Report No.367

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Particulate Matter from Diesel Vehicles: Emissions and Exposure

Authors: Meabh Gallagher, Bidroha Basu, Bidisha Ghosh, Md. Saniul Alam, Laurence Gill, Balz Kamber and Aonghus McNabola

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Rialtas na hÉireann
Government of Ireland

ENVIRONMENTAL PROTECTION AGENCY

The Environmental Protection Agency (EPA) is responsible for protecting and improving the environment as a valuable asset for the people of Ireland. We are committed to protecting people and the environment from the harmful effects of radiation and pollution.

The work of the EPA can be divided into three main areas:

Regulation: *We implement effective regulation and environmental compliance systems to deliver good environmental outcomes and target those who don't comply.*

Knowledge: *We provide high quality, targeted and timely environmental data, information and assessment to inform decision making at all levels.*

Advocacy: *We work with others to advocate for a clean, productive and well protected environment and for sustainable environmental behaviour.*

Our Responsibilities

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We regulate the following activities so that they do not endanger human health or harm the environment:

- waste facilities *(e.g. landfills, incinerators, waste transfer stations)*;
- large scale industrial activities (*e.g. pharmaceutical, cement manufacturing, power plants)*;
- intensive agriculture *(e.g. pigs, poultry)*;
- the contained use and controlled release of Genetically Modified Organisms *(GMOs)*;
- sources of ionising radiation *(e.g. x-ray and radiotherapy equipment, industrial sources)*;
- large petrol storage facilities;
- waste water discharges;
- dumping at sea activities.

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- Conducting an annual programme of audits and inspections of EPA licensed facilities.
- Overseeing local authorities' environmental protection responsibilities.
- Supervising the supply of drinking water by public water suppliers.
- Working with local authorities and other agencies to tackle environmental crime by co-ordinating a national enforcement network, targeting offenders and overseeing remediation.
- Enforcing Regulations such as Waste Electrical and Electronic Equipment (WEEE), Restriction of Hazardous Substances (RoHS) and substances that deplete the ozone layer.
- Prosecuting those who flout environmental law and damage the environment.

Water Management

- Monitoring and reporting on the quality of rivers, lakes, transitional and coastal waters of Ireland and groundwaters; measuring water levels and river flows.
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- Monitoring and reporting on Bathing Water Quality.

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- Monitoring air quality and implementing the EU Clean Air for Europe (CAFÉ) Directive.
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- Preparing Ireland's greenhouse gas inventories and projections.
- Implementing the Emissions Trading Directive, for over 100 of the largest producers of carbon dioxide in Ireland.

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- Funding environmental research to identify pressures, inform policy and provide solutions in the areas of climate, water and sustainability.

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- Assessing the impact of proposed plans and programmes on the Irish environment *(e.g. major development plans)*.

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- Monitoring radiation levels, assessing exposure of people in Ireland to ionising radiation.
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- Providing, or overseeing the provision of, specialist radiation protection services.

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- Generating greater environmental awareness and influencing positive behavioural change by supporting businesses, communities and householders to become more resource efficient.
- Promoting radon testing in homes and workplaces and encouraging remediation where necessary.

Management and structure of the EPA

The EPA is managed by a full time Board, consisting of a Director General and five Directors. The work is carried out across five Offices:

- Office of Environmental Sustainability
- Office of Environmental Enforcement
- Office of Evidence and Assessment
- Office of Radiation Protection and Environmental Monitoring
- Office of Communications and Corporate Services

The EPA is assisted by an Advisory Committee of twelve members who meet regularly to discuss issues of concern and provide advice to the Board.

EPA RESEARCH PROGRAMME 2014–2020

Particulate Matter from Diesel Vehicles: Emissions and Exposure

(2015-CCRP-MS.29)

EPA Research Report

A copy of the end-of-project Technical Report is available on request from the EPA

Prepared for the Environmental Protection Agency

by

Trinity College Dublin

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ACKNOWLEDGEMENTS

This report is published as part of the EPA Research Programme 2014–2020. The EPA Research Programme is a Government of Ireland initiative funded by the Department of the Environment, Climate and Communications. It is administered by the Environmental Protection Agency, which has the statutory function of co-ordinating and promoting environmental research.

The authors would like to acknowledge the members of the project steering committee, namely John McEntagart (EPA), Pat Kenny (EPA), David Dodd (Dublin Metropolitan Climate Action Regional Office – CARO), Micheál Young (DECC), Tessa Greally (HSE), Faye Carroll (DTTAS), Denise Keoghan (formerly DT), Matt Robinson (HSE) and Regina Kiernan (HSE); we would also like to acknowledge Oonagh Monahan (Research Project Manager on behalf of the EPA).

DISCLAIMER

This report is based on research carried out/data from May 2016 to April 2018. More recent data may have become available since the research was completed.

The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

EPA RESEARCH PROGRAMME 2014–2020
Published by the Environmental Protection Agency, Ireland

ISBN: 978-1-84095-982-6 February 2021

Price: Free Online version

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Executive Summary

A 2-year research project was conducted in Dublin, Ireland, to assess the contribution of diesel vehicle emissions to the concentrations of particulate matter < 2.5 µm in aerodynamic diameter ($PM_{2.5}$) that the population is exposed to (2016–2018). The project was conducted as a collaboration between the Department of Civil, Structural & Environmental Engineering and the School of Geology at Trinity College Dublin.

$PM_{2.5}$ was monitored for over 1 year at two locations in Dublin, Site A and Site B. Site A was a roadside location, on Pearse Street in Dublin city centre, whereas Site B was located in a residential area, in Phibsborough. Site B was representative of urban background concentrations. The mean concentration of $PM_{2.5}$ at Site B was 8.1 µg/m^3 and concentrations recorded here were consistently within European Union (EU) and World Health Organization (WHO) limit values. The concentrations at Site B were also in line with the four existing Environmental Protection Agency (EPA) $PM_{2.5}$ monitoring stations in Dublin and four Transport Infrastructure Ireland (TII) stations. Concentrations at Site A had an average value of 36.9 µg/m^3 and consistently exceeded EU and WHO limit values.

Source apportionment was conducted using the samples collected at Sites A and B, using laser-ablation inductively coupled plasma mass spectrometry. This new technique enabled a large number of chemical species to be determined at greatly reduced cost and time, and with lower limits of detection. A total of 34 chemical species were recorded during this study.

Positive matrix factorisation (PMF) modelling was conducted to determine the major sources of $PM_{2.5}$ in Dublin in this study. Chemical mass balance modelling was also conducted for comparison with the PMF results. The major source of $PM_{2.5}$ identified at both sites was solid fuel burning, contributing 46–50% of the total $PM_{2.5}$ mass recorded. The second largest contributor at Site A was diesel vehicle emissions (22%), followed closely by road dust (19%). Other sources made minor contributions at Site A (sea salt, soil and petrol vehicles were all < 4%). The second largest contributor at Site B was soil (20%), followed closely by sea spray (14%). Road dust and diesel exhaust emissions contributed significantly less at Site B, 8% and 9% respectively, than at Site A, as would be expected. Petrol emissions again contributed relatively little (1.4%).

Advanced land use regression (LUR) modelling was conducted to develop a spatial air quality model for Dublin using the available fixed-site and mobile-station $PM_{2.5}$ data. Data from 10 fixed-site monitors were available from the EPA, TII and this study. These were combined with shorter term mobile-station measurements from > 100 personal exposure samples. A new weighted support vector regression (SVR) model was developed to account for the non-linear relationship between $PM_{2.5}$ concentrations and the predictor variables (e.g. building area, land use type, population, traffic volume). The method also accounted for the difference in record length between fixed and mobile monitors. The accuracy of the method was very good, giving a coefficient of determination (R^2) value of 91%. The difference between predicted and observed $PM_{2.5}$ concentrations was very small, and the weighted SVR-based LUR model could be used to obtain the $PM_{2.5}$ concentration at any spatial location inside the city. The difference in maximum values of $PM_{2.5}$ concentration was found to be less than 1 µg/m^3 (< 7.5%) for the winter months and less than 4 µg/m^3 (< 8%) for the summer months.

