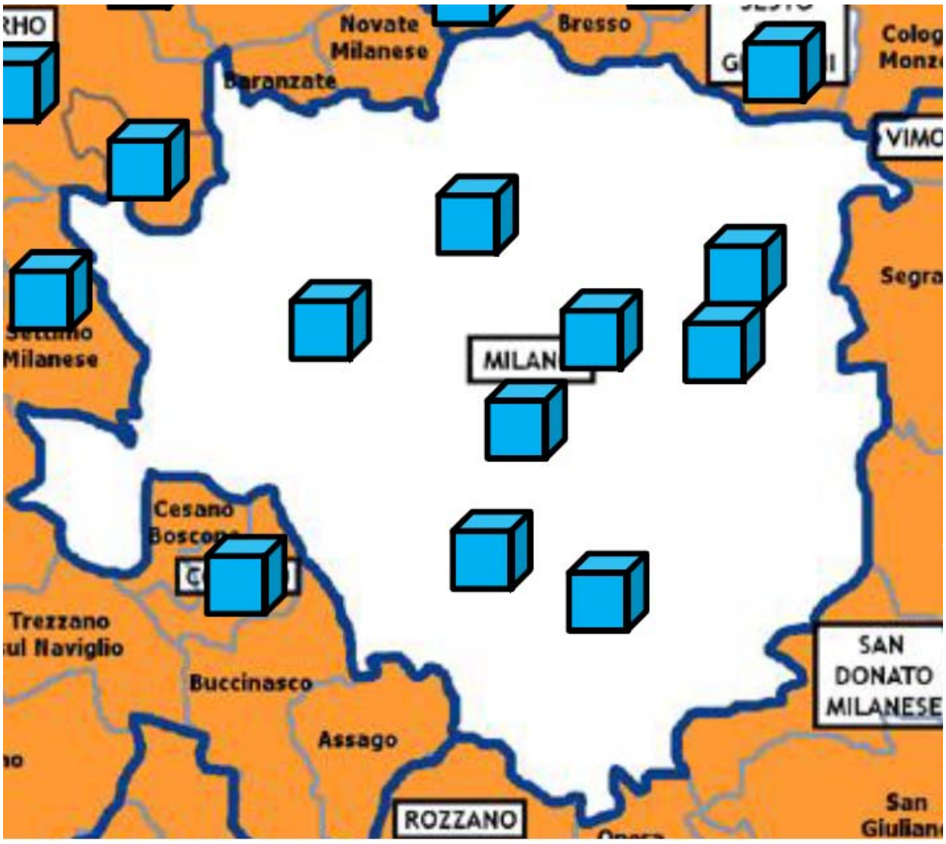
Available at http://www.mambiente.munimadrid.es/svca/index.php

Table B.8 Monitoring Stations in Madrid

Site	Period	Location Longitude	Location Latitude	Type
Plaza España	1978-now	3°42' 44.40" W	40° 25' 26.37" N	Urban traffic
Escuelas Aguirre	1972-now	3° 40' 56.35" W	40° 25' 17.63" N	Urban traffic
Avda. Ramon y Cajal	1978-now	3° 40' 38.47" W	40° 27' 05.30" N	Urban traffic
Arturo Soria	1978-now	3° 38' 21,24" W	40° 26' 24,17" N	Urban background
Villaverde	Jun 2009-now	3°42'47.98"W	40°20'49.56"N	Urban background
Farolillo	2010-now	3° 43' 54.60" W	40° 23' 41.20" N	Urban background
Casa de Campo	1992-now	3° 44' 50.44" W	40° 25' 09,68" N	Suburban
Barajas Pueblo	2003-now	3°°34' 48.10" W	40° 28' 36.94" N	Urban background
Plaza del Carmen	1995-now	3° 42' 11.42" W	40° 25' 09,15" N	Urban background
Moratalaz	1995-now	3° 38' 43.06" W	40° 24' 28,64" N	Urban traffic
Cuatro Caminos	1998-now	3° 42' 25.66" W	40° 26' 43,95" N	Urban traffic
Barrio del Pilar	1998-now	3° 42' 41.55" W	40° 28' 41.62" N	Urban traffic
Puente de Vallecas	1999-now	3° 39' 05.48" W	40° 23' 17.34" N	Urban background
Mendez Alvaro	2010-now	3°41'12"W	40°23'53" N	Urban background
Castellana	Jun 2010-now	3° 41' 25" W	40° 26' 23" N	Urban traffic
Retiro	2010-now	3°40'57" W	40°24'52" N	Urban background
Plaza de Castilla	1978-2008 & 2010-now	3°41'19"W	40º27'56"N	Urban traffic
Ensanche de Vallecas	2010-now	3° 36' 43"W	40° 22' 22" N	Urban background
Urbanizacion Embajada	2010-now	3° 34' 50" W	40° 27' 45" N	Urban background
Fernandez Ladreda	2008-2010 & 2010-now	3° 43' 7" W	40° 23' 05" N	Urban traffic
Sanchinarro	Nov 2009-now	3°39'37.8" W	40°29'39.1" N	Urban background
El Pardo	Dic 2009-now	3°46'28.6" W	40° 31' 5" N	Suburban
Juan Carlos I	2010-now	3° 36' 32" W	40° 27' 54" N	Suburban
Tres Olivos	2010-now	3° 41' 23' W	40° 30' 02" N	Urban background
Paseo de Recoletos	1978-May 2009	3° 41' 31" W	40° 25' 21" N	Urban traffic
Marañón	1978-2009	3° 41' 27" W	40° 26' 16" N	Urban traffic
Marques de Salamanca	1978-2009	3° 40' 49" W	40° 25' 18" N	Urban traffic
Luca de Tena	1978-2009	3° 41' 37" W	40° 24' 08" N	Urban traffic
Manuel de Becerra	1978-2009	3° 40' 07" W	40° 25' 43" N	Urban traffic
General Ricardos	2001-2009	Later known as	FAROLILLO	Urban background
Paseo Extremadura	1990-2009	3° 44' 31" W	40° 24' 28" N	Urban traffic
Isaac Peral	1990-2009	3° 43' 06" W	40° 26' 28" N	Urban traffic
Paseo Pontones	1991-2009	3° 42' 46" W	40° 24' 23" N	Urban traffic
C/ Alcala final	1992-2009	3° 36' 16" W	40° 27' 01" N	Urban traffic
Santa Eugenia	1997-Nov 2009	3° 36' 09" W	40° 22' 46" N	Urban traffic

Milan

Figure B.9 Map of Monitoring Stations in Milan (ARPA Lombardia, 2010)



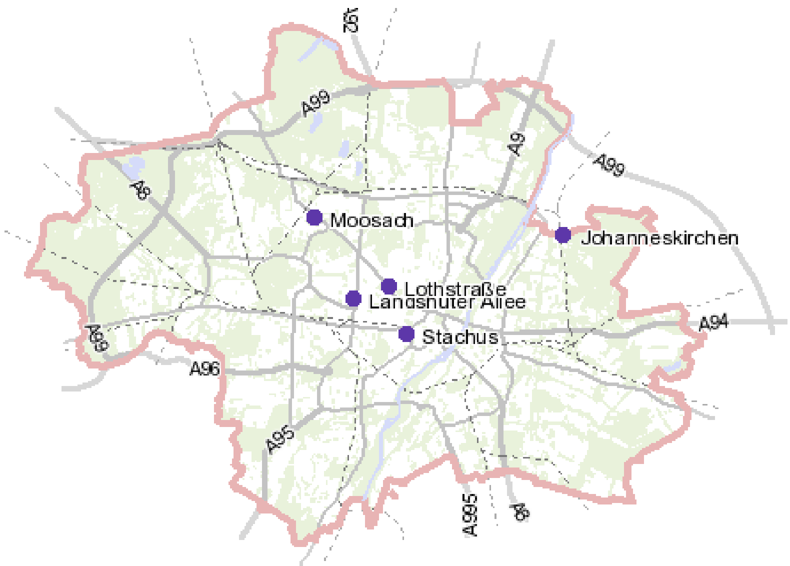
Available at http://ita.arpalombardia.it/ITA/qaria/doc_DatiRete.asp

Table B.9 Monitoring Stations in Milan

Site	Period	Location Longitude	Location Latitude	Type
Milano - Liguria	1991-now	09° 10' 57" E	45 26 57	Urban traffic
Milano - Parco Lambro	1995-now	09° 14' 52" E	45 29 56	Suburban background
Milano - Abbiategrasso	1995-now	09° 10' 56" E	45 25 53	Urban background
Milano - Senato	1995-now	09° 11' 53" E	45 28 11	Urban traffic
Milano - Marche	1973-now	09° 11' 29" E	45 29 44	Urban traffic
Milano - Verziere	1989-now	09° 11' 43" E	45 27 48	Urban traffic
Milano - Pascal Città	2005-now	09° 14' 11" E	45 28 43	Urban background
Milano - Zavattari	1968-now	09° 08' 32" E	45 28 31	Urban traffic

Munich

Figure B.10 Map of Monitoring Stations in Munich (Landeshauptstadt Muenchen, 2013)



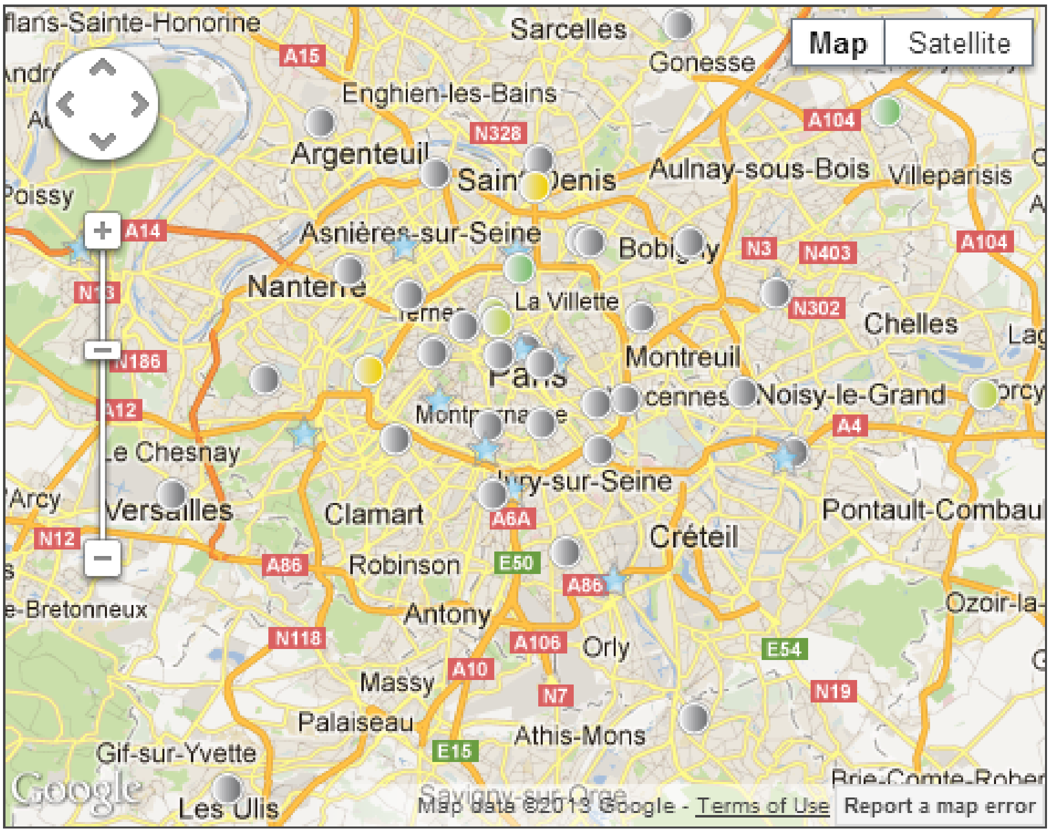
Available at http://maps.muenchen.de/rgu/luftmessstationen

Table B.10 Monitoring Stations in Munich

Site	Period	Location Longitude	Location Latitude	Type
Muenchen/ Johanneskirchen	1993-now	11.648036	48.173195	suburban, background
Muenchen/Landshuter Allee	2004-now	11.536514	48.149605	urban, traffic
Muenchen/Lothstrasse	1978-now	11.554669	48.154533	urban, background
Muenchen/Luise-Kiesselbach-Platz	1991-2009	11.517227	48.113098	urban, traffic
Muenchen/Moosach	1978-now	11.514714	48.179024	urban, traffic
Muenchen/Prinzregentenstrasse	2004-2011	11.59228	48.142742	urban, traffic
Muenchen/Stachus	1978-now	11.564925	48.137253	urban, traffic

Paris

Figure B.11 Map of Monitoring Stations in Paris (Google Maps and AIRPARIF, 2013)



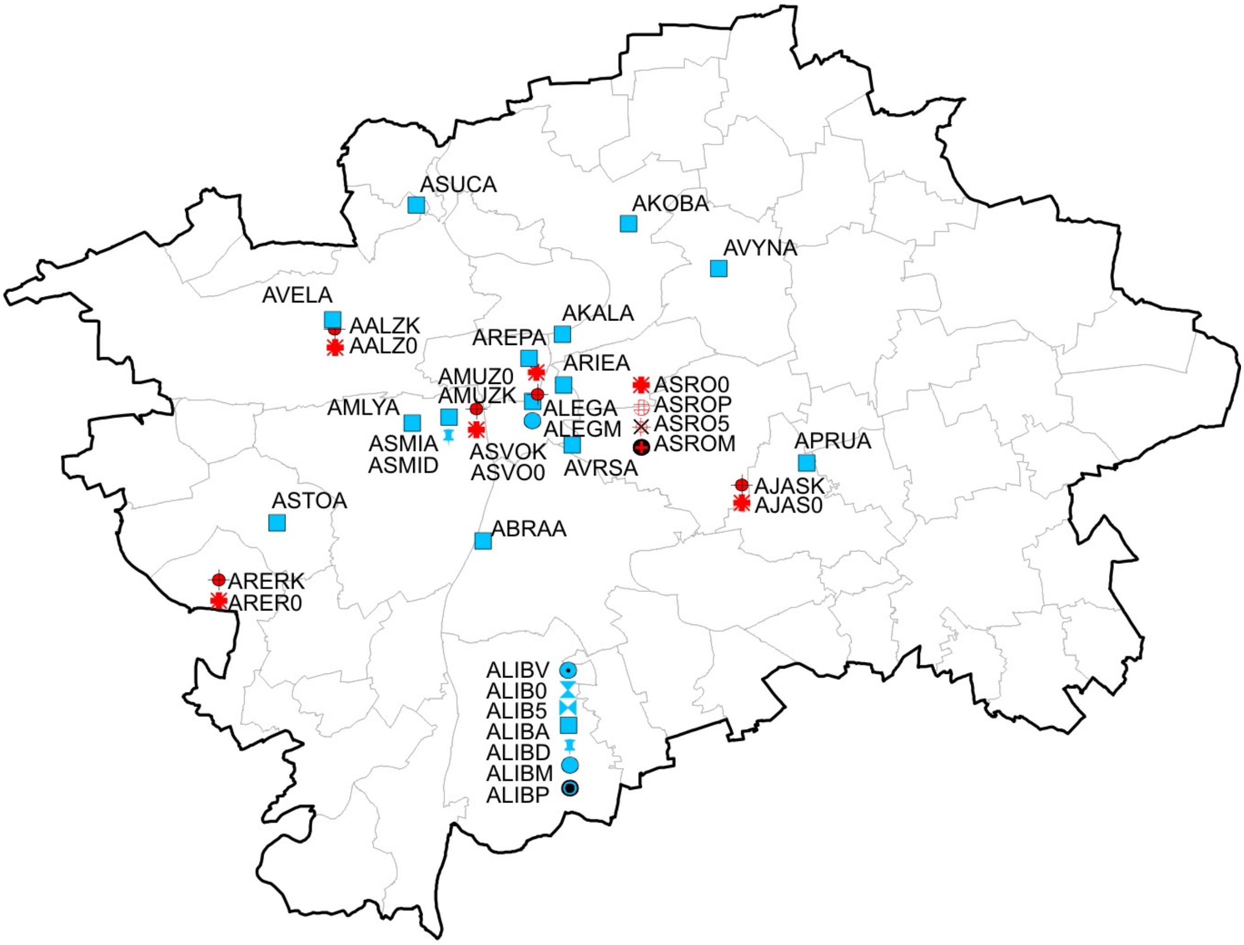
Available at http://www.airparif.asso.fr/stations/index