The concentrations predicted by the weighted SVR LUR model were used to model the health impact of $PM_{2.5}$ in Dublin, generally and as a result of diesel emissions. Expected death rates and disability-adjusted life years (DALYs) lost were quantified. Annually, in Dublin approximately 725 deaths associated with $PM_{2.5}$ pollution are expected to occur overall, with the DALYs lost being approximately 25 years. The numbers of expected deaths and DALYs lost because of $PM_{2.5}$ pollution contributed by diesel vehicles are in the ranges of 46–93 deaths and 2.53–5.07 years, respectively.

1 Introduction

1.1 Background

Clean air is considered a basic requirement of human health preservation and well-being. Epidemiological studies have shown that even low levels of air pollution in industrialised societies are linked to adverse health outcomes. Over the last few decades, the need for better air quality has been recognised and efforts have been made internationally to establish minimum quality standards for ambient air. However, air pollution continues to pose a significant threat to human health worldwide, playing a role in many of the major health challenges of our time, being linked to cancer, asthma, stroke and heart disease, diabetes, obesity and dementia. Globally, air pollution is the eighth most important risk factor in premature death worldwide (WHO, 2006), posing a significant threat to public health.

There are several types of air pollutants, originating from a variety of sources, all of which have well-known effects that have implications for both human health and well-being and the environment.

Particulate matter (PM) is the term used to describe all suspended aerosols and particles in the atmosphere. Unlike other pollutants, such as nitrogen dioxide or carbon monoxide, PM is not a specific chemical entity but instead is a complex mixture of particles from many different sources, and has diverse chemical and physical properties (Vallero, 2008). PM is a common physical classification of a variety of particles found in the ambient atmosphere, such as dirt, dust, smoke, soot and liquid droplets. Generally, PM is classified by aerodynamic diameter for regulatory purposes, because it is the size of the particle that is critical in determining the likelihood and location of deposition in the human respiratory system (WHO, 2006). Particulates can be categorised into three main groups based on the size of the particles: (1) coarse particles, for particles $>2.5\,\mu m$ in aerodynamic diameter; (2) fine particles, of $<2.5\,\mu m$ in aerodynamic diameter; and (3) ultrafine particles, for those $<0.1\,\mu m$ in aerodynamic diameter. Black carbon (BC) is a light-absorbing, carbon-containing constituent of PM and is mainly present in the so-called ultrafine fraction of PM ($PM_{1.0}$) (COMEAP, 2015). It is formed by the incomplete combustion of fossil fuels, biomass and biofuels, and is an air pollutant that both affects human health and contributes to climate change (e.g. WHO, 2012; Bond *et al*., 2013; IPCC, 2013).

Sources of PM are highly variable. They may be emitted directly into the ambient air as primary particulates or may be formed in the atmosphere as secondary particles. Most coarse PM is formed by frictional processes of comminution. It includes dust and dirt that are raised by vehicles or wind from farms as well as natural sources such as pollen and sea spray from breaking waves (Hill, 2010). Coarse particles generally account for 5%–20% of the urban background PM mass (Expert Panel on Air Quality Standards, 2001). Finer particles are released from the incomplete combustion of fossil fuels, especially from diesel motor vehicles, electricity power stations and industrial operations. These particles are known as primary PM because they are emitted directly to the air as particles or in the form of vapours that rapidly condense to form ultrafine particles. Particulate air pollution in the urban atmosphere is known to originate from sources such as sea salt, petrol and diesel vehicles, biomass burning, soil, secondary nitrate and sulfate, and industrial sources (Hasheminassab *et al*., 2014). Major sources of BC include vehicles (particularly diesel-powered road vehicles), non-road mobile machinery (e.g. forest machines), ships, residential heating (e.g. small coal or wood burning stoves) and open biomass burning (e.g. forest fires or burning of agricultural waste) (EEA, 2013).

Our world comprises a range of microenvironments through which we, as individuals, uniquely move, live and breathe through the course of a day – and indeed throughout our lifetime. Outdoors, we are exposed to a range of pollutants, many of which come from vehicles. In fact, road traffic is usually the main pollutant source in European urban environments (Colvile *et al*., 2001; Ruellan and Cachier, 2001; Harrison and Yin, 2008). However, in Ireland, domestic solid fuel burning has been cited as the dominant source of PM (e.g. Healy *et al*., 2010; Kourtchev *et al*., 2011; Dall'Osto *et al*., 2014; Lin *et al*., 2017). The quality of air indoors is important too, because we spend so much time

inside. One of the most important sources of indoor air pollution is outdoor air, gaining ingress through windows, doors and other infiltration mechanisms (Challoner and Gill, 2014). Road traffic emissions of PM are very significant in terms of total pollutant loading in outdoor air. Diesel vehicles in particular are known for their significant contribution to overall emissions of PM (Hasheminassab *et al*., 2014; Alam and McNabola, 2015), emitting significantly higher levels of PM than their petrol-driven equivalents.

In Ireland in 2015 and 2016, more than 70% of new cars sold were diesel-fuelled vehicles, whereas the average in the European Union (EU) was 50% (ACEA, 2016). Owing to the recent growth in private diesel vehicles in Ireland since 2008, this vehicle category represents a significant pressure on the quality of the urban environment in Ireland (Giblin and McNabola, 2009; Alam and McNabola, 2015). Thus, a reduction in PM and BC emissions from diesel vehicles is a valid target for further pollution-reduction measures, and a reduction in PM and BC emissions would be beneficial for human health, particularly in urban environments.

1.2 Project Aims

PM air pollution has been highlighted in the literature as having both chronic and acute effects on health (WHO, 2016). Short-term exposure to high PM concentrations is noted in the literature to have an adverse impact (Michaels and Kleinman, 2000), and such short-term exposure to elevated levels of particulates can occur in the transport microenvironment as well as in indoor microenvironments. To determine the impact of the growing levels of diesel particulate emissions in Ireland on public health, exposure and health impact assessments must be carried out to determine exposure both in the transport microenvironment and in critical indoor locations, such as the home and workplace. Such assessments in various microenvironments require determination of the proportion of the total PM concentration that has originated from diesel vehicle emissions using source apportionment techniques. Details of the chemical composition of PM measured at a receptor site can be used to estimate the relative contribution of major sources of PM to the total mass, such as diesel or petrol vehicles (e.g. Hasheminassab *et al*., 2014). The US Environmental Protection Agency (US EPA) positive matrix factorisation (PMF) model is a multivariate receptor model that has been used widely, in conjunction with chemical analysis, to conduct source apportionment analysis of PM in numerous investigations (e.g. Watson *et al*., 2008; Aldabe *et al*., 2011; Hasheminassab *et al*., 2014). Determination of the proportion of the total PM concentration in urban areas that has originated from diesel vehicle emissions using source apportionment techniques would be invaluable in assessing the contribution of diesel emissions to population exposure in Ireland. Thus, the first aim of this project is to estimate the contribution of PM < 2.5 µm in aerodynamic diameter ($PM_{2.5}$) that can be attributed to emissions from diesel vehicles in urban environments. A detailed review of the relevant literature on $PM_{2.5}$ measurement, modelling, source apportionment and health impacts can be found in the end-of-project Technical Report.

The second aim of this project is to determine the exposure of the population to emissions from diesel vehicles in urban environments. Population exposure is difficult to assess, given that the population is exposed to PM from a variety of sources and that different population subgroups may have differing typical activity patterns. The activities conducted by individuals have been shown to greatly influence their personal exposure to PM (McCreddin *et al*., 2013, 2015). Housing type, smoking prevalence, cooking, transport mode and recreational activities have all been shown to influence the magnitude of personal exposure to PM (McNabola *et al*., 2008; Abdullahi *et al*., 2013; McCreddin *et al*., 2013, 2015). Thus, McCreddin *et al*. (2015) developed a model of personal exposure to PM_{10} in Dublin using historical data records of personal exposure measurements and a Monte Carlo simulation, which enabled prediction within microenvironments with a high degree of accuracy. An alternative statistical approach to exposure modelling was taken by Alam and McNabola (2015). They used a combination of land use regression (LUR) and small numbers of background air quality data to predict average daily exposure concentration. Thus, the literature demonstrates that it is possible to develop models of personal exposure that are applicable to wide geographical areas, various microenvironments and large population groups using the limited monitoring input data available in Ireland. This project will generate evidence on the impact of diesel road transport vehicles in Ireland on the

exposure of the population to $PM_{2.5}$, and subsequently on health, through field measurement and modelling of personal exposure to $PM_{2.5}$. Details of the air pollution model developed in this project and public health impacts are available in the end-of-project Technical Report. These are omitted from this synthesis report for brevity.

2 Experimental Methodology

Source apportionment was carried out at two fixed locations within urban settings in the Greater Dublin Area (GDA). The two primary, outdoor fixed $PM_{2.5}$ monitoring sites in this study were located at (1) a roadside location – 193 Pearse Street, Trinity College Dublin, Dublin 2 (Site A); and (2) a family home in a residential neighbourhood – Shandon Park, Phibsborough, Dublin 7 (Site B). These sampling site locations are presented in Figure 2.1. Site A was chosen for its central location in a highly trafficked region in Dublin's city centre. Site A is situated approximately 1.5 m to the south and downwind of a major heavily trafficked road and is thus representative of a typical urban roadside microenvironment, where we would assume that vehicular emissions make a significant contribution to PM levels. The site is far from any other major industrial or point sources and is located approximately 2 km to the west of Dublin port. The site is located at an elevation of 13 m and the surrounding topography gently slopes to the east. Site B was chosen for its location in a residential region of Dublin – Shandon Park, Phibsborough, Dublin 7. The site is representative of a residential microenvironment and is far from any major industrial or point sources. The site is located about 2 km north-west of the city centre. It is a suburban site, situated about 2 km upwind of a motorway. The nearest main commuter road is 300 m away and it is located 3 km west of the coast. The site is located at an elevation of 49 m and the surrounding topography is relatively flat.

The sampling campaign was carried out at Site A from December 2016 to February 2018, a total of 15 months. The source apportionment sampling campaign commenced at Site B in March 2017 and continued for a total of 11 months, through to February 2018. Sample collection at each site took place over a ~1-year period during the project, to account for the long-term and seasonal variations in source contributions to $PM_{2.5}$. Samples for source apportionment were collected daily (~4 days per week), over 24-h periods, primarily on weekdays, from 6 p.m. to 6 p.m. at Site A and from 6 a.m. to 6 a.m. at Site B. The samples were collected with $PM_{2.5}$ sampling equipment that had been used extensively in air quality measurement campaigns in the past (e.g. Challoner and Gill, 2014; Pilla and Broderick, 2015). The samples were collected following a strict sampling procedure as described in full in section 3.1.5 of the full final report (omitted from this synthesis for brevity).

Figure 2.1. A Google Earth satellite image showing the locations of the two fixed outdoor sampling sites marked with a red or green circle. Site A (red circle) was located south of the river, at a central location in a highly trafficked region in Dublin's city centre (193 Pearse Street, Dublin 2), whereas Site B (green circle) was located north of the river, at a residential location (Shandon Park, Phibsborough, Dublin 7). Maps data: Google © 2016.

In total, more than 250 samples were collected from these two fixed-site sampling locations.

After samples were collected onto filters and the filters were weighed and photographed, they were prepared for chemical analysis. This involved a portion of each filter, approximately 1 x 0.5 cm^2 in size, being cut out from the centre of each of the samples (Figure 2.2).

All chemical data were obtained using laser-ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) on a Photon Machines Inc. Analyte Excite 193-nm excimer ArF laser-ablation system with a HelEx 2-volume ablation cell coupled to a Thermo iCapQ quadrupole inductively coupled plasma mass spectrometer at the Department of Geology, Trinity College Dublin, Ireland. Thirty-seven isotopes (^{23}Na, ^{24}Mg, ^{27}Al, ^{29}Si, ^{31}P, ^{34}S, ^{35}Cl, ^{39}K, ^{43}Ca, ^{47}Ti, ^{51}V, ^{52}Cr, ^{55}Mn, ^{56}Fe, ^{60}Ni, ^{63}Cu, ^{66}Zn, ^{71}Ga, ^{73}Ge, ^{75}As, ^{77}Se, ^{79}Br, ^{85}Rb, ^{88}Sr, ^{95}Mo, ^{107}Ag, ^{111}Cd, ^{115}In, ^{118}Sn, ^{121}Sb, ^{125}Te, ^{137}Ba, ^{178}Hf, ^{202}Hg, ^{205}Tl, ^{208}Pb, ^{209}Bi) were acquired, with dwell times across the mass range kept constant at 0.02 seconds for each isotope. Full details of the chemical analysis conducted in the project are available in Chapter 3 of the final report.

The LA-ICP-MS method is well established within the geochemical community and widely accepted as a versatile low-blank method for ultra-trace element analysis (Sylvester and Jackson, 2016). It has a significant number of advantages over other analysis techniques and is also being applied to the analysis of aerosols and PM (e.g. Suzuki, 2006). The main strengths are that a full suite of trace metals can be analysed very rapidly and the method has very low detection limits, yielding precise and accurate data for elements present at parts per million (ppm) concentrations (e.g. Kamber *et al*., 2014). Conventional studies that have attempted to resolve diesel from petrol combustion PM have used multiple chemical analysis techniques for metals (e.g. energy-dispersive X-ray fluorescence – XRF-EDX; wavelength-dispersive X-ray fluorescence – XRF-WDS; particle-induced X-ray emission – PIXE; solution-based inductively coupled plasma optical emission spectroscopy – ICP-OES; and mass spectroscopy). This results in a significantly longer analytical processing time, a much higher cost, as well as a significantly lower number of resulting elements than the 37 recorded here. Moreover, the various methods have very different detection limits and uncertainties, resulting in the compilation of very complex datasets, as exemplified by the SPECIEUROPE database (Pernigotti *et al*., 2016). However, there are also four disadvantages to the LA-ICP-MS method:

1. It cannot determine several anions (e.g. N, F).
2. It cannot distinguish between different species of elements (e.g. between elemental sulfur and sulfate).

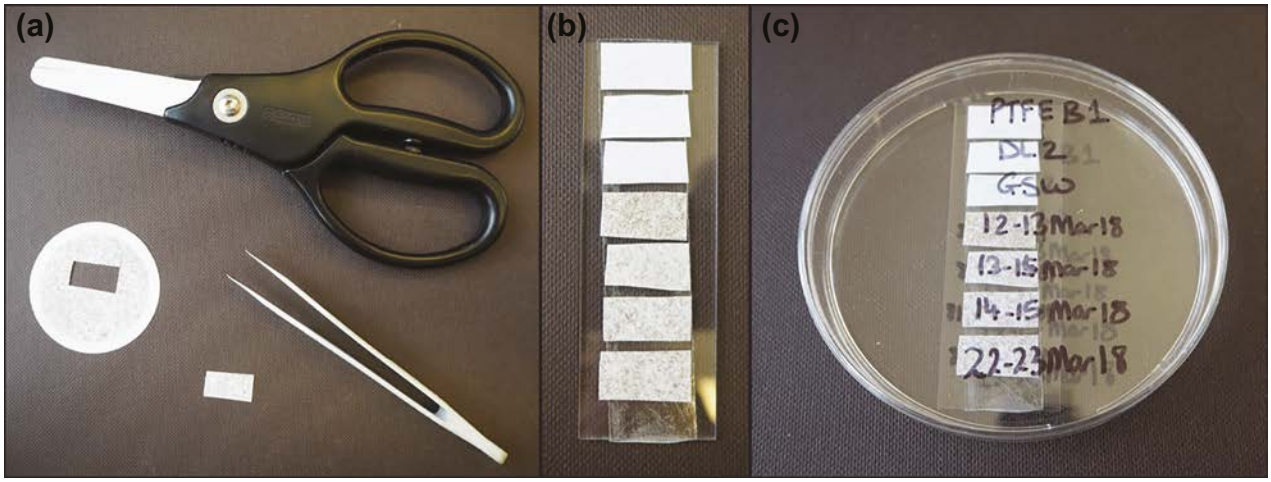

Figure 2.2. Filter preparation for chemical analysis. (a) A 1 × 0.5 cm^2 portion of filter was cut from each filter using clean ceramic scissors and plastic tweezers. (b) The filter portions were secured to a glass microscope slide using double sided tape. (c) The slides were labelled and stored in clean labelled Petri dishes.