Table B.11 Monitoring Stations in Paris

Site	Period	Location Longitude	Location Latitude	Type
Paris Centre	05/04/2001-2010	2.345833	48.863581	Urban background
Paris Centre (4ème)	21/07/2011-now	2.351111	48.859444	Urban background
Paris 7ème	27/02/1992-now	2.293889	48.857222	Urban background
Paris 12ème	07/09/1991-now	2.395	48.837222	Urban background
Paris 13ème	19/07/1991-now	2.360278	48.828609	Urban background
Paris 18ème	21/01/1986-now	2.346667	48.891667	Urban background
Garches	04/01/1994-now	2.189444	48.846389	Urban background
Gennevilliers	01/01/1979-now	2.295011	48.931114	Urban background
Issy-les-Moulineaux	04/01/1986-now	2.269444	48.82222	Urban background
La Défense	02/05/1995-now	2.240556	48.891389	Urban background
Neuilly-sur-Seine	01/01/1986-now	2.278056	48.881389	Urban background
Aubervilliers	01/01/1988-now	2.385278	48.903611	Urban background
Bagnolet	14/12/2006-now	2.422222	48.871914	Urban background
Bobigny	19/05/1995-now	2.4525	48.902503	Urban background
Saint-Denis	01/01/1991-now	2.361667	48.937222	Urban background
Tremblay-en-France (P)	14/05/1998-now	2.575278	48.955553	Suburban background
Villemomble	13/01/2004-now	2.507222	48.881947	Urban background
Cachan	07/07/1994-now	2.330556	48.799444	Urban background
Champigny-sur-Marne	14/12/2004-now	2.5175	48.816389	Urban background
Ivry-sur-Seine	04/01/1994-now	2.396389	48.818611	Urban background
Nogent-sur-Marne	12/12/2003-now	2.484444	48.840556	Urban background
Vitry-sur-Seine	23/03/1991-now	2.377222	48.776111	Urban background
Avenue des Champs Elysées	24/01/1990-now	2.311944	48.868889	Urban traffic
Rue Bonaparte	22/02/1994-now	2.335278	48.856389	Urban traffic
Boulevard périphérique Auteuil	01/01/1993-now	2.253336	48.850277	Urban traffic
Boulevard périphérique Est	N/A	N/A	N/A	Urban traffic
Quai des Célestins	24/08/1993-now	2.360556	48.852778	Urban traffic
Place Victor Basch	01/01/1991-now	2.3275	48.827778	Urban traffic
Boulevard Haussmann	08/02/2010-now	2.330278	48.873333	Urban traffic
Place de l'Opéra	24/01/2011-now	2.3325	48.870275	Urban traffic
Autoroute A1 Saint-Denis	22/01/1993-now	2.356667	48.925278	Urban traffic
RN2 Pantin	30/10/2008-now	2.390833	48.902222	Urban traffic
Tour Eiffel 3ème étage	25/06/1993-now	2.295	48.858333	Observation

Prague

Figure B.12 Map of Monitoring Stations in Prague (Czech Hydrometeorological Institute, 2011)



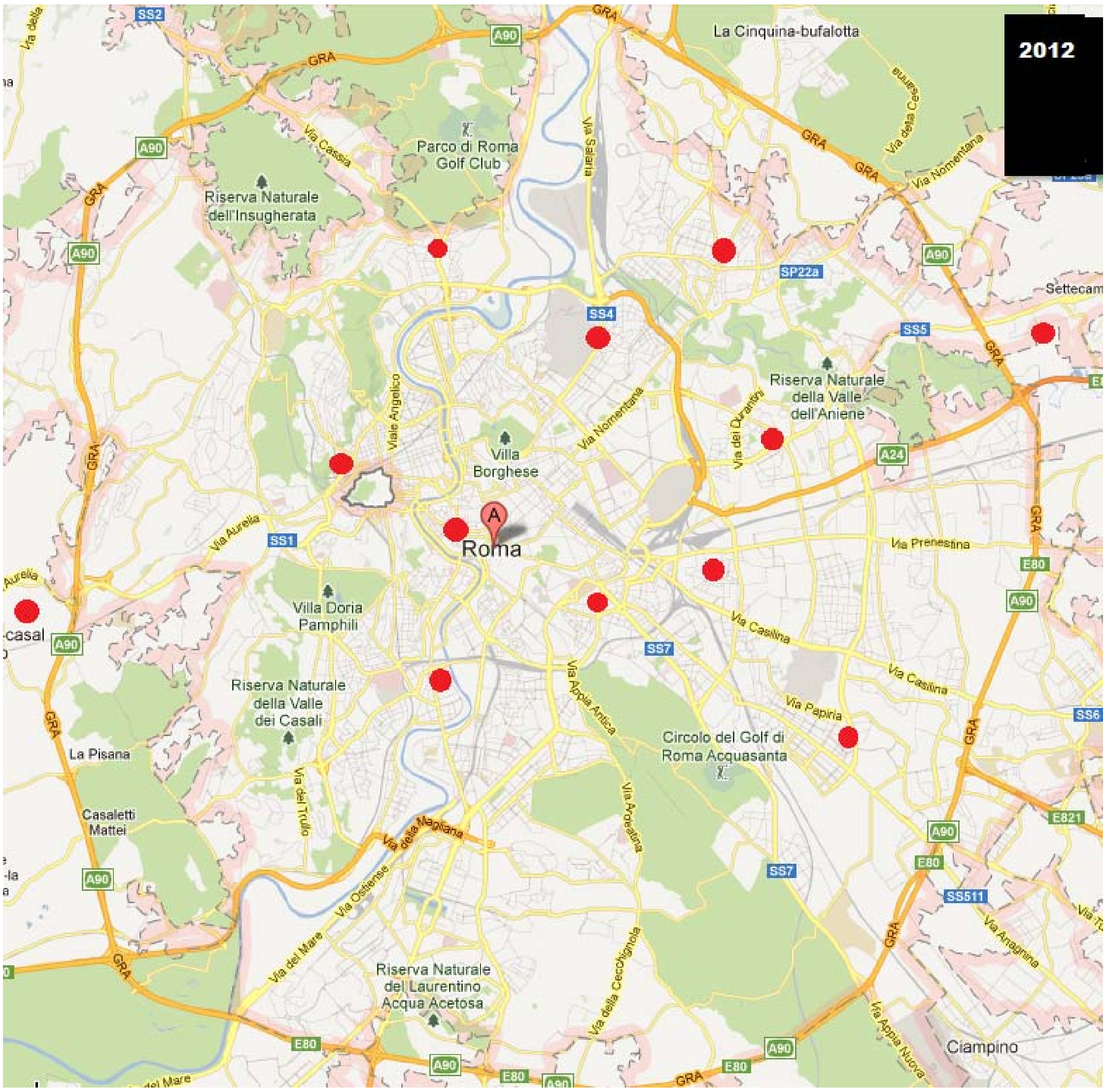
Available at
http://portal.chmi.cz/portal/dt?action=content&provider=JSPTabContainer&menu=JSPTabContainer/P1_0_Home&nc=1&portal_lang=en#PP_TabbedWeather

Table B.12 Monitoring Stations in Prague

Site	Period	Location Longitude	Location Latitude	Type
Pha6-Alzirska	2008-now	14.358611	50.096943	Traffic
Pha4-Branik	2005-now	14.411824	50.042	Traffic
Pha10-Jasminova	2008-now	14.511972	50.055473	Traffic
Pha8-Karlin	1992-now	14.44205	50.094238	Traffic
Pha8-Kobylisy	1992-now	14.467578	50.122189	Background
Pha2-Legerova	2008-now	14.430673	50.072388	Traffic
Pha4-Libus	2003-now	14.445933	50.007301	Background
Pha5-Mlynarka	1992-now	14.383689	50.071617	Traffic
Pha1-Narodni muzeum	1992-2011	14.432711	50.079181	Traffic
Pha10-Prumyslova	1992-now	14.53782	50.062298	Industrial
Pha1-nam. Republiky	1992-now	14.42922	50.088065	Traffic
Pha5-Reporyje	2008-now	14.311666	50.030834	Background
Pha2-Riegrovy sady	1999-now	14.442692	50.081482	Background
Pha5-Smichov	2004-now	14.398142	50.073135	Traffic
Pha8-Sokolovska	2008-2010	14.481389	50.103333	Traffic
Pha10-Srobarova	2008-now	14.473611	50.075832	Background
Pha5-Stodulky	2004-now	14.331414	50.046131	Background
Pha6-Suchdol	1992-now	14.384639	50.126526	Background
Pha5-Svornosti	2004-now	14.410833	50.070278	Traffic
Pha6-Veleslavin	1992-now	14.352567	50.097462	Background
Pha10-Vrsovice	2008-now	14.446153	50.066429	Traffic
Pha9-Vysocany	2004-now	14.503098	50.111084	Traffic

Rome

Figure B.13 Map of Monitoring Stations in Rome (Google Maps, ARPA Lazio, 2012)



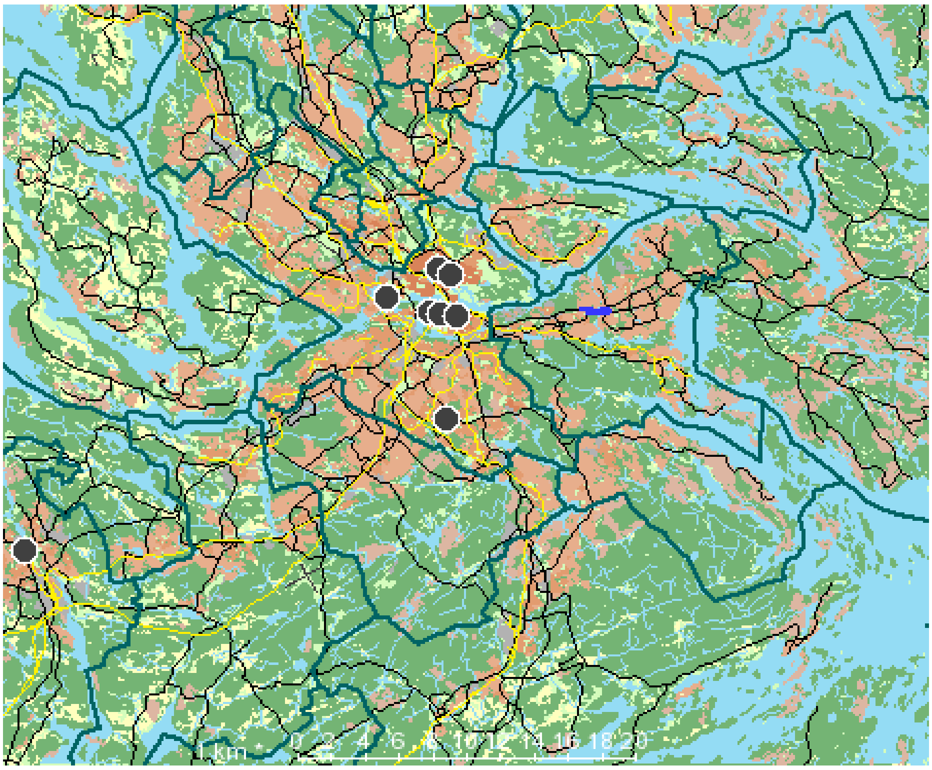
Available at http://www.arpalazio.net/main/aria/doc/RQA/locRQA.php

Table B.13 Monitoring Stations in Rome

Site	Period	Location Longitude	Location Latitude	Type
Arenula	2008-now	12.475277	41.89389	Urban background
Preneste	1992-now	12.540001	41.888058	Urban background
Francia	1993-now	12.469722	41.947502	Urban traffic
Magna Grecia	1993-now	12.508889	41.883053	Urban Traffic
Cinecitta	1998-now	12.568611	41.857777	Urban background
Villa Ada	1994-now	12.506945	41.932777	Urban
Castel di Guido	1997-now	12.266389	41.889446	Rural
Cavaliere	1997-now	12.659166	41.931389	Suburban
Fermi	2006-now	12.469444	41.864166	Urban traffic
Bufalotta	2006-now	12.533611	41.947781	Urban background
Cipro	2006-now	12.4475	41.906391	Urban background
Tiburtina	2006-now	12.548889	41.910278	Urban traffic
Malagrotta	2010-now	12.344999	41.875553	Urban background

Stockholm

Figure B.14 Map of Monitoring Stations in Stockholm (Stockholm-Uppsala County Air Quality Management Association, 2013)



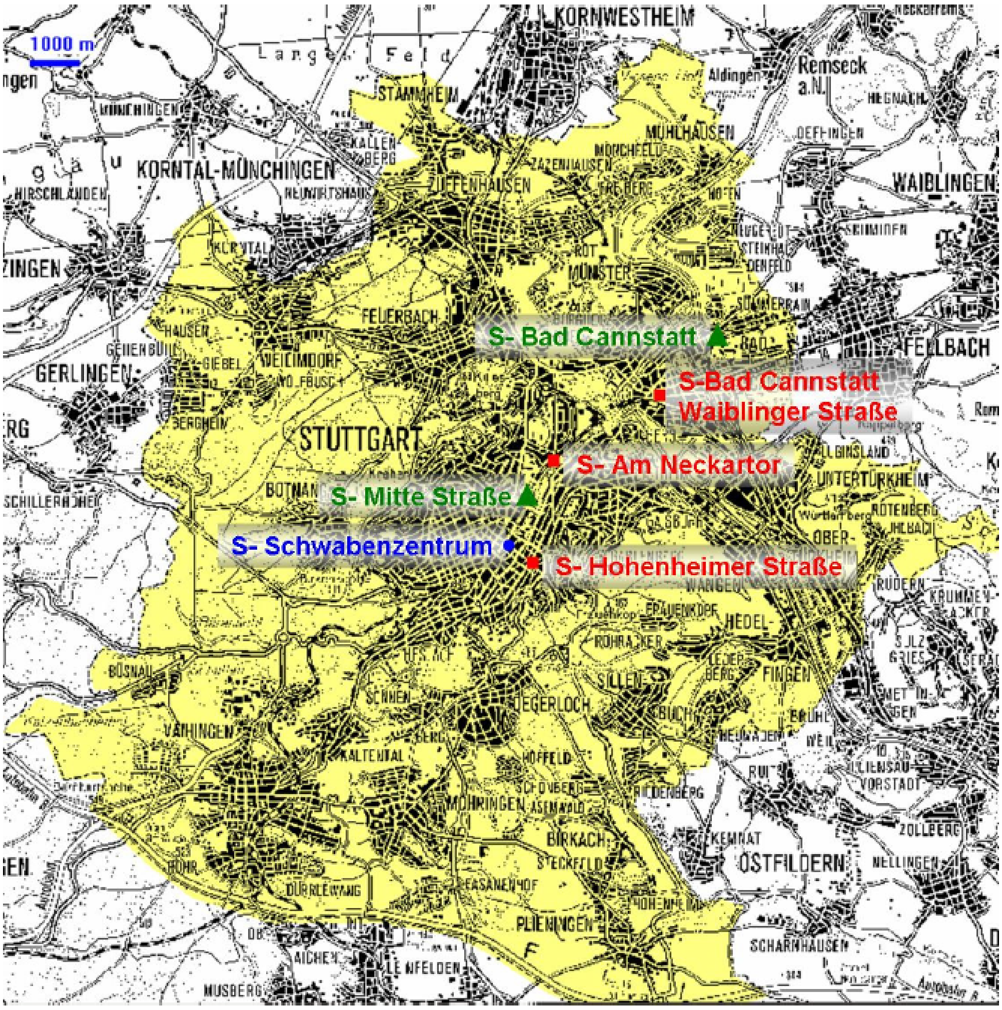
Available at http://www.slb.nu/elvf/

Table B.14 Monitoring Stations in Stockholm

Site	Period	Location Longitude	Location Latitude	Type
Hornsgatan	1990-now	18.0486	59.3172	Inner city, traffic, rooftop (Urban traffic)
Lilla Essingen	2005-now	18.0044	59.325497	Traffic, motorway (Suburban traffic)
Norrlandsgatan	2002-now	18.070837	59.336388	Inner city, traffic (Urban traffic)
Sveavägen	1990-now	18.058619	59.34111	Inner city, traffic, rooftop (Urban traffic)
Folkungagatan	2009-now	18.0751	59.3145	Inner city, traffic (Urban)
Torkel Knutssonsgatan	1966-now	18.0577	59.3161	Inner city, rooftop (Urban)
Kanaan	1980-now	17.8587	59.3498	Recreation area (Rural background)