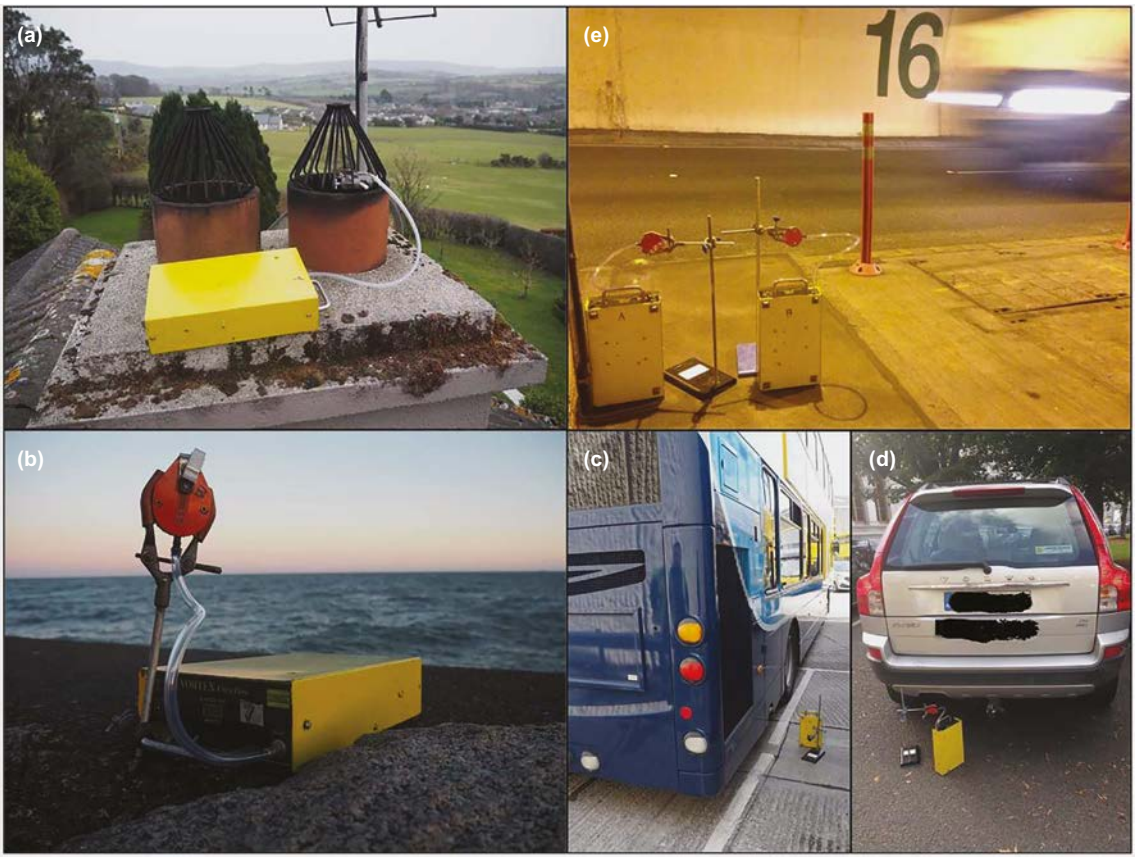

Figure 2.3. Direct $PM_{2.5}$ source sampling set-up. The typical set-up for sampling $PM_{2.5}$ sources, directly from source, using a conical inhalable sampler and a Casella Vortex Ultra Flow sampling pump. The $PM_{2.5}$ sources sampled include (a) solid fuel emissions, (b) sea spray, (c) Dublin Bus exhaust emissions, (d) passenger vehicle exhaust emissions and (e) traffic emissions from inside the Dublin Port Tunnel.

3. It requires the collection of PM on filters with little or no impurities in the filter material.
4. There are currently no certified reference materials with comparable chemistry to PM collected on typical and suitable filter materials.

A variety of direct $PM_{2.5}$ source samples were also collected, including sea spray samples from a variety of locations in Dublin Bay, exhaust emission samples from a variety of diesel and petrol passenger vehicles, exhaust emission samples from a representative selection of diesel vehicles in the Dublin Bus fleet, ambient traffic samples from inside the Dublin Port Tunnel and chimney emission samples from burning a variety of solid fuels commonly used for residential heating in Ireland (Figure 2.3).

3 Data Collection Results

For a 15-month period, from December 2016 to February 2018, 24-h $PM_{2.5}$ mass concentrations were monitored at Site A (city centre roadside). A total of 161 24-h samples were collected at this site. Eight of these samples were deemed invalid owing to sampling errors. Full details of the sampling dates, times, durations, mass concentrations and invalid samples are given in Appendix 1 of the final report. The mean 24-h $PM_{2.5}$ mass concentration that was recorded at this site during the 15-month sampling period was 36.9 µg/m³ (Figure 3.1). There was close agreement between the mean and the median $PM_{2.5}$ mass concentrations at this site, with the median value, which was 31.4 µg/m³, being within 5.5 µg/m³ of the mean value. A wide range of $PM_{2.5}$ mass concentrations was recorded at this monitoring site, with a maximum 24-h $PM_{2.5}$ mass concentration of 129.5 µg/m³ and a minimum 24-h $PM_{2.5}$ mass concentration of 4.8 µg/m³ (Figure 3.1).

For an 11-month period, from March 2017 to February 2018, 24-h $PM_{2.5}$ mass concentrations were monitored at Site B (urban residential neighbourhood). A total of 109 24-h samples were collected at this site and, of these, five were deemed invalid as a result of sampling errors. Full details of the sampling dates, times, durations, mass concentrations and rejected/invalid samples are given in Appendix 1 of the final report.

The mean 24-h $PM_{2.5}$ mass concentration that was recorded at this site during the sampling period was 8.1 µg/m³ (Figure 3.2). There was close agreement between the mean and median $PM_{2.5}$ mass concentrations at this site, with the median value, which was 7.2 µg/m³, being within 1 µg/m³ of the mean value. A much narrower range of $PM_{2.5}$ mass concentrations were recorded at this monitoring site than at Site A, with a maximum 24-h $PM_{2.5}$ mass concentration of 30.1 µg/m³ and a minimum of 0.8 µg/m³ (Figure 3.2).

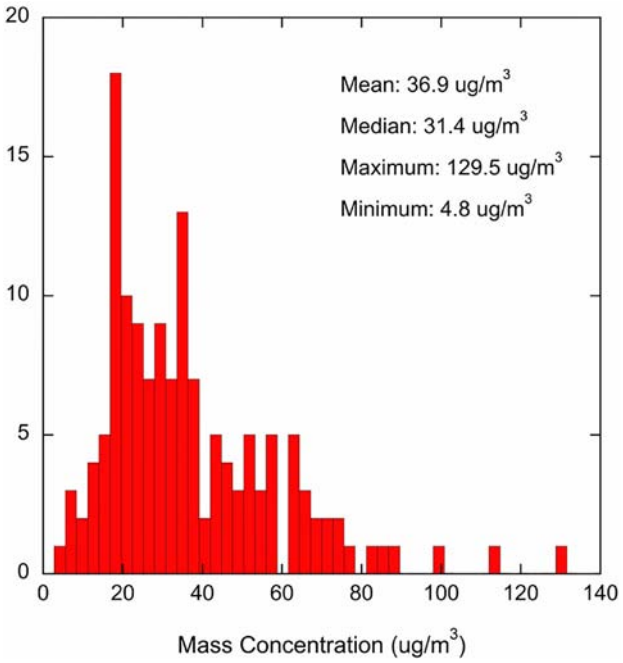

Figure 3.1. Histogram of 24-h $PM_{2.5}$ mass concentrations recorded at Site A, a busy, heavily trafficked roadside location at 193 Pearse Street in Dublin's city centre, during a 15-month period, from December 2016 to February 2018.

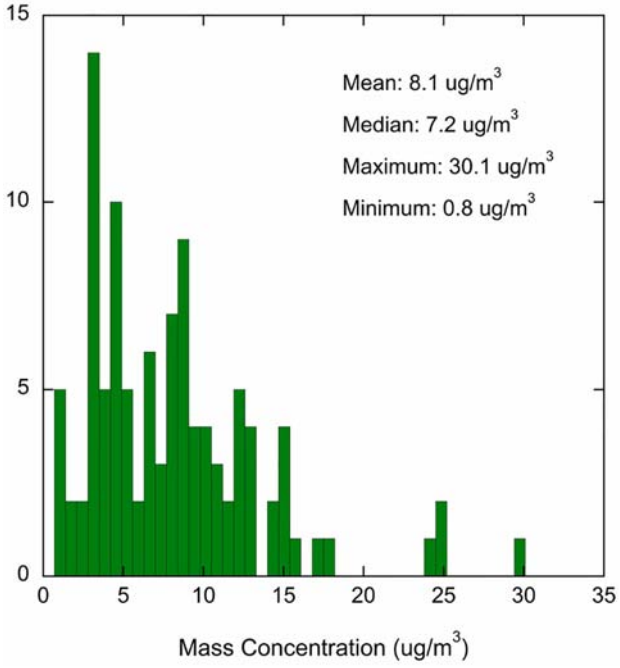

Figure 3.2. Histogram of 24-h $PM_{2.5}$ mass concentrations recorded at Site B, an urban, residential location at Shandon Park, Phibsborough, Dublin 7, during an 11-month period, from March 2017 to February 2018.

Figures 3.3 and 3.4 show comparisons of the ranges of $PM_{2.5}$ concentrations observed during 2016 at three Environmental Protection Agency (EPA) $PM_{2.5}$ monitoring sites in Dublin – Finglas, Coleraine Street and Rathmines – with data collected in this project at the roadside location on Pearse Street in Dublin's city centre (Site A) and the residential location in Phibsborough, Dublin 7 (Site B). The range of $PM_{2.5}$ concentrations observed at Site B was within the ranges of concentrations observed at the three EPA $PM_{2.5}$ monitoring sites for both the winter and summer months. However, the range of $PM_{2.5}$ concentrations observed at Site A far exceeded the ranges of concentrations observed at the three EPA $PM_{2.5}$ monitoring sites.

The annual mean $PM_{2.5}$ concentration levels monitored by the EPA in Ireland are consistently below both the stage 1 and stage 2 EU Clean Air for Europe (CAFE) Directive (Directive 2008/50/EC) limit values of 25 µg/m^3 and 20 µg/m^3, respectively (EU, 2008). However, the World Health Organization (WHO) has proposed $PM_{2.5}$ concentration level guideline values of an annual mean value of 10 µg/m^3 and a 24-h mean value of 25 µg/m^3 (WHO, 2005). In Ireland, although annual mean $PM_{2.5}$ concentration levels at EPA monitoring sites to date have been below the EU limit values, concentration levels have often been above the WHO annual mean guideline value. The annual mean $PM_{2.5}$ concentration level that was recorded at Site A was 36.9 µg/m^3 (Figure 3.1), which is well above both the two EU CAFE Directive limit values and the WHO annual mean guideline value.

The differences between Site A and all other monitoring stations gives rise to concerns about the representativeness of these concentrations of the general urban air quality in Dublin. After the completion of this research project, an additional monitoring station was installed at Pearse Street at a location close to Site A, and it recorded concentrations in the range of 3.4–28.5 µg/m^3 with an average of 11.2 µg/m^3 during the period 1 November 2019 to 29 January 2020.

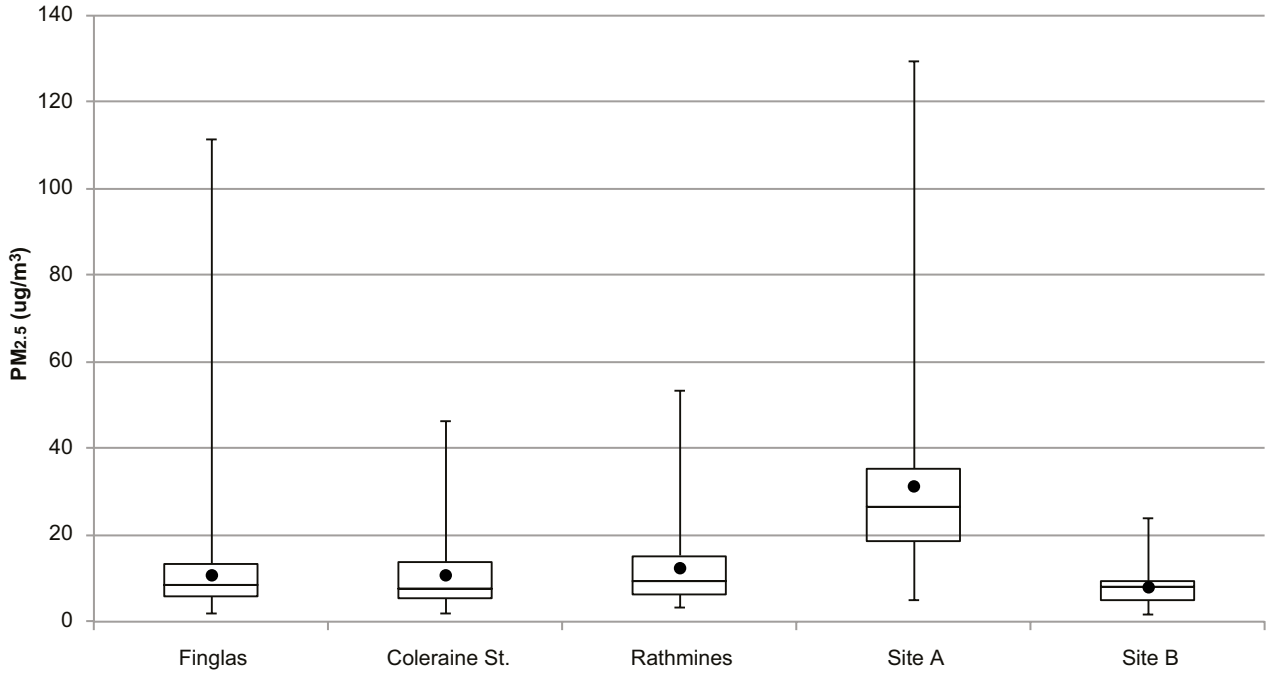

Figure 3.3. A comparison of the range of winter (October–March) $PM_{2.5}$ concentrations observed at three EPA $PM_{2.5}$ monitoring sites in Dublin during 2016, with the $PM_{2.5}$ concentrations observed at Sites A and B.