Stuttgart

Figure B.15 Map of Monitoring Stations in Stuttgart (City of Stuttgart, Office for Environmental Protection, Section of Urban Climatology, 2013)



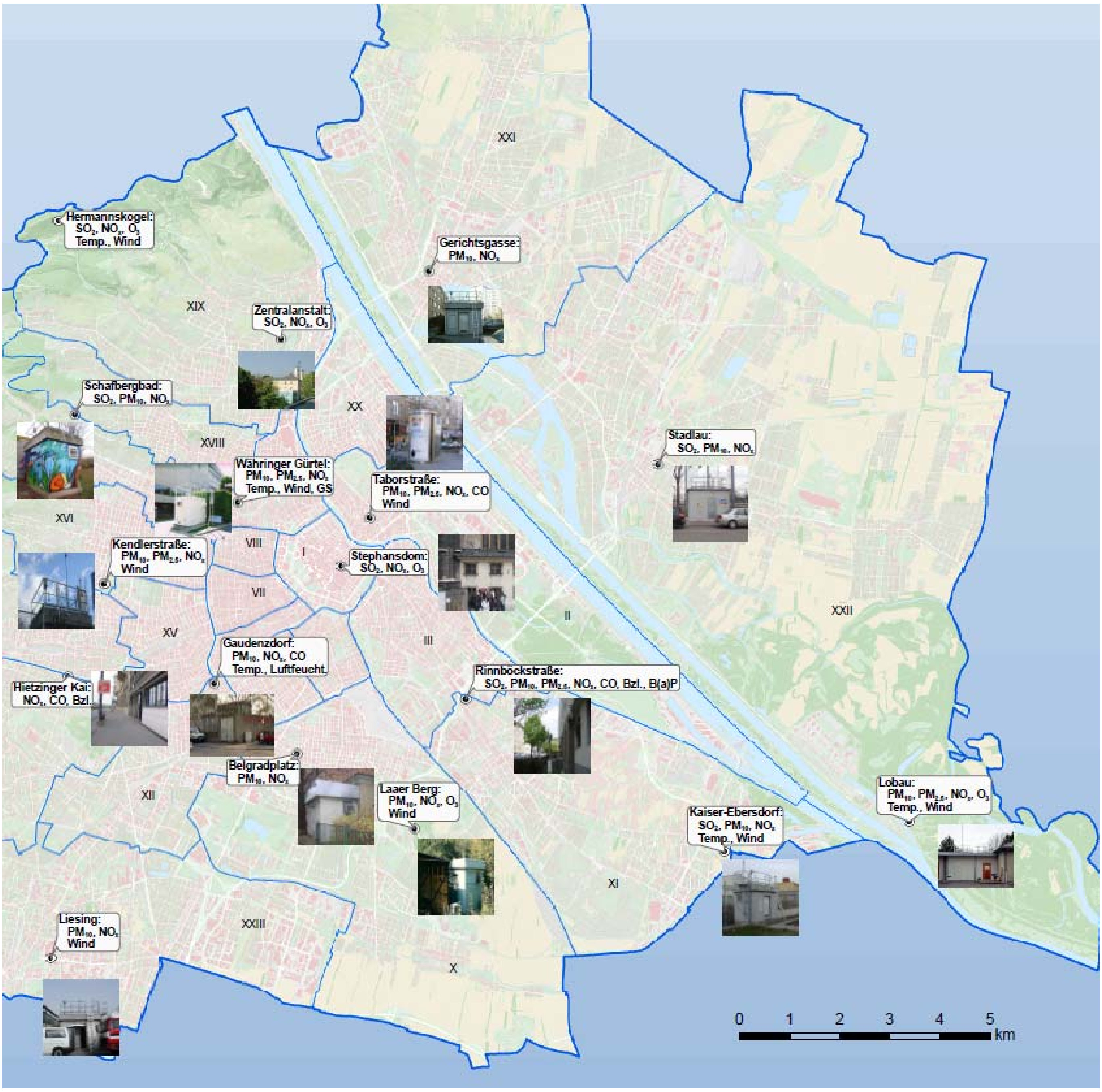
Available at http://www.stadtklima-stuttgart.de/index.php?air_measured_data_stations_in_stuttgart

Table B.15 Monitoring Stations in Stuttgart

Site	Period	Location Longitude	Location Latitude	Type
Stuttgart Mitte - Schwabenzentrum	1990-now	9.177308	48.772565	Urban background, 25 m height (on a roof)
Stuttgart Am Neckartor (S)	2003-now	9.191389	48.78825	Urban traffic
Stuttgart Bad Cannstatt	1981-now	9.229744	48.8088	Urban background
Stuttgart Hohenheimer Strasse (S)	2003-now	9.184539	48.768658	Urban traffic
Stuttgart-Bad_Cannstatt	2004-now	9.229906	48.808908	Urban traffic
Stuttgart-Zuffenhausen	1994-now	9.172506	48.825575	Urban traffic
Stuttgart_Arnulf-Klett-Platz	1981-2010	9.180767	48.783125	Urban traffic

Vienna

Figure B.16 Map of Monitoring Stations in Vienna (Vienna City Hall, 2011)



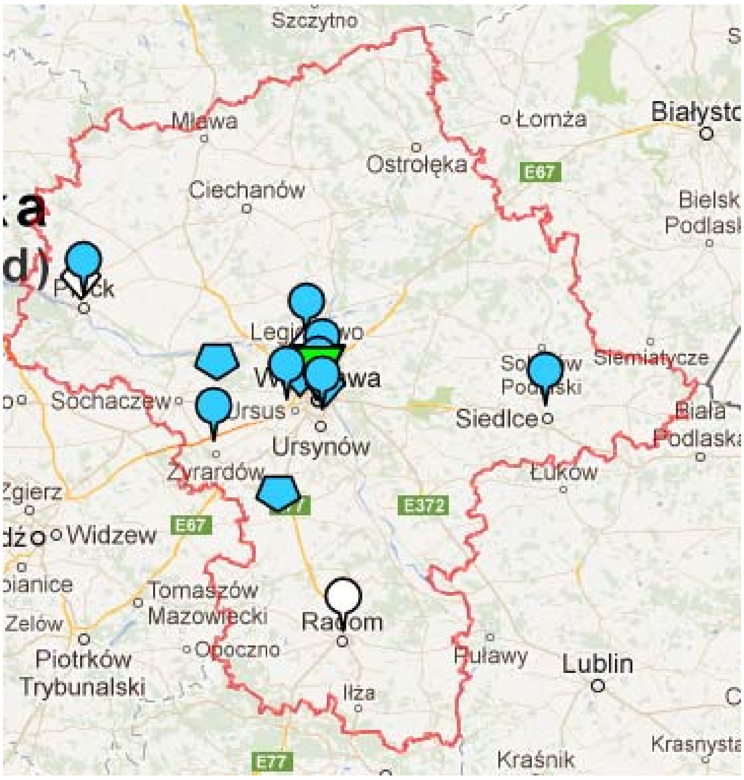
Available at https://www.wien.gv.at/umweltschutz/luft/messnetz.html

Table B.16 Monitoring Stations in Vienna

Site	Period	Location Longitude	Location Latitude	Type
Stephansdom	1975-now	16° 22' 26" E	48° 12' 32" N	Urban background
Taborstraße	1977-now	16° 22' 55" E	48° 13' 05" N	Urban traffic
Währinger Gürtel	1986-now	16° 20' 45" E	48° 13' 09" N	Urban traffic
Belgradplatz	1977-now	16° 21' 47" E	48° 10' 30" N	Urban traffic
Laaer Berg	1986-now	16° 23' 34" E	48° 09' 41" N	Suburban background
Kaiser-Ebersdorf	1977-now	16° 28' 32" E	48° 09' 25" N	Industrial suburban
Rinnböckstraße	1987-now	16° 24' 28" E	48° 11' 06" N	Urban traffic
Gaudenzdorf	1977-now	16° 20' 26" E	48° 11' 16" N	Urban traffic
Hietzinger Kai	1980-now	16° 18' 07" E	48° 11' 20" N	Urban traffic
Kendlerstraße	1977-now	16° 18' 38" E	48° 12' 20" N	Urban traffic
Schafbergbad	1977-now	16° 18' 11" E	48° 14' 09" N	Suburban background
Hermannskogel	1988-now	16° 17' 56" E	48° 16' 162 N	Suburban background (near city)
Zentralanstalt	1973-now	16° 21' 28" E	48° 14' 57" N	Urban background
Gerichtsgasse	1988-now	16° 23' 49" E	48° 15' 39" N	Urban traffic
Lobau	1986-now	16° 31' 36" E	48° 09' 45" N	Suburban background (near city)
Stadlau	1984-now	16° 27' 38" E	48° 13' 41" N	Urban background
Liesing	1974-now	16° 17' 48" E	48° 08' 17" N	Suburban traffic

Warsaw

Figure B.17 Map of Monitoring Sites in Warsaw (Google Maps, WIOS Warsaw, 2013)



Available at http://sojp.wios.warszawa.pl/?par=4

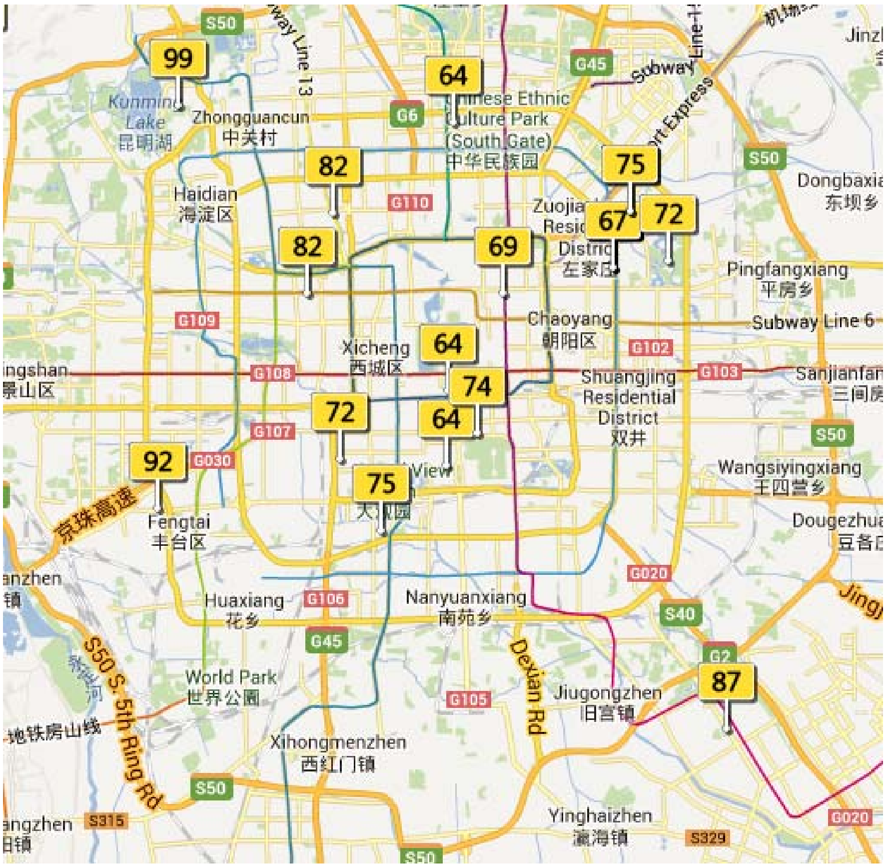
Table B.17 Monitoring Stations in Warsaw

Site	Period	Location Longitude	Location Latitude	Type
MzWarNiepodKom	2003-now	21° 00 '16" E	52° 13' 09" N	Urban traffic
MzWarPodIMGW	2002-now	20° 57' 44" E	52° 16' 51" N	Urban background
MzWarTarKondra	2003-now	21° 02' 33" E	52° 17' 2" N	Urban background
MzWarZeganWSSE	2004-2009	20° 10' 10" E	52° 12' 21" N	Urban background
MzWarszAKrzywon	/2004-now	20° 55' 03" E	52° 13' 43" N	Urban background
MzWarszBernWoda	1992-now	21° 03' 04" E	52° 11' 30" N	Industrial urban
MzWarszKrucza	1990-now	21° 01' 08" E	52° 13' 28" N	Urban background
MzWarszPorajow	1993-2009	20° 57' 32" E	52° 18' 52" N	Urban background
MzWarszPuszSolska	1993-now	20° 54' 31" E	52° 13' 35" N	Urban background
MzWarszSGGW	1993-2010	21° 02' 51" E	52° 09' 38" N	Urban background
MzWarszUrsynow	2003-now	21° 02' 02" E	52° 09' 39" N	Urban background
MzWarszZelazWSSE	1976-2009	20° 59' 19" E	52° 14' 14" N	Urban background
MzWarszMarsz	N/A	21° 00' 53" E	52° 13' 30" N	Urban Traffic

Non-EU Cities

Beijing

Figure B.18 Map of monitoring sites in Beijing (Beijing Environmental Protection Monitoring Centre, Google maps, 2013)



Available at http://aqicn.org/map/

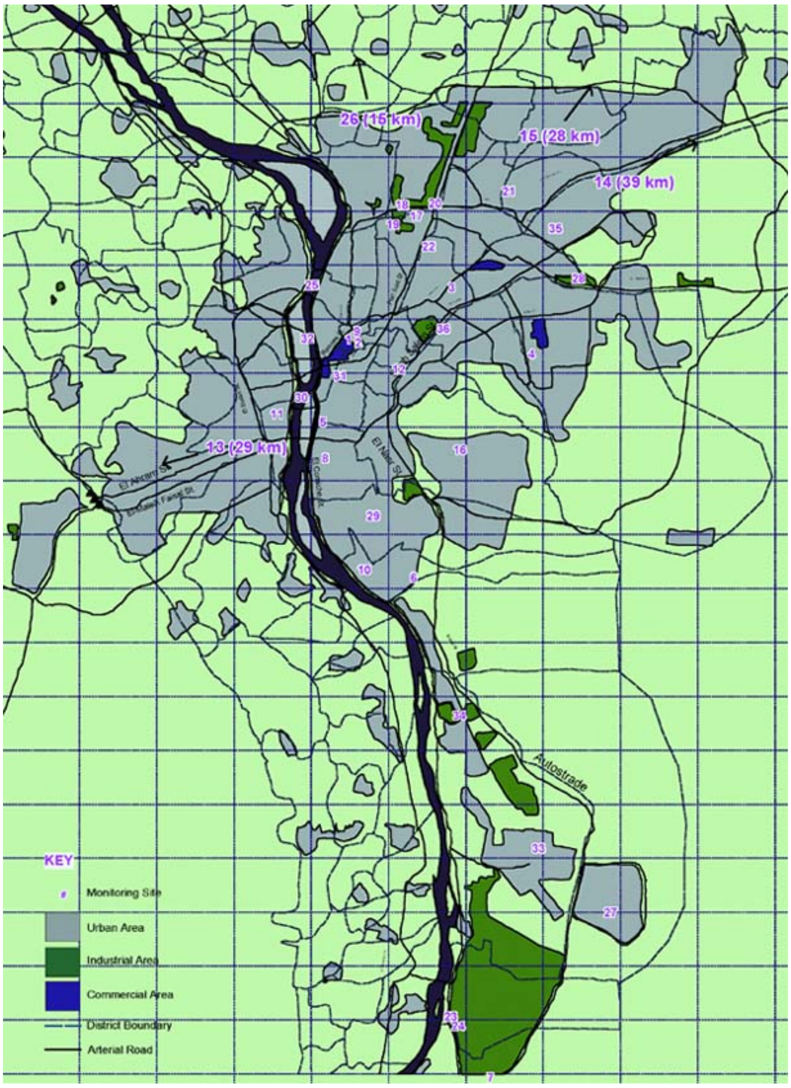
Table B.18 Monitoring Stations in Beijing

Site	Period	Location Longitude	Location Latitude	Type
Tong zhou new town	-	116.65644	39.90997	-
BDA (chaolin building)	-	116.50232	39.80034	-
Fang shan, Liangxiang	-	116.13572	39.74196	-
Yungang, Fengtai	-	116.14587	39.82423	-
Shijingshan City	-	116.18385	39.91439	-
Haidian Beijing Botanical Garden	-	116.20696	40.00188	-
The Haidian Northern New Area	-	116.17351	40.09015	-
Fengtai Garden	-	116.27898	39.86303	-
Haidian Wanliu (park)	-	116.28659	39.98702	-