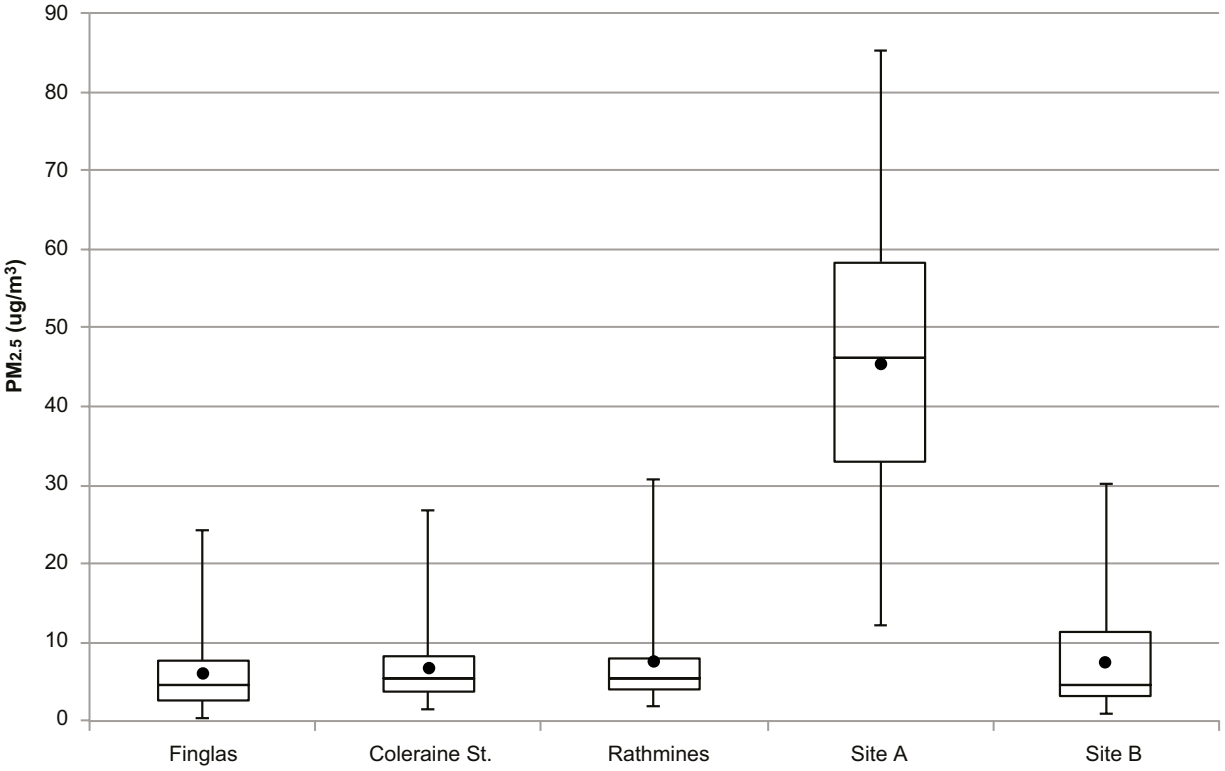

Figure 3.4. A comparison of the range of summer (April–September) $PM_{2.5}$ concentrations observed at three EPA $PM_{2.5}$ monitoring sites in Dublin during 2016, with the $PM_{2.5}$ concentrations observed at Sites A and B.

4 Source Apportionment

4.1 Positive Matrix Factorisation Modelling

A PMF model is a receptor model used in source apportionment studies. Recently, it has been used widely for the source apportionment of PM all around the world (e.g. Yatkin and Bayram, 2008; Hasheminassab *et al*., 2014; Dall'Osto *et al*., 2014). PMF was utilised here to quantify sources of ambient $PM_{2.5}$ in the GDA, using data collected between 2016 and 2018.

Time-integrated 24-h $PM_{2.5}$ samples were also collected in parallel on 47-mm-diameter, 2-µm pore size Teflon membrane filters (Teflo, Pall Gelman Sciences, MI, USA). These Teflon $PM_{2.5}$ samples were chemically analysed and the concentrations of 37 isotopes (^{23}Na, ^{24}Mg, ^{27}Al, ^{29}Si, ^{31}P, ^{34}S, ^{35}Cl, ^{39}K, ^{43}Ca, ^{47}Ti, ^{51}V, ^{52}Cr, ^{55}Mn, ^{56}Fe, ^{60}Ni, ^{63}Cu, ^{66}Zn, ^{71}Ga, ^{73}Ge, ^{75}As, ^{77}Se, ^{79}Br, ^{85}Rb, ^{88}Sr, ^{95}Mo, ^{107}Ag, ^{111}Cd, ^{115}In, ^{118}Sn, ^{121}Sb, ^{125}Te, ^{137}Ba, ^{178}Hf, ^{202}Hg, ^{205}Tl, ^{208}Pb, ^{209}Bi) were acquired. These data are available in Table 5.2 of the end-of-project Technical Report. The chemical composition of PM measured at a receptor site can be used to estimate the relative contribution of major sources to total PM mass.

PMF modelling identified five significant sources, i.e. >0.05% total $PM_{2.5}$ mass concentration (µg/m^3), at both Site A and Site B. The contributions of these five significant $PM_{2.5}$ sources are shown in Figure 4.1, and the relative and absolute contributions of the sources to the total $PM_{2.5}$ load at each site are summarised in Table 4.1. The source profiles and the percentage of species apportioned to each of the five significant sources at Sites A and B are respectively shown in Figures 5.3 and 5.4 of the end-of-project Technical Report. The five significant sources identified by the PMF model were sea spray, soil, road dust, an Ni-rich source and a combustion source. The PMF model was therefore successful in distinguishing combustion sources from non-combustion sources and was particularly successful in resolving three distinct, non-combustion sources of $PM_{2.5}$ (sea spray, soil and road dust). However, PMF modelling was unsuccessful in directly resolving distinct combustion sources of $PM_{2.5}$, instead identifying a single indistinct combustion source, which is the most significant contributor to

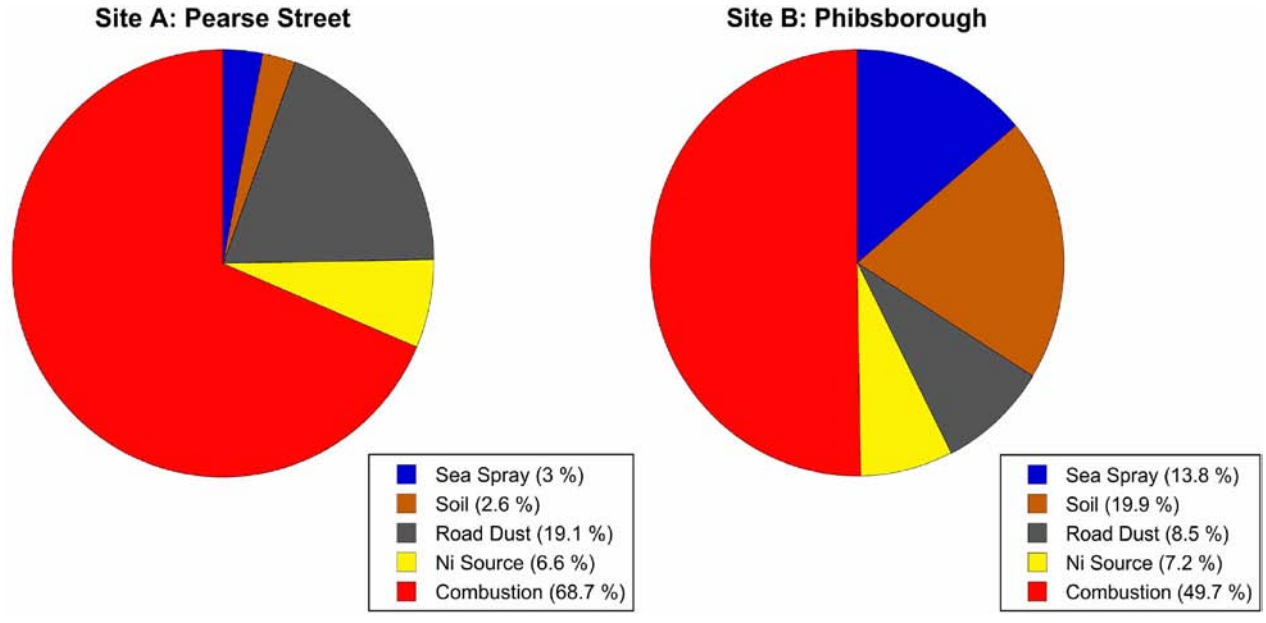

Figure 4.1. The percentage contributions of the five significant sources of $PM_{2.5}$ derived from PMF at Sites A and B.

Table 4.1. The relative contributions and the absolute contributions of the five significant $PM_{2.5}$ sources derived from PMF at Sites A and B

	Site A: Pearse Street		Site B: Phibsborough	
$PM_{2.5}$ source	Relative contribution (%)	Absolute contribution ($\mu g/m^3$)	Relative contribution (%)	Absolute contribution ($\mu g/m^3$)
Sea spray	3.0	1.1	13.8	1.1
Soil	2.6	0.9	19.9	1.6
Road dust	19.1	7.1	8.5	0.7
Ni source	6.6	2.4	7.2	0.6
Combustion	68.7	25.4	49.7	4.0

$PM_{2.5}$ in terms of mass, and a poorly resolved Ni-rich source.

The PMF model was successful only at distinguishing non-combustion sources from combustion sources (Table 4.1), and this is likely to be related to the element carbon. Carbon is the dominant chemical species present in combustion-related $PM_{2.5}$ sources, which include both diesel and petrol exhaust emissions and emissions from burning solid fuel, and is present at very high concentrations, thus making a very significant contribution to total $PM_{2.5}$ in terms of mass concentration. Conversely, the characteristic chemical species identifying combustion-related $PM_{2.5}$ sources, which were identified in this study through the direct sampling of these sources, are trace metals that are present at very low concentrations, thus making a very insignificant contribution to total $PM_{2.5}$ in terms of mass concentration. This study was originally designed to focus on trace element analysis of $PM_{2.5}$ samples, because it was the trace elements that showed the greatest promise in terms of distinguishing carbon-rich combustion-related $PM_{2.5}$ sources from one another. For example, trace element species such as Ni, Cr, Cu, Zn, Se and Hg were identified as key diagnostic species for resolving distinct PMF combustion source profiles including diesel and petrol exhaust emissions and emissions from burning solid fuel. However, because the major, mass-contributing components of $PM_{2.5}$ such as elemental carbon, organic carbon (OC), sulfate, nitrate and ammonium ions were not measured, and because the trace elements analysed made an insignificant contribution to total $PM_{2.5}$ in terms of mass concentration, the PMF model was not able to fully resolve the major carbon and mass-bearing $PM_{2.5}$ combustion sources.

4.2 Indirect Estimation of Diesel Contribution

Because our approach was unsuccessful in directly resolving discrete combustion-related $PM_{2.5}$ sources via PMF, it was necessary to indirectly deduce the contributions of the primary combustion sources of $PM_{2.5}$ in Dublin, including motor vehicle exhaust emissions, from both diesel and petrol vehicles, and emissions from burning solid fuel, using the EPA's national air pollutant inventory report (EPA, 2017). This national air pollutant inventory report (EPA, 2017) shows that, in terms of the total road transport sector, non-exhaust emissions (automobile tyre and brake wear and automobile road abrasion) account for 43% of total road transport sector $PM_{2.5}$ emissions. The primary combustion sources of $PM_{2.5}$ in Dublin include motor vehicle exhaust emissions from both diesel and petrol vehicles (e.g. Giblin and McNabola, 2009; Alam and McNabola, 2015), along with emissions from burning solid fuel (e.g. Healy *et al*., 2010; Kourtchev *et al*., 2011; Dall'Osto *et al*., 2014; Lin *et al*., 2017). Instead of distinguishing distinct combustion sources of $PM_{2.5}$, the PMF model resolved one large combustion source, which was the most significant $PM_{2.5}$ source in terms of the contribution to mass concentration, along with a Ni-rich source, which is also combustion related and most likely represents only a portion of the total $PM_{2.5}$ from exhaust emissions. The contributions from both the PMF-resolved combustion and Ni-rich sources were combined and are referred to as the combustion total, and on an average basis this combustion total source accounted for 75.3% and 56.9% of ambient $PM_{2.5}$ at Sites A and B, respectively.

These proportions of road transport sector non-exhaust and exhaust emissions from the EPA's

national air pollutant inventory were used to indirectly deduce the contribution of exhaust emissions from the non-combustion-related road dust PMF-resolved $PM_{2.5}$ source contributions at each site. These indirectly deduced exhaust emission contributions were subtracted from the total combustion contributions in order to indirectly deduce the total contribution of $PM_{2.5}$ from burning solid fuels at each site (Table 4.2).

The contributions of these indirectly deduced exhaust emissions accounted for 25.3% and 11.2% of ambient $PM_{2.5}$ at Sites A and B, respectively, whereas the contributions of the indirectly deduced solid fuel emissions accounted for 50.0% and 45.7% of ambient $PM_{2.5}$ at Sites A and B, respectively. In turn, the relative contributions of the three major fuel types to total road transport sector $PM_{2.5}$ exhaust emissions were used to indirectly deduce the diesel and petrol exhaust emission contributions to ambient $PM_{2.5}$ at each site. The contributions of the indirectly deduced diesel exhaust emissions accounted for 22.1% and 9.8% of ambient $PM_{2.5}$ at Sites A and B, respectively, whereas the contributions of the indirectly deduced petrol exhaust emissions accounted for 3.2% and 1.4% of ambient $PM_{2.5}$ at Sites A and B, respectively.

It must be noted that there are limitations associated with the indirect approach using the EPA's national air pollutant inventory report (EPA, 2017) to deduce the contributions of exhaust emissions. First, the EPA emissions inventory is based on established/published emission factors and these may not be fully representative of real-world emissions in Dublin. Emission factors commonly result in conservative estimates of average emissions from classes of vehicle for urban or rural driving conditions. Furthermore, the EPA's national air pollutant inventory report (EPA, 2017) provides an estimation of emissions for all of Ireland and may not be fully representative of $PM_{2.5}$ emissions in Dublin city. For example, the contribution of heavy goods vehicles (HGVs) to emissions in Dublin may differ from the national average. Similarly, more mopeds, motorcycles and buses may be responsible for greater $PM_{2.5}$ emissions in Dublin city than in Ireland as a whole. However, as the PMF model provides a single estimate of the percentage contribution of a given source based on daily average concentrations of species across a full year or more, the short-term variations in the contributions of these sources are less important and the use of the average inventory estimates are appropriate for the resolution of the PMF output.

Table 4.2. The relative contributions at Sites A and B of non-combustion $PM_{2.5}$ sources (sea spray, soil and road dust), derived from PMF modelling, and combustion $PM_{2.5}$ sources (diesel, petrol and solid fuel), indirectly deduced using data from the EPA's national air pollutant inventory report (EPA, 2017)

$PM_{2.5}$ source	Site A: Pearse Street	Site B: Phibsborough
	Relative contribution (%)	Relative contribution (%)
Sea spray	3.0	13.8
Soil	2.6	19.9
Road dust	19.1	8.5
Diesel	22.1	9.8
Petrol	3.2	1.4
Solid fuel	50.0	45.7

4.3 Comparison with Other Source Apportionment Methods

As a validation of the results of the PMF model, source apportionment was also carried out using the chemical mass balance (CMB) approach (see the end-of-project Technical Report for details of the methodology). Table 4.3 shows the level of agreement between the two methodologies.