Notes: Type of station not officially stated

Cairo

Figure B.19 Map of monitoring sites in Cairo (Ministry of State For Environmental Affairs/Egyptian Environmental Affairs Agency, 2013)



Available at http://www.eeaa.gov.eg/english/main/35.html

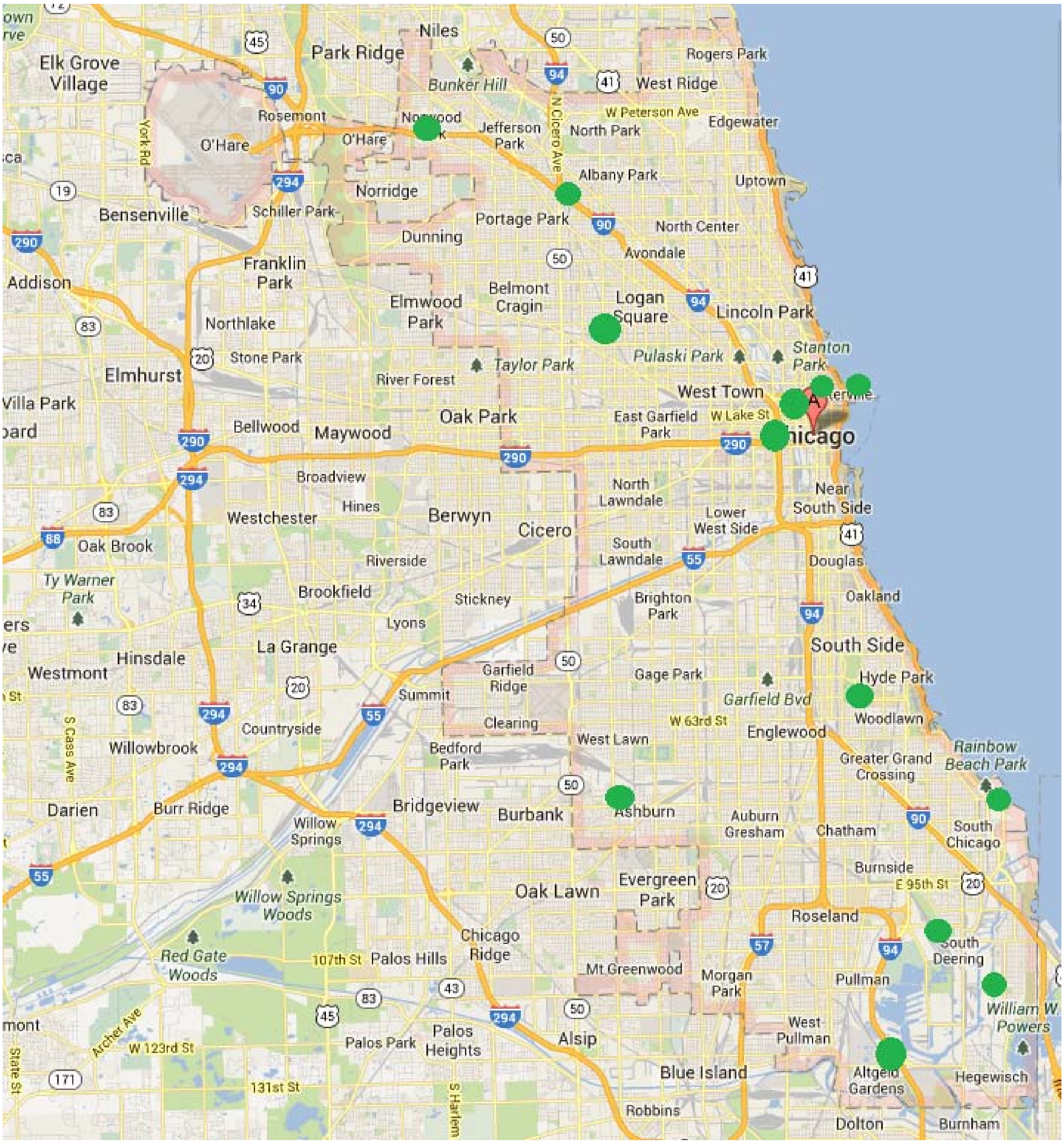
Table B.19 Monitoring Stations in Cairo

Site	Period	Location Longitude	Location Latitude	Type
El-Kolali	24/12/1998-ongoing	-	-	Urban background
El-Gomboria	25/12/1997-ongoing	-	-	Urban traffic
Abbassyria	22/05/1999-ongoing	-	-	Urban background
Nasr City	08/10/1998-ongoing	-	-	Suburban background
Tabbin	10/12/1998-ongoing	-	-	Suburban background
Tabbin South	21/10/1997-ongoing	-	-	Industrial background
Fum El-Khalig	19/10/1998-ongoing	-	-	Industrial background
Abu-Zabel	01/11/1998-ongoing	-	-	Urban traffic
Shoubra El-Kheima	16/11/1998-ongoing	-	-	Industrial background
Cairo University	01/05/1998-ongoing	-	-	Industrial background
Kaha	18/07/1998-ongoing	-	-	Suburban background
6 October	01/07/2000-ongoing	-	-	Urban background
10 Ramadan	12/01/1999-ongoing	-	-	Suburban background
Suez	13/12/1998-ongoing	-	-	Suburban background
Port Said	03/02/1999-ongoing	-	-	Urban background
Ismailia	10/05/1999-ongoing	-	-	Suburban background
El-Fryum	04/02/1999-ongoing	-	-	Urban background
El-Ivfinya	03/02/1999-ongoing	-	-	Urban background
Assyut 1	09/07/1999-ongoing	-	-	Suburban background
Assyut 2	08/07/1999-ongoing	-	-	Suburban background
Nag Hammadi	01/01/2000-ongoing	-	-	Suburban background
Luxor	07/07/1999-ongoing	-	-	Industrial background
Edfu	08/06/1999-ongoing	-	-	Urban background
Kom Ombo	06/07/1999-ongoing	-	-	Industrial background
Aswan	09/07/1999-ongoing	-	-	Industrial background
Ras Mohammed	23/06/1999-ongoing	-	-	Urban background
Abu Keir	13/03/1999-ongoing	-	-	Urban background
El Shouhada	22/03/2000-ongoing	-	-	Industrial background
El-Max	13/11/1998-ongoing	-	-	Urban traffic
IGSR	13/11/1998-ongoing	-	-	Industrial background
El-Asafra	13/11/1998-ongoing	-	-	Suburban background
Gheat ElHab	13/11/1998-ongoing	-	-	Suburban background
IGSR Regional	13/11/1998-ongoing	-	-	Urban background
El-Nahda	20/02/2000-ongoing	-	-	Industrial background

Site	Period	Location Longitude	Location Latitude	Type
Damanhur	13/02/2000-ongoing	-	-	Industrial background
Kafr El Zayat	20/08/1999-ongoing	-	-	Industrial background
Tania	13/06/1999-ongoing	-	-	Urban background
El-Mahalla	17/06/1999-ongoing	-	-	Industrial background
El-Mansura	13/04/1999-ongoing	-	-	Industrial background
Damiatta	13/05/1999-ongoing	-	-	Suburban background
Kafr El-Dagvar	13/05/1999-ongoing	-	-	Suburban background

Chicago

Figure B.20 Map of monitoring sites in Chicago (Illinois AQ network, 2011; Google maps, 2013)



● = Monitoring station

Available at http://www.epa.state.il.us/air/monitoring/index.html

Table B.20 Monitoring stations in Chicago

Site	Period	Location Longitude	Location Latitude	Type
0310060 (Carver High School)	-	-87.59065	41.65638	-
0310026 (Cermak Pump Sta)	-	-87.64511	41.87391	-
0310063 (CTA building)	-	-87.63524	41.87783	-
0310076 (Com Ed Maintenance Bldg)	-	-87.7141	41.75107	-
0310072 (Jardine Water Plant)	-	-87.6114	41.89247	-
0310052 (Mayfair Pump Sta)	-	-87.74888	41.96436	-
0310042 (Sears Tower/Willis Tower)	-	-87.62115	41.88777	-
0310050 (Southeast Police Station)	-	-87.56822	41.70797	-
0310032 (South Water Filtration Plant)	-	-87.54534967	41.75583241	-
0310057 (Springfield Pump. Sta.)	-	-87.72272345	41.91286212	-
0311003 (Taft HS)	-	-87.7920017	41.98433233	-
0310064 (University of Chicago)	-	-87.60164649	41.79078688	-
0310022 (Washington HS)	-	-87.53931548	41.68716544	-

Notes: [1] Type and operating period not provided

Hong Kong

Figure B.21 Map of monitoring sites in Hong Kong (Environmental Protection Department of Hong Kong, 2006)

Available at http://epic.epd.gov.hk/EPICDI/air/station/?lang=en

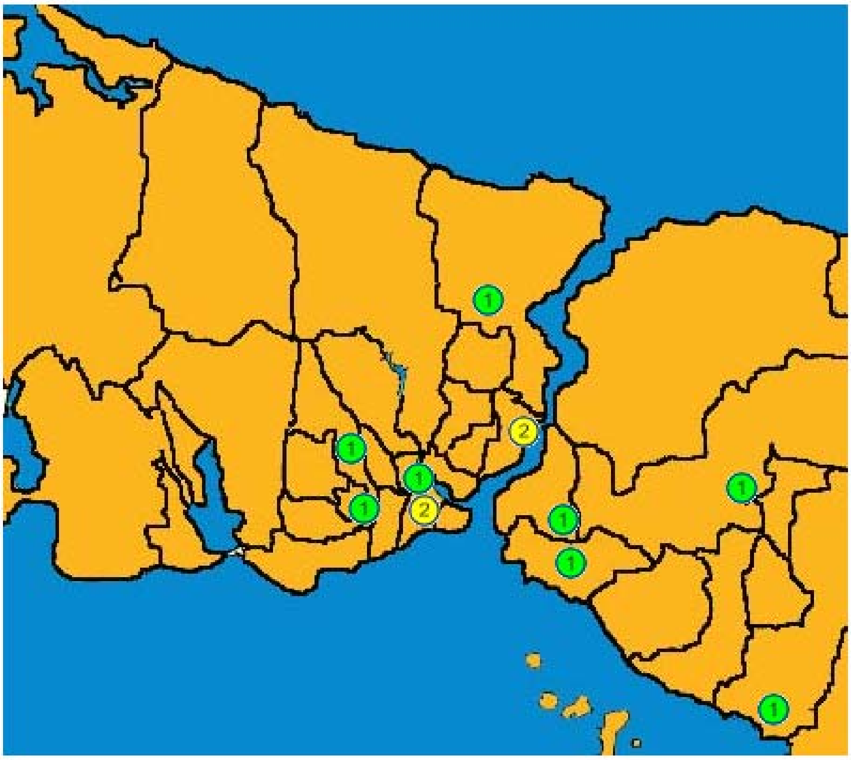
Table B.21 Monitoring stations in Hong Kong

Site	Period	Location Longitude	Location Latitude	Type
Central/Western	1990-ongoing	114.1095	22.39643	Urban Centre [x]
Eastern	1999-ongoing	114.21933	22.2829	Urban Background
Kwai Chung	1999-ongoing	114.12928	22.35684	Urban Background
Kwun Tong	1990-ongoing	114.22473	22.31341	Urban Centre [x]
Sha Tin	1991-ongoing	114.1095	22.39643	Suburban background
Sham Shui Po	1990-ongoing	114.15872	22.33019	Urban Background
Tai Po	1990-ongoing	114.16432	22.45084	Suburban background
Tap Mun	1998-ongoing	114.3608	22.47125	Rural background
Tsuen Wan	1990-ongoing	114.11441	22.37164	Urban Background
Tung Chung	1999-ongoing	114.30416	22.38056	Suburban background
Yuen Long	1995-ongoing	114.02321	22.44553	Suburban background
Causeway Bay	1998-ongoing	114.185338	22.280072	Urban traffic
Central	1999-ongoing	114.15779	22.28205	Urban traffic
Mong Kok	2001-ongoing	114.168827	22.322512	Urban traffic

[x] Urban centre has been considered as “traffic stations after site description analysis

Istanbul

Figure B.22 Map of monitoring sites in Istanbul (Istanbul Metropolitan Municipality, 2013)



Note: Numbers refer to a snap shot of an AQ index value

Available at http://application2.ibb.gov.tr/IBBWC/HavaKalitesi.aspx

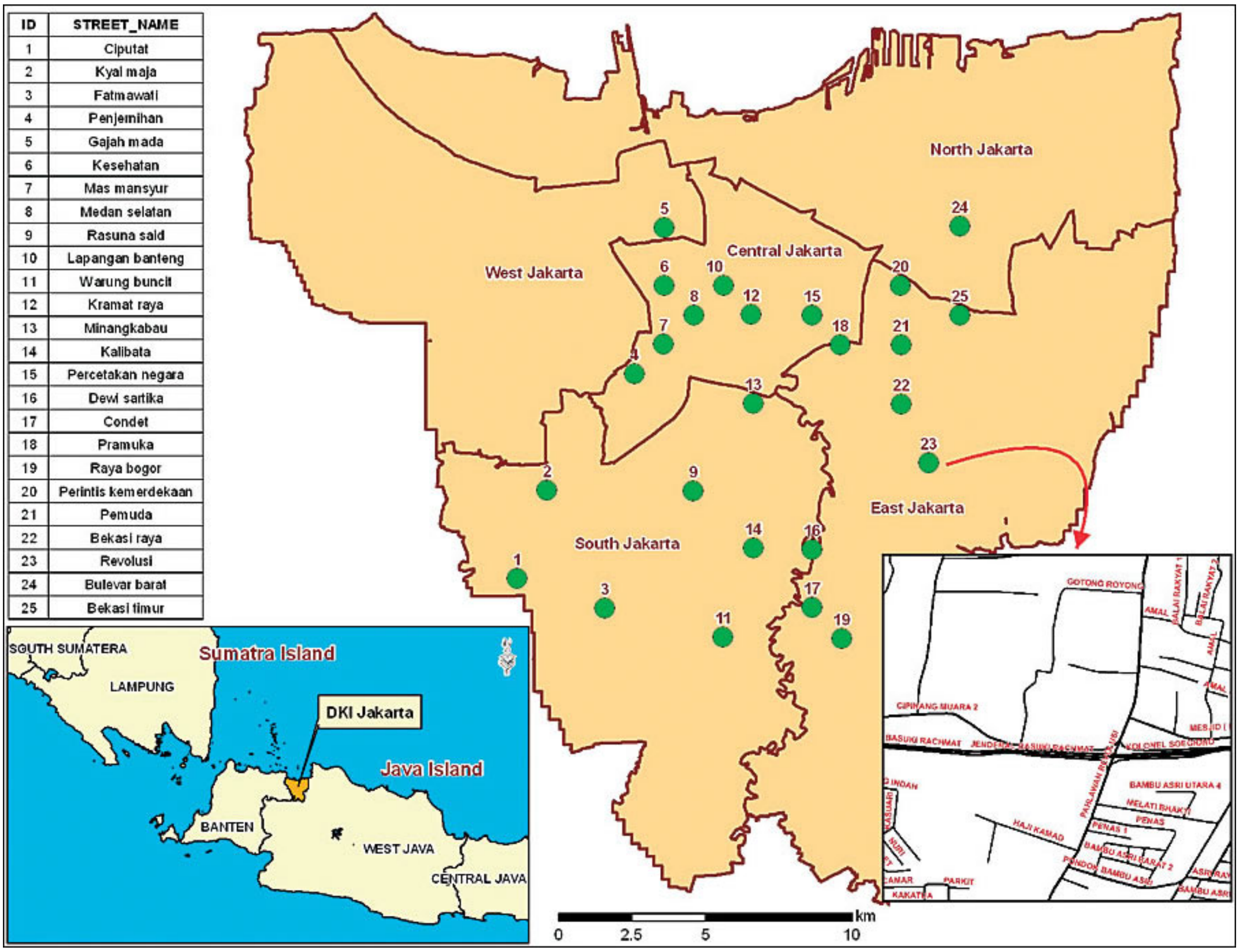
Table B.22 Monitoring stations in Istanbul

Site	Period	Location Longitude	Location Latitude	Type
Aksaray (aka Sarahçane)	2008[1]-ongoing	28.954723	41.014721	Urban traffic
Alibeyköy	2008[1]-ongoing	28.945555	41.072777	Urban background
Beşiktaş	2008[1]-ongoing	29.01	41.053886	Urban traffic
Esenler	2008[1]-ongoing	28.888056	41.038334	Urban background
Kadıköy	2008[1]-ongoing	29.033611	40.991943	Urban background
Kartal	2008[1]-ongoing	29.2075	40.890003	Industrial background
Sarıyer	2008[1]-ongoing	29.049721	41.128887	Urban background
Ümraniye	2008[1]-ongoing	29.162222	41.013611	Industrial background
Üsküdar	2008[1]-ongoing	29.025	41.015278	Urban background
Yenibosna	2008[1]-ongoing	28.826668	40.99889	Industrial background
Mobile station		Several		

[1] Year in which they will included in the AirBase database

Jakarta

Figure B.23 Map of monitoring sites in Jakarta (National Institute of Health Research and Development, Ministry of Health, Indonesia; ESRI, 2007)



ID	STREET_NAME
1	Ciputat
2	Kyai maja
3	Fatmawati
4	Penjernihan
5	Gajah mada
6	Kesehatan
7	Mas mansyur
8	Medan selatan
9	Rasuna said
10	Lapangan banteng
11	Warung buncit
12	Kramat raya
13	Minangkabau
14	Kalibata
15	Percetakan negara
16	Dewi sartika
17	Condet
18	Pramuka
19	Raya bogor
20	Perintis kemerdekaan
21	Pemuda
22	Bekasi raya
23	Revolusi
24	Bulevar barat
25	Bekasi timur

Available at http://www.esri.com/news/arcnews/fall07articles/addressing-ambient-air.html

Table B.23 Monitoring stations in Jakarta

Site (Street name)	Period [2]	Location[1]	Type [2]
Ciputat	-	South Jakarta	-
Kyal maja	-	South Jakarta	-
Fatmawati	-	South Jakarta	-
Penjemihan	-	Central Jakarta	-
Gajah mada	-	West Jakarta	-
Kesehatan	-	Central Jakarta	-
Mas mansyur	-	Central Jakarta	-
Medan selatan	-	Central Jakarta	-
Rasuna said	-	South Jakarta	-
Lapangan banfeng	-	Central Jakarta	-
Warung buncil	-	South Jakarta	-
Kramat raya	-	Central Jakarta	-
Minangkabau	-	South Jakarta	-
Kalibata	-	South Jakarta	-
Percetakan negara	-	Central Jakarta	-
Dewl sartika	-	South Jakarta	-
Condet	-	East Jakarta	-
Pramuka	-	East Jakarta	-
Raya bogor	-	East Jakarta	-
Perintis kemerdekaan	-	East Jakarta	-
Pemuda	-	East Jakarta	-
Bekasi raya	-	East Jakarta	-
Revolusi	-	East Jakarta	-
Bulevar barat	-	North Jakarta	-
Bekasi Timur	-	East Jakarta	-

Notes:

[1] Regional location. Coordinates not available.

[2] Type of station and active period not available

Johannesburg

Figure B.24 Map of monitoring sites in Johannesburg (Department of Development Planning, Transportation and Environment and the Department of Environmental Health, City of Johannesburg, 2003)

Available at http://www.joburg-archive.co.za/2006/pdfs/jhbair_quality.pdf

Table B.24 Monitoring stations in Johannesburg

Site	Period[1]	Location Longitude[1]	Location Latitude[1]	Type[2]
JHB South - City Deep				non-domestic fuel burning; residential - suburban – industrial
Mobile station (Buccleuch)				traffic site - suburban - residential
Orange Farm - Stratford Clinic				domestic fuel burning - suburban Commercial - urban -
Inner City - New Town				industry/residential
Delta Park				non-domestic fuel burning; residential - suburban
Alexandra				domestic fuel burning - suburban - traffic
Soweto - Dhlamini				domestic fuel burning - suburban
Soweto - Jabavu				domestic fuel burning - suburban
Rietvlei				background – rural
Diepsloot				domestic fuel burning - suburban
Ivory Park				domestic fuel burning - suburban

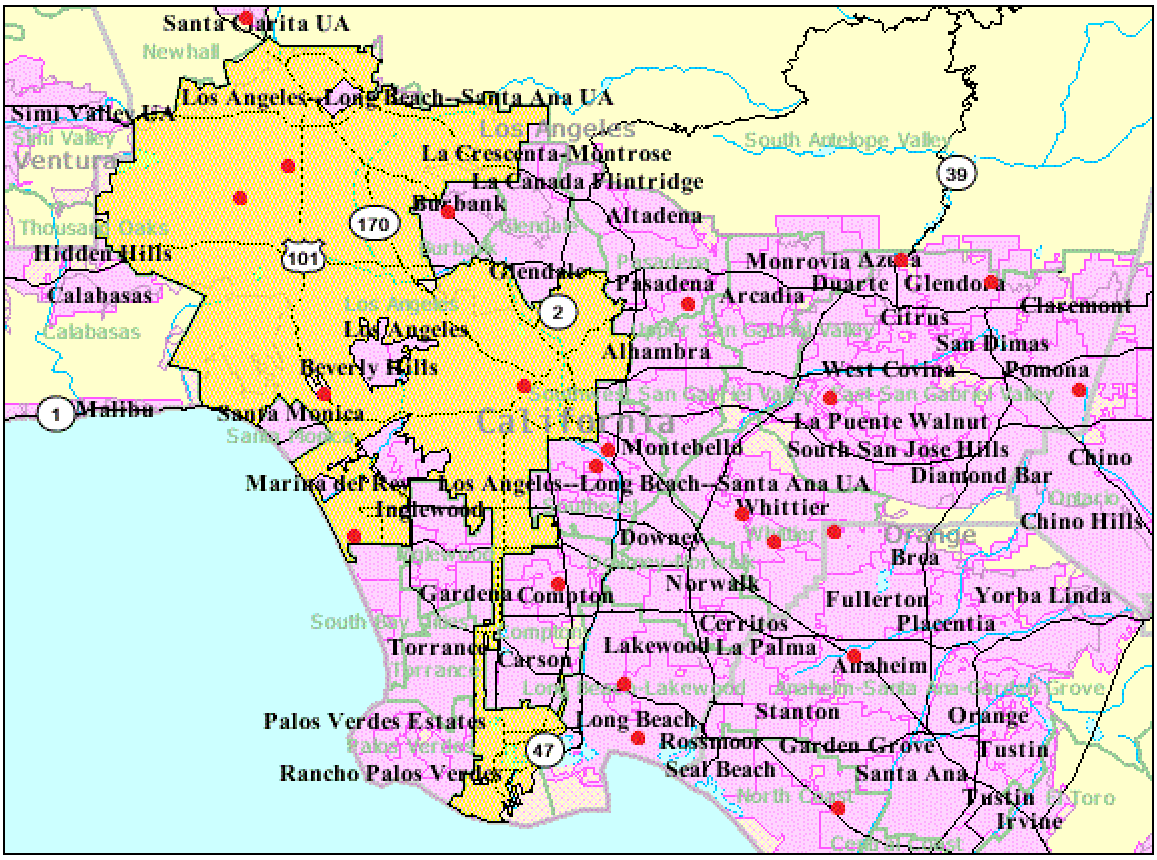
Notes:

[1]Unknown

[2]Different classification system

Los Angeles

Figure B.25 Map of monitoring sites in Los Angeles metropolitan area (South Coast AQ management district, 2013)



Notes: Yellow-shaded area= Municipal area. Pink-shaded area= Metropolitan area. ●= Monitoring station

Available at http://www3.aqmd.gov/webappl/gisaqi2/VEMap3D.aspx

Table B.25 Monitoring stations in greater Los Angeles area[2]

Site	Period	Location Longitude	Location Latitude	Type[1]
Anaheim	2001-	117° 56' 18"W	33° 49' 50"N	-
ATSF (Exide)	1999-	118° 11' 26"W	34° 00' 30" N	-
Azusa	1957-	117° 55' 26"W	34° 08' 11"N	-
Burbank	1961-	118° 19' 01"W	34° 10' 33"N	-
Closet World Quemetco	2008-	117° 58' 54"W	34° 01' 34"N	-
Compton	2004-	118° 12' 18"W	33° 54' 05"N	-
Costa Mesa	1989-	117° 55' 33"W	33° 40' 28"N	-
Glendora	1980-	117° 51' 01"W	34° 08' 39"N	-
La Habra	1960-	117° 57' 09"W	33° 55' 30"N	-
LAX Hastings	2004-	118° 25' 49"W	33° 57' 18"N	-
Long Beach North	1962-	118° 11' 20"W	33° 49' 25"N	-
Long Beach South	2003-	118° 10' 31"W	33° 47' 32"N	-
Los Angeles	1979-	118° 13' 36"W	34° 03' 59"N	-
Pasadena	1982-	118° 07' 37"W	34° 07' 57"N	-
Pico Rivera	2005-	118° 04' 07"W	34° 0' 37"N	-
Pomona	1965-	117° 45' 05"W	34° 04' 01"N	-
Rehrig (Exide)	2007-	118° 11' 35"W	34° 00' 23"N	-
Reseda	1965-	118° 31' 58"W	34° 11' 57"N	-
Santa Clarita	2001-	118° 31' 42"W	34° 23' 0"N	-
Uddeholm	1992-	118° 03' 19"W	33° 57' 17"N	-
Van Nuys Airport	2010-	118° 29' 20"W	34° 13' 7 "N	-
West Los Angeles	1984-	118° 27' 23"W	34° 03' 03"N	-

Notes:

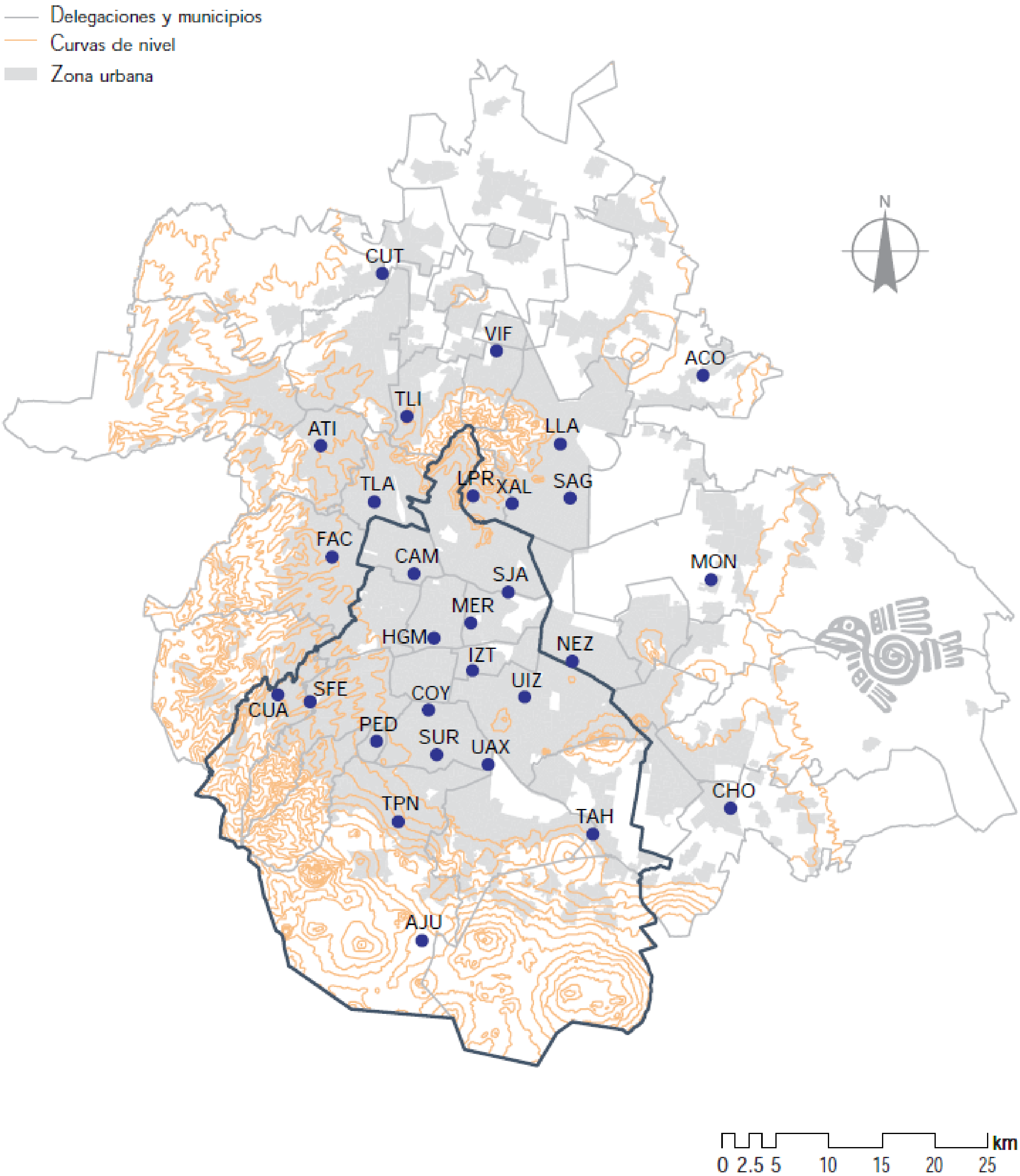
[1] Los Angeles does not provide differentiation of stations

[2] Officially defined by the US Office of Management and Budget and composed by Los Angeles and Orange counties

Data were sent for four sites identified as being in the metropolitan area: Compton, La Habra, Los Angeles and Pico Rivera.

Mexico City

Figure B.26 Map of monitoring sites in Mexico City (Secretaría del Medio Ambiente del Gobierno del Distrito Federal, 2011)



Available at http://www.calidadaire.df.gob.mx/calidadaire/index.php

Table B.26 Monitoring Stations in Mexico City

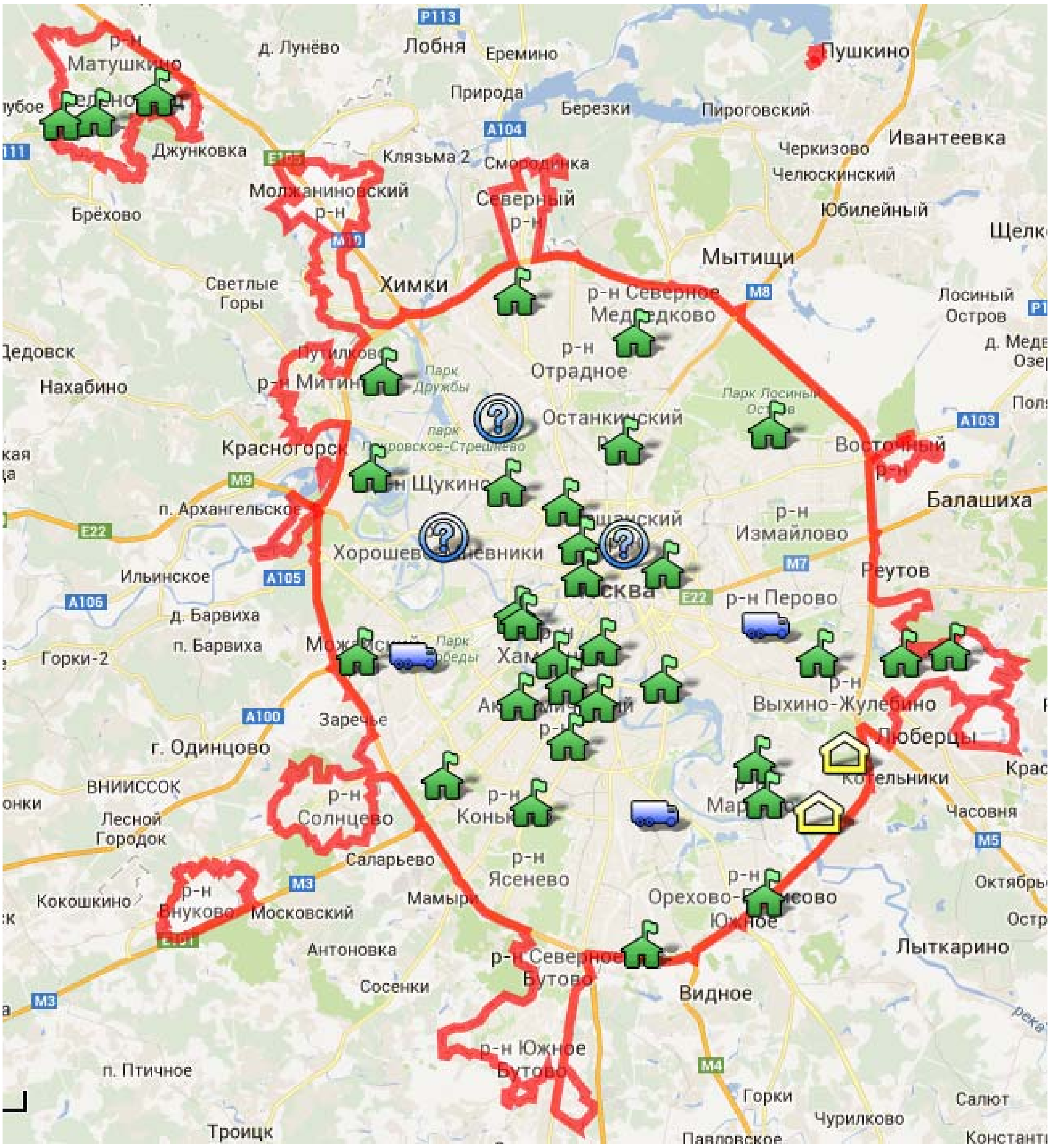
Site	Period	Location[1]	Type
Pedregal	1986-present	South west	-
Camarones	2003-present	North west	-
Coyoacan	2003-present	South west	-
Santa Úrsula	1986-present	South west	-
Cuajimalpa	1993-present	South west	-
San Juan de Aragón	2003-present	North east	-
Iztacalco	2007-present	Centre	-
UAM Iztapalapa	1986-present	South east	-
Tlalpan	1993-present	South west	-
Merced	1986-present	Centre	-
Tláhuac	1993-present	South east	-
Acolman	2007-present	North east	-
Atizapán	1993-present	North west	-
Chalco	2007-present	South east	-
Villa de las Flores	1993-present	North east	-
Los Laureles	1986-present	North east	-
San Agustín	1986-present	North east	-
Xalostoc	1986-present	North east	-
FES Acatlán	1986-present	North west	-
Nezahualcóyotl	2001-present	North east	-
Montecillo	1993-present	North east	-
La Presa	1986-present	North east	-
Tlalnepantla	1986-present	North west	-
Tultitlán	1993-present	North west	-

Notes:

[1] Geographical location within the city. Mexico City does not provide with coordinates or type of station

Moscow

Figure B.27 Map of monitoring sites in Moscow (State Environmental Organization, Google maps, 2013)



Existing station under the public automatic stations network   Station owned by GAZPROM   Mobile station

Temporarily unavailable station

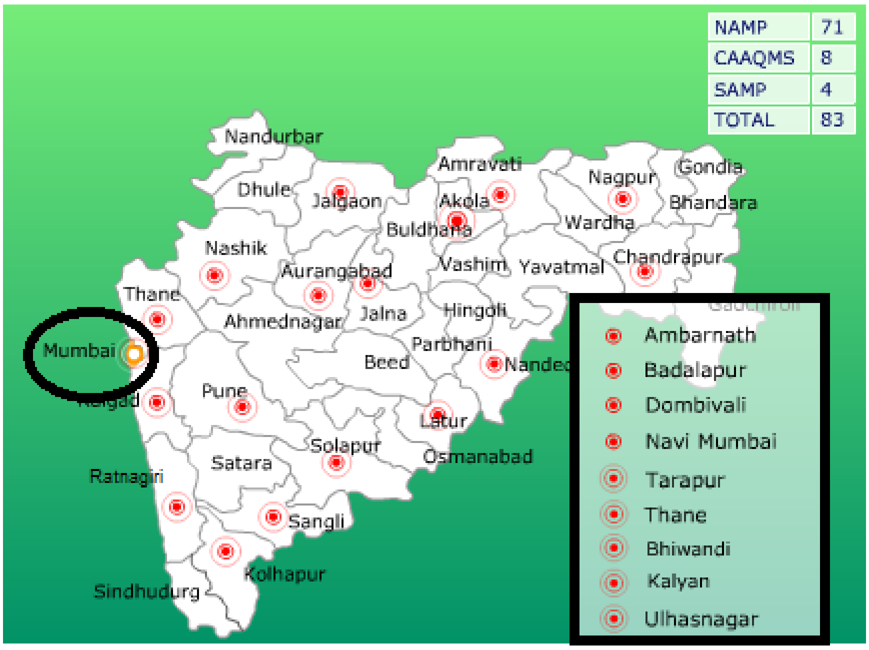
Available at http://www.mosecom.ru/air/air-today/

Table B.27 Monitoring stations in Moscow

Site	Period	Location Longitude	Location Latitude	Type
Kozhukhovskiy travel	unknown	37.662149	55.70724	Unknown
Shabolovka	1996-present	37.610786	55.725563	Urban background
Spiridonovka	2005-present	37.595705	55.759034	Urban background
Kazakova	2000-present	37.663659	55.762763	Urban background
Biryulevo	2001-present	37.645758	55.579611	Industrial
Chayanova	2003-present	37.593056	55.774256	Urban background
Butlerova	2003-present	37.550792	55.648508	Suburban/Industrial
Cheremushki	2004-present	37.583347	55.679744	Urban background
Gagarin Square	unknown	37.581491	55.707119	Unknown
Marino	2003-present	37.750180	55.652029	Industrial
Guryevsky travel	2010-present	37.749954	55.605069	Urban background
Lublin	2009-present	37.741285	55.668775	Roadside
Hamovniki	2003-present	37.570042	55.719642	Unknown
Koshino	2003-present	37.865997	55.719424	Urban background
Elk Island	2003-present	37.753785	55.830192	Urban background
Kozhukhovo	2007-present	37.907986	55.722911	Urban background
Polar	2004-present	37.639128	55.873875	Urban background
Ostankino	1999-present	37.629949	55.821959	Industrial
MADI	2001-present	37.528950	55.801788	Roadside
Lower Maslivka	unknown	37.57785	55.792789	Unknown
Dolgoprudnaya	2004-present	37.538228	55.893616	Urban background
Flight	unknown	37.413891	55.808878	Unknown
Tourist	2004-present	37.423080	55.855468	Urban background
MSU	2003-present	37.541286	55.69955	Urban background
Vernadsky	2003-present	37.476027	55.661396	Urban background
Mozhayskoe	2003-present	37.403538	55.720669	Urban background
Kutuzov	2002-present	37.537187	55.741173	Urban
Veshnyaki	2003-present	37.795683	55.72017	Roadside

Mumbai

Figure B.28 Map of monitoring sites in Mumbai (Maharastra Pollution Control Board, 2012)



Available at http://mpcb.gov.in/envtdata/envtair.php

Table B.28 Monitoring stations in Mumbai

Site	Period[1]	Location[2]	Type[3]
Ambernath		Ambernath	Rural & other areas
Premataihall		Bhiwandi	Commercial
I.G.Mhospital		Bhiwandi	Sensitive
Dombivali		Dombivali	Industrial
MIDC Office Domdivali		Dombivali	Industrial
MPCB Ro Kalyan office		Kalyan	Commercial
Sion		Mumbai	Residential
Bandra		Mumbai	Residential
Neeri office, Worli		Mumbai	Residential
Vashi		Navi Mumbai	Residential
Airoli		Navi Mumbai	Rural & other areas
Nerul		Navi Mumbai	Residential
Rabale		Navi Mumbai	Industrial
MPCB-Nirmal Bhavan, Mahape		Navi Mumbai	Industrial
Panvel Water Supply		Panvel	Residential

Site	Period[1]	Location[2]	Type[3]
Kharghar		Taloja	Residential
MIDC Taloja		Taloja	Industrial
Kolshet		Thane	Industrial
Balkum		Thane	Industrial
Naupada		Thane	Industrial
Kopri		Thane	Residential
Powai Chowk		Ulhasnagar	Rural & other areas
Smt. Chandibai Himmatlal Mansukhani College Campus		Ulhasnagar	Rural & other areas

Notes:

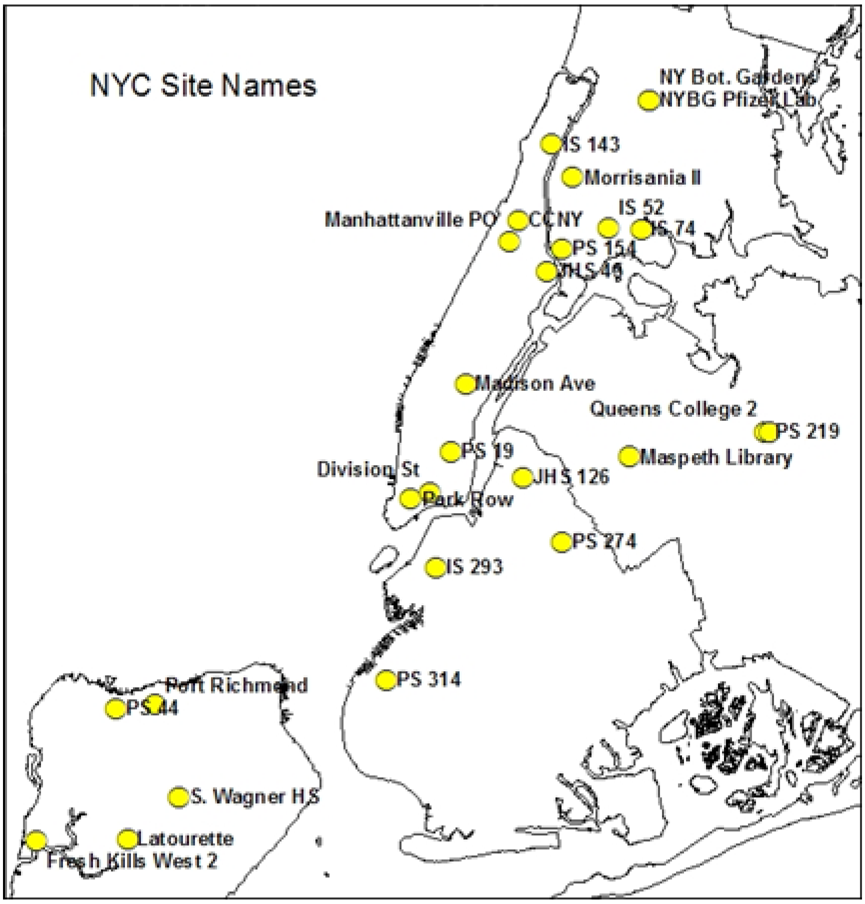
[1]Unknown

[2]Town within Mumbai metropolitan area

[3]Station classification system differs. Only industrial stations indicated as such.

New York

Figure B.29 Map of monitoring sites in New York (New York State. Department for environmental conservation, 2013)



Available at http://www.dec.ny.gov/chemical/27442.html

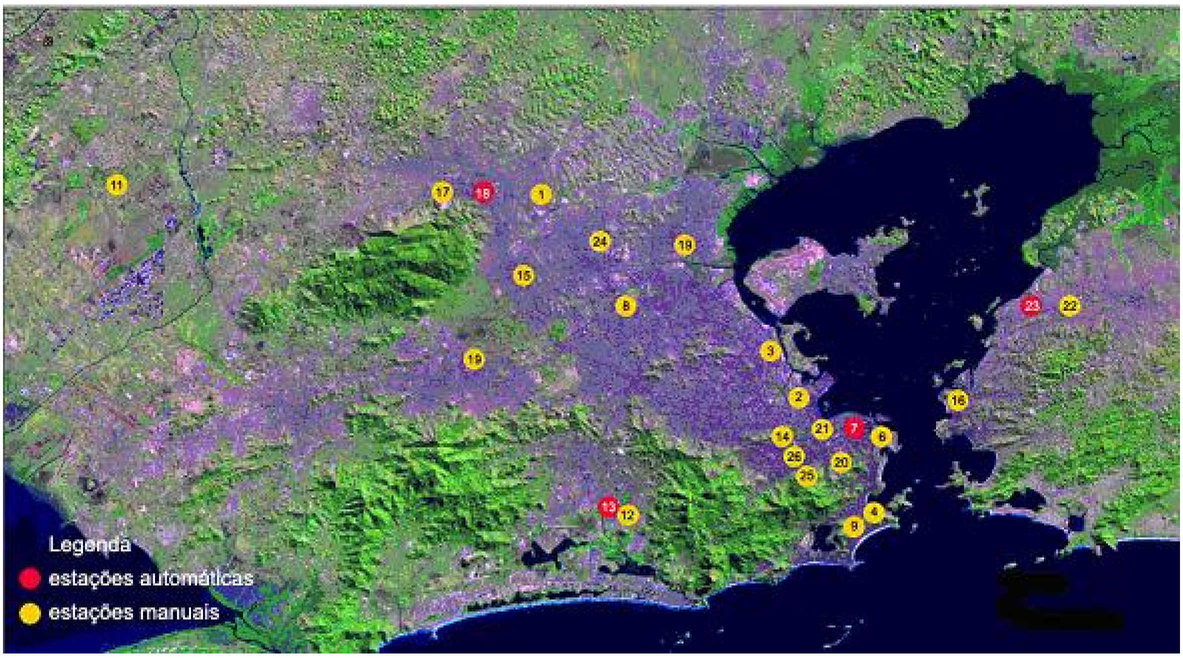
Table B.29 Monitoring stations in New York

Site	Period	Location Longitude	Location Latitude	Type[1]
PS 59 (7093)	Closed in 2008	-73.966851	40.759914	-
IS 52 (7094)	1999-	-73.9018	40.81566	-
Pfizer Lab/Botanical Garden (7094)	1995-ongoing	-73.88311	40.86656	-
Queen College 2 (7096)	1978-	-73.82114	40.73709	-
JHS 45 (7093)	1985-	-73.93352	40.79861	-
IS 143 (7093)	2000-	-73.93095	40.84894	-
Manhattanville PO (7093)	finished in 2011	-73.95322	40.81123	-
Park Row (7093)	Closed in 2011	-74.00528	40.71139	-
PS 19 (7093)	2001-	-73.98391	40.72952	-
Division Street (7093)	2006-	-73.99551	40.71419	-
CCNY (7093)	2007-	-73.94952	40.81955	-
Morrisania (7094)	1989-	-73.93063	40.81537	-
IS 74 (7094)	2000-	-73.88567	40.8158	-
PS 154 (7094)	finished in 2011	-73.92548	40.80813	-
PS 314 (7095)	1982-	-74.01931	40.64194	-
JHS 126 (7095)	2000-	-73.94842	40.71977	-
IS 293 (7095)	finished in 2011	-73.99344	40.68545	-
PS 274 (7095)	2000-	-73.9386	40.70744	-
Maspeth Library (7096)	2000-	-73.89295	40.72707	-
PS 219 (7096)		-73.82114	40.73709	-
Susan Wagner (7097)	1970-	-74.12313	40.59858	-
Port Richmond (7097)	1984-	-74.13716	40.63309	-
Freshkills West (7097)	1999-	-74.20396	40.55908	-
PS 44 (7097)	Closed in 2011	-74.15732	40.63168	-
Madison Ave (7093)	2008-2010	-73.97693	40.75638	-

[1] Classification not available

Rio de Janeiro

Figure B.30 Map of monitoring sites in Rio de Janeiro (Instituto estadual do ambiente, Governo do Rio de Janeiro, 2009)



Notes:

Automatic stations Manual stations

Available at http://www.inea.rj.gov.br/Portal/index.htm

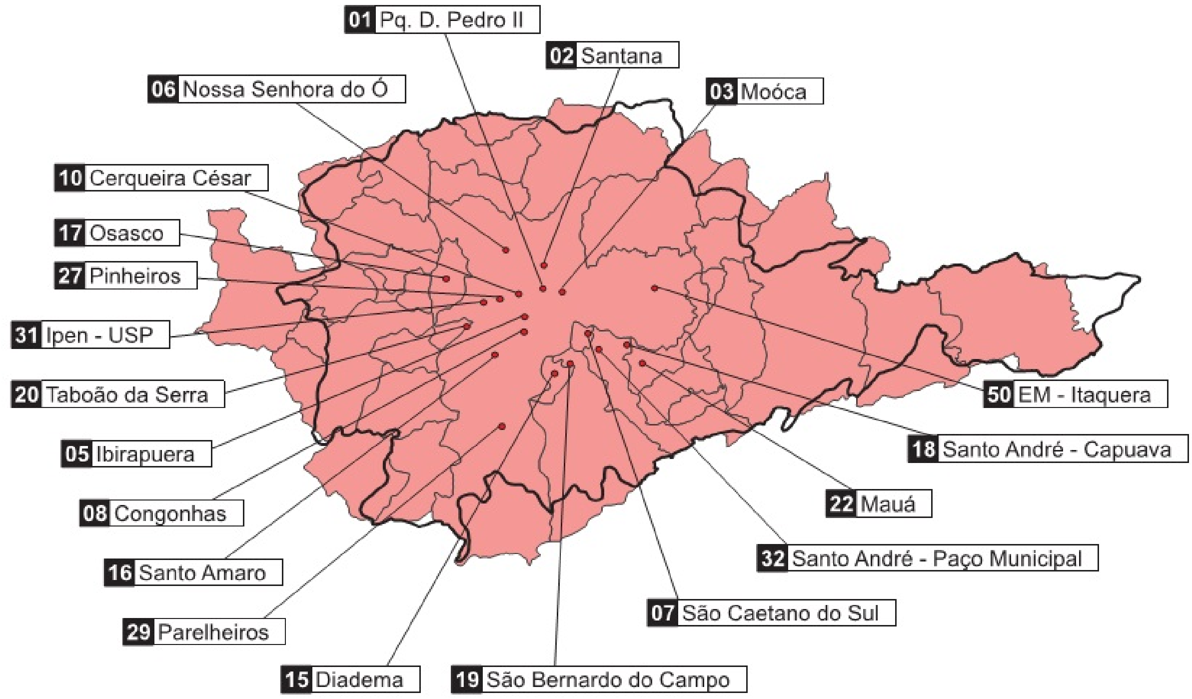
Table B.30 Monitoring stations in Rio de Janeiro

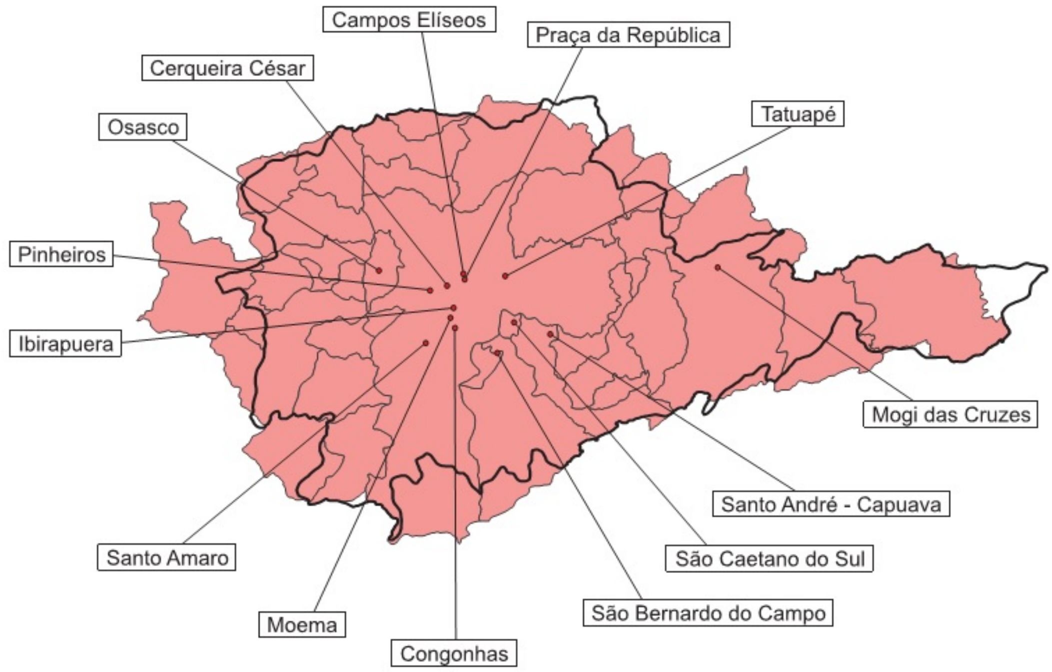
Site	Period	Location Longitude	Location Latitude	Type
Belford Roxo		-22.742219	-43.390904	-
Benfica		-22.892847	-43.237583	-
Bonsucesso		-22.8538	-43.248408	-
Botafogo		-22.953334	-43.176281	-
Centro		-22.907659	-43.172492	-
Centro Automática				-
Coelho Neto				-
Copacabana		-22.966722	-43.188721	-
Duque de Caxias		-22.792603	-43.30453	-
Engenho da Rainha				-
Itaguaí		-22.874843	-43.770067	-
Jacarepaguá				-
Jacarepaguá Automática				-
Maracanã		-22.910465	-43.235799	-
Nilópolis		-22.810766	-43.414247	-
Niterói		-22.883906	-43.11961	-
Nova Iguaçu		-22.762148	-43.441402	-
Nova Iguaçu Automática		-22.762034	-43.441116	-
Realengo		-22.866244	-43.425111	-
Santa Tereza		-22.92958	-43.19512	-
São Cristóvão		-22.902256	-43.212295	-
São Gonçalo		-22.823995	-43.048428	-
São Gonçalo Automática		-22.832154	-43.073343	-
São João de Meriti		-22.787741	-43.364541	-
Sumaré		-22.932095	-43.221879	-
Tijuca		-22.921736	-43.22816	-

Notes:
[1] Types of station not available

São Paulo

Figure B.31 Map of monitoring sites in São Paulo (CETESB, 2011)





Notes: Automatic stations in the map above. Manual stations below

Available at http://www.cetesb.sp.gov.br/ar/qualidade-do-ar/31-publicacoes-e-relatorios#

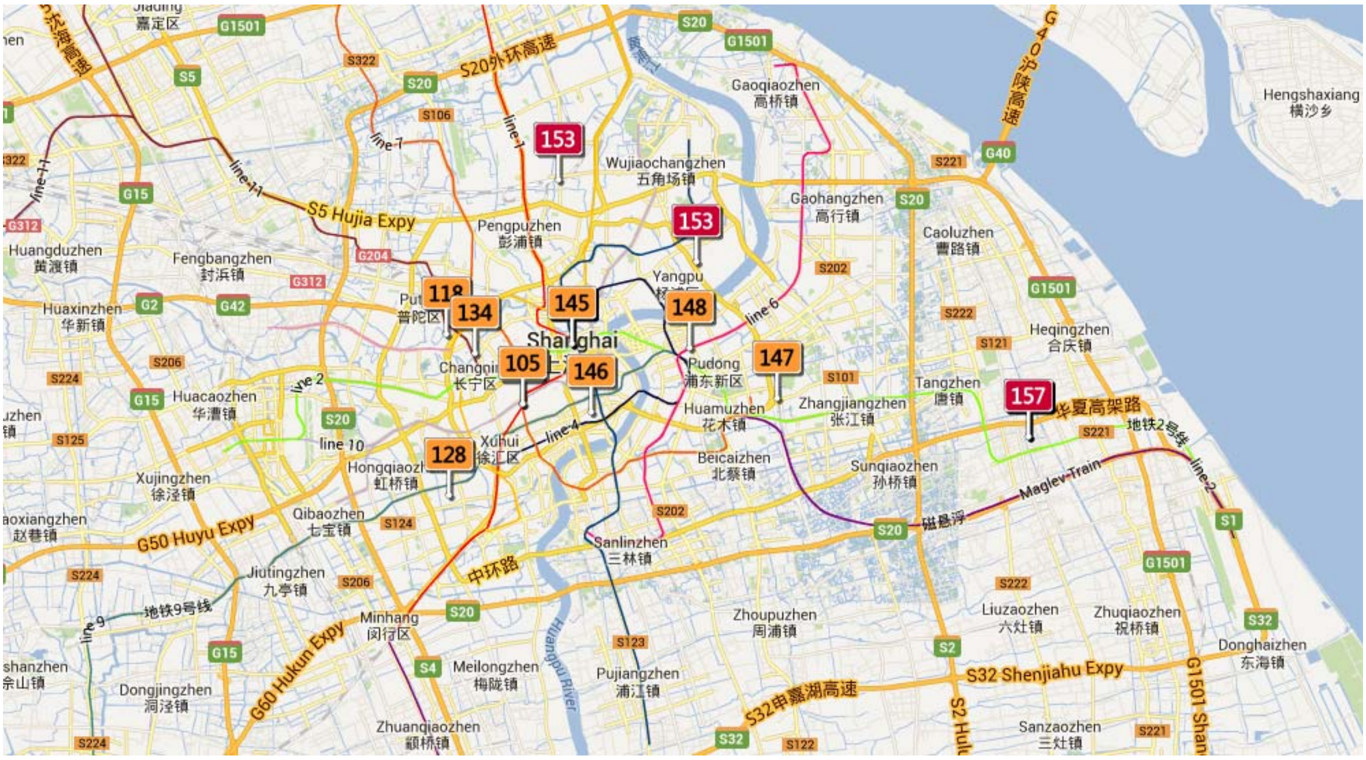
Table B.31 Monitoring stations in Sao Paulo

Site	Period	Location Longitude	Location Latitude	Type[1]
Capão Redondo		-46.780076	-23.662115	-
Centro	Inactive since 2010	-46.642252	-23.547767	-
Cerqueira César		-46.673622	-23.553124	-
Congonhas		-46.663278	-23.615879	-
Ibirapuera		-46.659506	-23.588118	-
IPEN - USP		-46.7295	-23.567633	-
Interlagos	2011-	-46.676046	-23.682421	-
Itaim Paulista	2011-	-46.420396	-23.501953	-
Itaquera		-46.471632	-23.580299	-
Marginal Tietê Ponte dos Remedios	2011-	-46.745986	-23.520221	-
Moóca		-46.601404	-23.549584	-
Nossa Senhora do Ó		-46.692335	-23.480072	-
Parelheiros		-46.697694	-23.77551	-
Parque D. Pedro II		-46.631479	-23.54529	-
Pinheiros		-46.701838	-23.561253	-
Santana		-46.473045	-23.456372	-
Santo Amaro		-46.710226	-23.654318	-
Carapicuíba		-46.836109	-23.531159	-
Diadema		-46.309173	-23.53427	-
Guarulhos - P.Munic.		-46.51841	-23.456231	-
Mauá		-46.464423	-23.668493	-
S. André - P. Munic.		-46.532668	-23.472765	-
S. André - Capuava		-46.700132	-23.583637	-
S. Bernardo do Campo		-46.639303	-23.546615	-
S. Caetano do Sul		-46.556374	-23.618379	-
Osasco		-46.792084	-23.52673	-
Taboão da Serra		-46.757667	-23.609156	-
Campos Elíseos		-46.644617	-23.533193	-
Moema		-46.667664	-23.611085	-
Praça da República		-46.6439	-23.544332	-
Tatuapé - Centro		-46.571973	-23.535989	-
Mogi das Cruzes - Centro		-46.200777	-23.521947	-

Notes: [1] Station classification not available

Shanghai

Figure B.32 Map of monitoring sites in Shanghai (Shanghai Environment Monitoring Centre, Google maps, 2013)



Available at http://aqicn.org/map/

Table B.32 Monitoring stations in Shanghai

Site	Period[1]	Location Longitude	Location Latitude	Type[2]
Shanghai Normal University	-	121.416424	31.161577	-
Shanghai US consulate	-	121.447489	31.208966	-
Jingan	-	121.425042	31.226124	-
Putuo	-	121.410722	31.234821	-
Shanghai Normal College Primary Division	-	121.483098	31.200854	-
Lingshan Road	-	121.532926	31.229225	-
Zhangjiang	-	121.577012	31.207011	-
Chuansha	-	121.701885	31.190667	-
Hongkou Liangcheng	-	121.467179	31.300867	-
Yangpu Sipiao	-	121.416424	31.161577	-

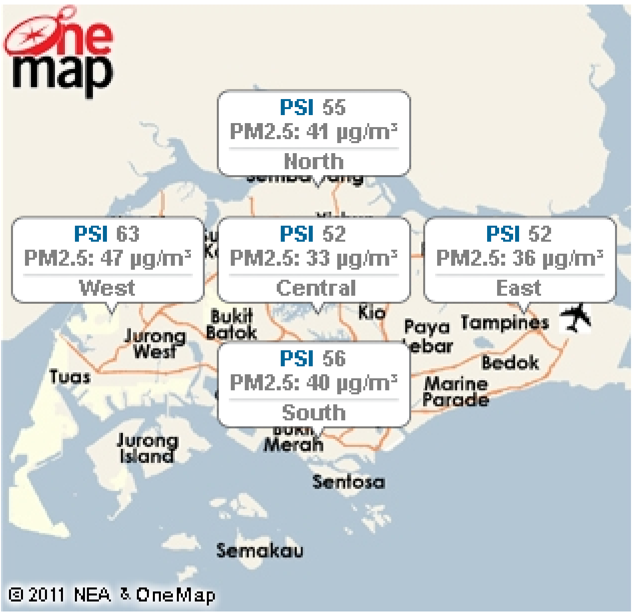
Notes:

[1] Unknown

[2] Type of station and period not available

Singapore

Figure B.33 Map of monitoring sites in Singapore (National Environment Agency, 2010)



Notes: Five sites located in the north, east, south, west and central areas, but no further details found.

Available at http://app2.nea.gov.sg/anti-pollution-radiation-protection/air-pollution-control/psi/psi

Sydney

Figure B.34 Map of monitoring sites in Sydney (NSW Government, 2012)

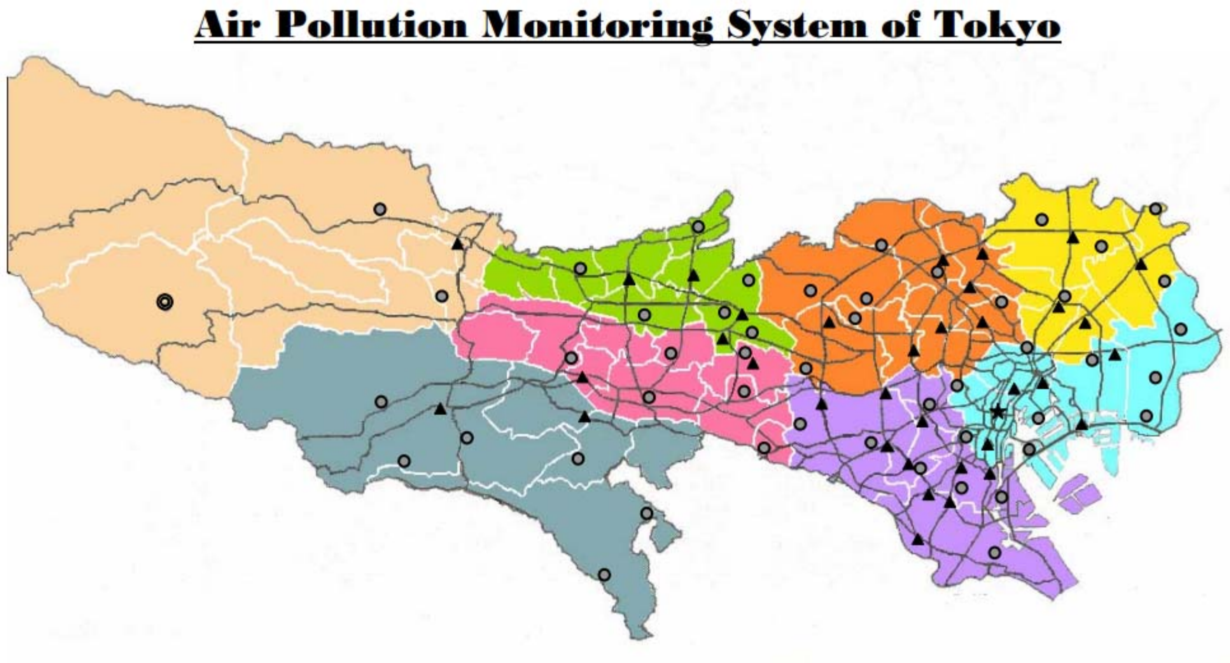
Available at http://www.environment.nsw.gov.au/AQMS/sitesyd.htm

Table B.34 Monitoring stations in Sydney

Site	Period	Location Longitude	Location Latitude	Type
Bargo	1996-present	34° 18' 27"	150° 34' 48"	Suburban
Bringelly	1992-present	33° 55' 10"	150° 45' 40"	Suburban
Campbelltown West	2012-present	34° 04' 00"	150° 47' 43"	Suburban
Chullora	2003-present	33° 53' 38"	151° 02' 43"	Urban roadside
Earlwood	1978-present	33° 55' 04"	151° 08' 05"	Suburban
Lindfield	1992-present	33° 46' 58"	151° 09' 00"	Suburban
Liverpool	1990-present	33° 55' 58"	150° 54' 21"	Suburban
Macarthur	2004-present	34° 04' 16"	150° 46' 54"	Suburban/Rural
Oakdale	1996-present	34° 03' 11"	150° 29' 50"	Rural
Prospect	2007-present	33° 47' 41"	150° 54' 45"	Suburban roadside
Randwick	1995-present	33° 56' 00"	151° 14' 31"	Suburban
Richmond	1992-present	33° 37' 06"	150° 44' 45"	Suburban/Rural
Rozelle	1978-present	33° 51' 57"	151° 09' 45"	Urban background
St Marys	1992-present	33° 47' 50"	150° 45' 57"	Suburban/Rural
Vineyard	1994-present	33° 39' 28"	150° 50' 48"	Suburban/Rural

Tokyo

Figure B.35 Map of monitoring sites in Tokyo (Environment of Tokyo, year unknown)

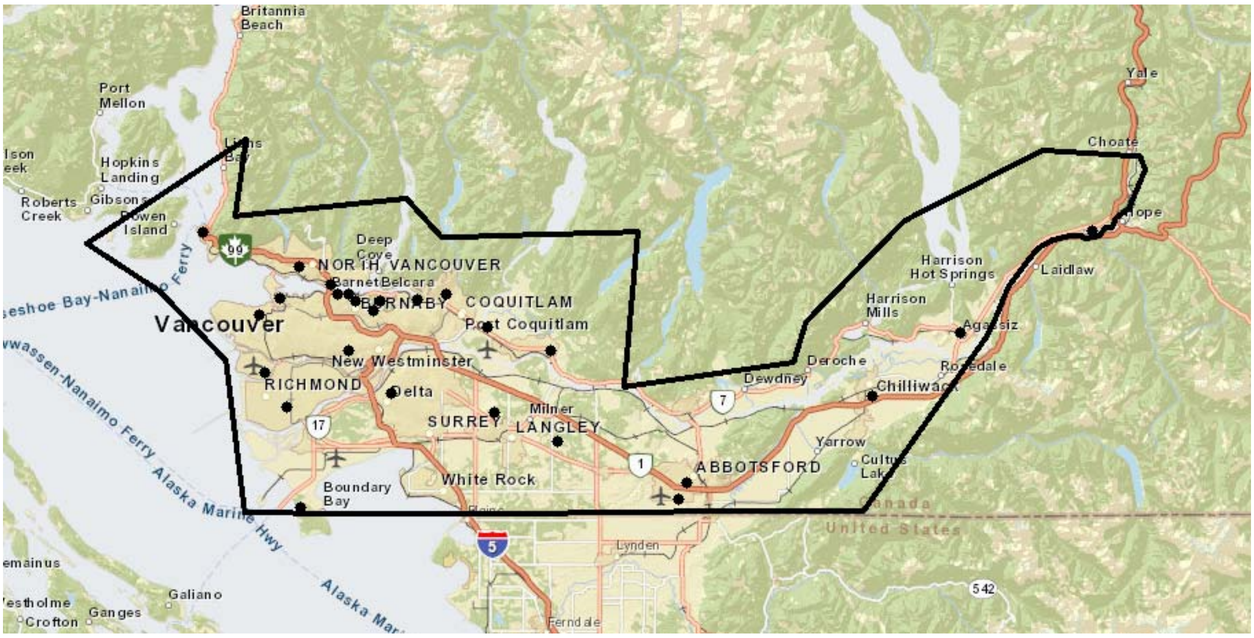


Notes: Total of 82 monitoring sites - 47 of which are in background locations and 35 of which are in roadside locations. It is not known which pollutants are monitored at each site.

Available at http://www.kankyo.metro.tokyo.jp/en/attachement/Air%20Pollution%20Monitoring%20System.pdf

Vancouver

Figure B.36 Map of monitoring stations in Vancouver (Metro Vancouver, 2012)



Available at http://www.ec.gc.ca/rnspa-naps/default.asp?lang=En&n=8BE12DF0-1

Table B.36 Monitoring stations in Vancouver (Official stations in Metro Vancouver network)

Site	Period	Location Longitude	Location Latitude	Type
Vancouver Downtown	1975 -ongoing	123.1219° W	49.2823° N	-
Vancouver Kitsilano	1986 -ongoing	123.1635° W	49.2617° N	-
Burnaby Kensington Park	1975 -ongoing	122.9707° W	49.2792° N	-
N. Vancouver Secon Narrows	1977 -ongoing	123.0204°W	49.2809° N	-
Port Moody	1977 -ongoing	122.8493° W	49.3015° N	-
Chilliwack	1984 -ongoing	121.9403° W	49.1558° N	-
North Delta	1987 -ongoing	122.9017° W	49.1583° N	-
Burnaby Mountain	1984 -ongoing	122.9223° W	49.2798° N	-
Surrey East	1984 -ongoing	122.6942° W	49.1329° N	-
Richmond South	1986 -ongoing	123.1082°W	49.1414° N	-
Burnaby South	1987 -ongoing	122.9857° W	49.2152° N	-
Pitt Meadows	1998 -ongoing	122.7089° W	49.2452° N	-
Burnaby Burmount	1989 -ongoing	122.9355° W	49.2667° N	-
Burnaby Capitol Hill	1995 -ongoing	122.9856° W	49.2879° N	-

Site	Period	Location Longitude	Location Latitude	Type
Burnaby North	1999 -ongoing	123.0080° W	49.2875° N	-
N. Vancouver Mahon Park	1990 -ongoing	123.0835° W	49.3240°N	-
Langley	1992 -ongoing	122.5671° W	49.0956° N	-
Hope Airport	1996 -ongoing	121.4991° W	49.3699° N	-
Maple Ridge	1998 -ongoing	122.5821° W	49.2149° N	-
Richmond Airport	1998 -ongoing	123.1524° W	49.1863° N	-
Coquitlam	2000 -ongoing	122.7916° W	49.2883° N	-
Abbotsford Mill Lake	1998 -ongoing	122.3098° W	49.0426° N	-
Horseshoe Bay	2002 -ongoing	123.2767°W	49.3686°N	-
Tsawwassen	2010 -ongoing	123.0820° W	49.0099° N	-
Abbotsford Airport	2012 -ongoing	122.3265° W	49.0215° N	-

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Environment Canadian maintains the National Air Pollution Surveillance (NAPS) network, which has multiple monitors in Vancouver. The data were requested data but not received for inclusion in the report.

Appendix C
Alternative Ranking Schemes

Table C.1 Citywide/ Traffic Focussed Index for Each Year (2008-2012) and the 5-Year Average

City	2008	2009	2010	2011	2012	Average
Amsterdam	0.88	0.78	0.77	0.76		0.79
Barcelona	1.10	1.08	0.88	0.94	0.91	0.93
Beijing	2.15	2.18	2.23			2.18
Berlin	0.73	0.78	0.80	0.78		0.77
Brussels	0.84	0.86	0.82	0.83	0.68	0.83
Bucharest	1.20	1.27	0.89	0.80		0.98
Budapest	0.84	0.76	0.86	0.93	0.76	0.84
Cairo	2.61	2.31	2.13			2.35
Chicago	0.78	0.72	0.74	0.65		0.72
Frankfurt	0.80	0.85	0.81	0.81		0.82
Hong Kong	1.51	1.43	1.49	1.43	1.40	1.45
Istanbul	1.58	1.51	1.45	1.36	1.50	1.48
Jakarta	0.76	0.93	0.85	1.34		0.97
London	0.88	0.90	0.90	0.93	0.89	0.90
Los Angeles	1.15	1.01	0.91	0.86	0.94	0.96
Madrid	0.93	0.91	0.76	0.78	0.70	0.82
Mexico City	1.78	1.79	1.73	1.74		1.76
Milan	1.33	1.29	1.18	1.38	1.25	1.28
Moscow					0.81	0.81
Mumbai	2.99	2.43	2.48	2.53	2.44	2.58
Munich	0.96	1.01	1.01	0.93		0.98
New York	0.80	0.71	0.84	0.67		0.74
Paris	0.83	0.91	0.90	0.93	0.93	0.90
Prague	0.75	0.73	0.81	0.78	0.74	0.76
Rio de Janeiro	1.44	1.34	1.11			1.30
Rome	1.03	1.05	0.95	1.04	0.94	1.00
Sao Paulo	1.00	0.90	0.99	0.95		0.96
Shanghai	1.75	1.68	1.61			1.68
Singapore	0.58	0.66	0.63	0.66		0.64
Stockholm	0.72	0.63	0.67	0.65	0.58	0.65
Stuttgart	1.14	1.21	1.15	1.17		1.17
Sydney	0.41	0.50	0.40	0.39	0.41	0.42
Tokyo	1.25	1.22	1.15	1.08		1.18
Vancouver	0.40	0.41	0.35	0.34	0.36	0.37
Vienna	0.70	0.72	0.79	0.77	0.66	0.73
Warsaw	0.78	0.84	0.95	0.95	0.90	0.89

Table C.2 Citywide/ Traffic Focussed Ranking for Each Year (2008-2012) and the 5-year Average

City	2008	2009	2010	2011	2012	Average
Amsterdam	16	11	7	7	-	10
Barcelona	22	23	16	20	12	19
Beijing	33	33	34	-	-	34
Berlin	6	10	9	10	-	9
Brussels	14	14	12	14	5	14
Bucharest	25	26	17	12	-	24
Budapest	15	9	15	18	8	15
Cairo	34	34	33	-	-	35
Chicago	10	7	5	4	-	5
Frankfurt	12	13	11	13	-	13
Hong Kong	29	29	30	29	17	30
Istanbul	30	30	29	27	18	31
Jakarta	8	19	14	26	-	22
London	**17**	**15**	**19**	**17**	10	**17**
Los Angeles	24	20	20	15	15	20
Madrid	18	17	6	11	6	12
Mexico City	32	32	32	30	-	33
Milan	27	27	28	28	16	28
Moscow	-	-	-	-	9	11
Mumbai	35	35	35	31	19	36
Munich	19	21	24	19	-	23
New York	11	5	13	6	-	7
Paris	13	18	18	16	13	18
Prague	7	8	10	9	7	8
Rio de Janeiro	28	28	25	-	-	29
Rome	21	22	21	23	14	25
Sao Paulo	20	16	23	22	-	21
Shanghai	31	31	31	-	-	32
Singapore	3	4	3	5	-	3
Stockholm	5	3	4	3	3	4
Stuttgart	23	24	26	25	-	26
Sydney	2	2	2	2	2	2
Tokyo	26	25	27	24	-	27
Vancouver	1	1	1	1	1	1
Vienna	4	6	8	8	4	6
Warsaw	9	12	22	21	11	16

Table C.3 Citywide/ Traffic Focussed Index - Overall 5-Year Ranking for City Air Quality (36 Cities)

City	Ranking	Descriptor
Vancouver	1	Best Air Quality
Sydney	2	
Singapore	3	
Stockholm	4	
Chicago	5	
Vienna	6	
New York	7	
Prague	8	
Berlin	9	
Amsterdam	10	
Moscow	11	
Madrid	12	
Frankfurt	13	
Brussels	14	
Budapest	15	
Warsaw	16	
London	17	
Paris	18	
Barcelona	19	
Los Angeles	20	
Sao Paulo	21	
Jakarta	22	
Munich	23	
Bucharest	24	
Rome	25	
Stuttgart	26	
Tokyo	27	
Milan	28	
Rio de Janeiro	29	
Hong Kong	30	
Istanbul	31	
Shanghai	32	
Mexico city	33	
Beijing	34	
Cairo	35	
Mumbai	36	Worst Air Quality

Table C.4 Health Impacts City Index for Each Year (2008-2012) and the 5-Year Average

City	2008	2009	2010	2011	2012	Average
Amsterdam	0.68	0.66	0.64	0.66		0.65
Barcelona	0.72	0.77	0.68	0.75	0.78	0.74
Beijing	2.98	2.93	2.93			2.94
Berlin	0.66	0.70	0.74	0.70		0.70
Brussels	0.73	0.76	0.71	0.74	0.66	0.72
Bucharest	1.19	0.66	0.87	0.89		0.96
Budapest	0.78	0.76	0.84	0.90	0.74	0.82
Cairo	3.51	3.56	3.02			3.36
Chicago	0.55	0.55	0.59	0.52		0.55
Frankfurt	0.58	0.65	0.62	0.61		0.62
Hong Kong	1.43	1.24	1.23	1.29	1.12	1.26
Istanbul	1.43	1.31	1.23	1.19	1.28	1.29
Jakarta	1.13	1.35	1.23	1.73		1.37
London	0.63	0.63	0.61	0.66	0.61	0.63
Los Angeles	1.04	0.98	0.82	0.79	0.92	0.89
Madrid	0.65	0.60	0.54	0.56	0.52	0.58
Mexico City	1.20	1.33	1.23	1.31		1.27
Milan	1.13	1.09	0.97	1.24	1.12	1.11
Moscow					0.65	0.65
Mumbai	2.90	2.36	2.41	2.46	2.39	2.51
Munich	0.65	0.72	0.72	0.67		0.69
New York	0.52	0.50	0.53	0.48		0.50
Paris	0.69	0.80	0.75	0.79	0.78	0.76
Prague	0.65	0.64	0.72	0.70	0.65	0.68
Rio de Janeiro	1.22	1.23	1.65			1.33
Rome	0.84	0.83	0.72	0.81	0.75	0.79
Sao Paulo	0.88	0.77	0.89	0.90		0.86
Shanghai	2.10	2.00	1.94			2.01
Singapore	0.62	0.72	0.65	0.67		0.68
Stockholm	0.62	0.53	0.50	0.55	0.48	0.54
Stuttgart	0.73	0.75	0.78	0.76		0.76
Sydney	0.39	0.55	0.36	0.37	0.39	0.41
Tokyo	0.62	0.62	0.59	0.56		0.60
Vancouver	0.27	0.27	0.24	0.24	0.24	0.25
Vienna	0.62	0.66	0.76	0.75	0.60	0.68
Warsaw	0.80	0.88	0.99	0.96	0.94	0.93

Table C.5 Health Impacts City Ranking for Each Year (2008-2012) and the 5-year Average

City	2008	2009	2010	2011	2012	Average
Amsterdam	15	12	10	9	-	11
Barcelona	17	20	12	16	12	18
Beijing	34	34	34	-	-	35
Berlin	14	14	17	13	-	16
Brussels	18	18	13	15	9	17
Bucharest	27	13	23	22	-	26
Budapest	20	19	22	24	10	22
Cairo	35	35	35	-	-	36
Chicago	4	5	6	4	-	5
Frankfurt	5	10	9	8	-	8
Hong Kong	31	28	27	28	17	28
Istanbul	30	29	29	26	18	30
Jakarta	25	31	28	30	-	32
London	10	8	8	10	6	9
Los Angeles	24	25	21	19	14	24
Madrid	12	6	5	6	4	6
Mexico City	28	30	30	29	-	29
Milan	26	26	25	27	16	27
Moscow	-	-	-	-	7	10
Mumbai	33	33	33	31	19	34
Munich	11	15	16	12	-	15
New York	3	2	4	3	-	3
Paris	16	22	18	20	13	20
Prague	13	9	14	14	8	12
Rio de Janeiro	29	27	31	-	-	31
Rome	22	23	15	21	11	21
Sao Paulo	23	21	24	23	-	23
Shanghai	32	32	32	-	-	33
Singapore	7	16	11	11	-	14
Stockholm	8	3	3	5	3	4
Stuttgart	19	17	20	18	-	19
Sydney	2	4	2	2	2	2
Tokyo	9	7	7	7	-	7
Vancouver	1	1	1	1	1	1
Vienna	6	11	19	17	5	13
Warsaw	21	24	26	25	15	25

Table C.6 Health Impacts Index - Overall 5-Year Ranking for City Air Quality (36 Cities)

City	Ranking	Descriptor
Vancouver	1	Best Air Quality
Sydney	2	
New York	3	
Stockholm	4	
Chicago	5	
Madrid	6	
Tokyo	7	
Frankfurt	8	
London	**9**	
Moscow	10	
Amsterdam	11	
Prague	12	
Vienna	13	
Singapore	14	
Munich	15	
Berlin	16	
Brussels	17	
Barcelona	18	
Stuttgart	19	
Paris	20	
Rome	21	
Budapest	22	
Sao Paulo	23	
Los Angeles	24	
Warsaw	25	
Bucharest	26	
Milan	27	
Hong Kong	28	
Mexico city	29	
Istanbul	30	
Rio de Janeiro	31	
Jakarta	32	
Shanghai	33	
Mumbai	34	
Beijing	35	
Cairo	36	Worst Air Quality