The ultimate aim of this project was to assess the impact of diesel emissions on the population's exposure to $PM_{2.5}$. However, neither the PMF model nor the CMB model was successful in resolving the contribution of a diesel source to ambient $PM_{2.5}$. However, the diesel emission contribution to ambient $PM_{2.5}$ at Sites A and B can be indirectly estimated from

Table 4.3. The relative contributions of the significant $PM_{2.5}$ sources derived from CMB and PMF modelling at Sites A and B

$PM_{2.5}$ source	Site A: Pearse Street		Site B: Phibsborough	
	PMF (%)	CMB (%)	PMF (%)	CMB (%)
Sea spray	3.0	2.4	13.8	5.6
Soil	2.6	3.5	19.9	3.1
Cement[a]	–	9.2	–	9.1
Road dust	19.1	11.0	8.5	6.8
Exhausts	25.3	40.2	11.2	7.2
Solid fuel	50.0	33.8	45.7	43.4

[a]**Not predicted by PMF method.**

the contribution of exhaust emissions using the relative contributions of the major fuel types to total road transport sector $PM_{2.5}$ exhaust emissions provided in the EPA's national air pollutant inventory report (EPA, 2017). Thus, we were able to indirectly deduce the contributions of diesel exhaust emissions to ambient $PM_{2.5}$ at each site (Table 4.4). These indirectly deduced contributions of diesel exhaust emissions accounted for 28.6% ± 6.5% and 8.1% ± 1.8% of ambient $PM_{2.5}$ at Sites A and B, respectively.

Table 4.4. The relative contributions of $PM_{2.5}$ from diesel and petrol exhaust emissions derived from both PMF and CMB source apportionment models at Sites A and B

	Site A: Pearse Street		Site B: Phibsborough	
$PM_{2.5}$ source	PMF (%)	CMB (%)	PMF (%)	CMB (%)
Diesel	22.1	35.1	9.8	6.3
Petrol	3.2	5.1	1.4	0.9

5 Exposure Model and Health Impact

5.1 Introduction

LUR modelling is a powerful yet relatively simple technique for the modelling of air pollution on a city scale. In the present study, we aimed to develop and validate a LUR model for $PM_{2.5}$ concentrations in Dublin. This model was designed to overcome the limitations of previous LUR models developed in other cities. Specifically, we have applied the following:

- mobile- and fixed-station data to the LUR model to increase spatial variability;
- alternative non-linear problem formulations to improve the accuracy of the model's predictions; and
- a systematic approach to the selection of appropriate buffer lengths for predictor variables.

The present LUR model combines long-term fixed-station data with short-term mobile-station data. These data were used to augment the limited set of statutory long-term fixed-site monitors available in Dublin for the purposes of LUR model development. In a further attempt to improve model performance, the study develops a weighted support vector regression (SVR)-based LUR model to quantify the non-linear relationship between the set of predictors and the air pollution concentration. The study introduces a weight function to account for uncertainty in different types of data on account of the variation in record lengths between long-term and short-term, and fixed- and mobile-station data. The study also introduces a systematic approach to the selection of buffer distance optimisation.

In addition, this chapter describes the application of the LUR model concentrations developed to quantifying the health impact of $PM_{2.5}$ in Dublin using a disability-adjusted life year (DALY) approach. This health impact assessment required the determination of the proportion of the total PM concentration from diesel vehicle emissions, obtained from the LUR model. This study estimates the expected mortality and the DALYs lost as a result of exposure to $PM_{2.5}$ in the study area.

5.2 Methodology and Input Data

A full description of the methodologies and input data used in the development of the LUR model and the health impact assessment are available in the end-of-project Technical Report.

5.3 Land Use Regression Model Results

A total of 14 sets of LUR models were developed, comparing the use of fixed-site and mobile-station data, and comparing a number of linear and non-linear approaches to the LUR formulation. These approaches included (1) standard ordinary least squares multiple linear regression (OLS-MLR); (2) weighted least squares multiple linear regression (WLS-MLR), where a weighting was applied to the reliability of the air quality data, reflecting the record lengths; (3) SVR, a non-linear approach; and (4) weighted SVR (W-SVR), again accounting for differing record lengths. The data were also divided into winter and summer periods. Non-linear approaches were believed to be able to explain the relationships between air quality and its predictor variables more reliably than linear approaches.

The performance/error measures – bias, abias, root mean square error (RMSE) and coefficient of determination (R^2) – are provided in Table 5.1 for winter and summer seasons, for both sets of data and for all four types of models (OLS-MLR, WLS-MLR, SVR and W-SVR).

5.4 Land Use Regression Model Discussion

The model performance measures provided in Table 5.1 indicate that the use of a combination of fixed-site and mobile-station data improves model performance significantly. Another important observation is that a non-linear SVR equation-based LUR performs better than a multiple linear regression-based LUR model. It can also be noted that there is an improvement in model performance when different weights are provided for fixed-site and mobile-station data. For both summer

Table 5.1. Performance measure of developed LUR models in leave-one-out cross-validation framework for winter and summer seasons

	Model	Bias	Abias	RMSE	R^2
Winter					
Set A: FS	OLS-MLR	–6.65	6.65	7.00	–5.164
	WLS-MLR	–10.52	10.52	12.59	–1.988
	SVR	–1.56	4.10	7.01	0.072
	W-SVR	–1.22	2.46	4.63	0.595
Set B: FS + MS	OLS-MLR	–0.80	2.58	3.19	0.219
	WLS-MLR	2.09	3.46	4.30	–0.420
	SVR	–0.50	1.13	1.61	0.802
	W-SVR	–0.32	0.66	1.07	0.912
Summer					
Set A: FS	OLS-MLR	–2.08	3.95	9.03	0.216
	WLS-MLR	–1.21	3.76	8.56	0.295
	SVR	–1.97	2.98	8.31	0.336
	W-SVR	–1.96	2.93	8.24	0.348
Set B: FS + MS	OLS-MLR	–1.54	2.99	3.95	0.688
	WLS-MLR	–1.31	2.97	3.90	0.695
	SVR	–1.22	1.90	2.96	0.824
	W-SVR	–0.73	1.25	2.05	0.916

FS, fixed site; MS, mobile site.

and winter seasons, the best fitted model is the W-SVR model developed by considering both fixed-site and mobile-station datasets. However, based on the bias, it was found that the models developed (except the OLS-MLR-based LUR model in the winter season) underpredicted the $PM_{2.5}$ concentration by a small amount.

The spatial variation in $PM_{2.5}$ concentrations obtained using the observed data and W-SVR model are plotted for comparison in Figure 5.1. The spatial variability was interpolated by using the spline interpolation technique, where the station data were the basis for interpolation. The difference between predicted and observed $PM_{2.5}$ concentrations is very low, and the W-SVR-based LUR model can be used to obtain $PM_{2.5}$ concentrations at any spatial location inside the city. The difference in maximum values of $PM_{2.5}$ concentrations was found to be less than 1 µg/m^3 (< 7.5%) for the winter months and less than 4 µg/m^3 (< 8%) for the summer months.

It should be noted that the results obtained based on the developed non-linear model with different weightages applied to station data based on their record length are considerably better than those obtained by other studies using the conventional LUR model.

5.5 Health Impact Results and Discussion

5.5.1 $PM_{2.5}$ health impact in Dublin

The spatial variation in $PM_{2.5}$ concentrations obtained using the W-SVR model was used to estimate the environmental burden of disease in terms of mortality due to long-term exposure, corresponding to mortality caused by cardiopulmonary disease and lung cancer. To estimate the relative risk, the target/threshold $PM_{2.5}$ concentrations were considered to be 5 µg/m^3, as per WHO guidelines (WHO, 2013). The expected number of deaths and the expected death rates for cardiopulmonary disease and lung cancer corresponding to different Dublin divisions (divisions 0 to 15 – not postcodes) for the winter and summer months are provided in Table 5.2.

In order to estimate the DALYs lost as a result of cardiopulmonary disease and lung cancer, the

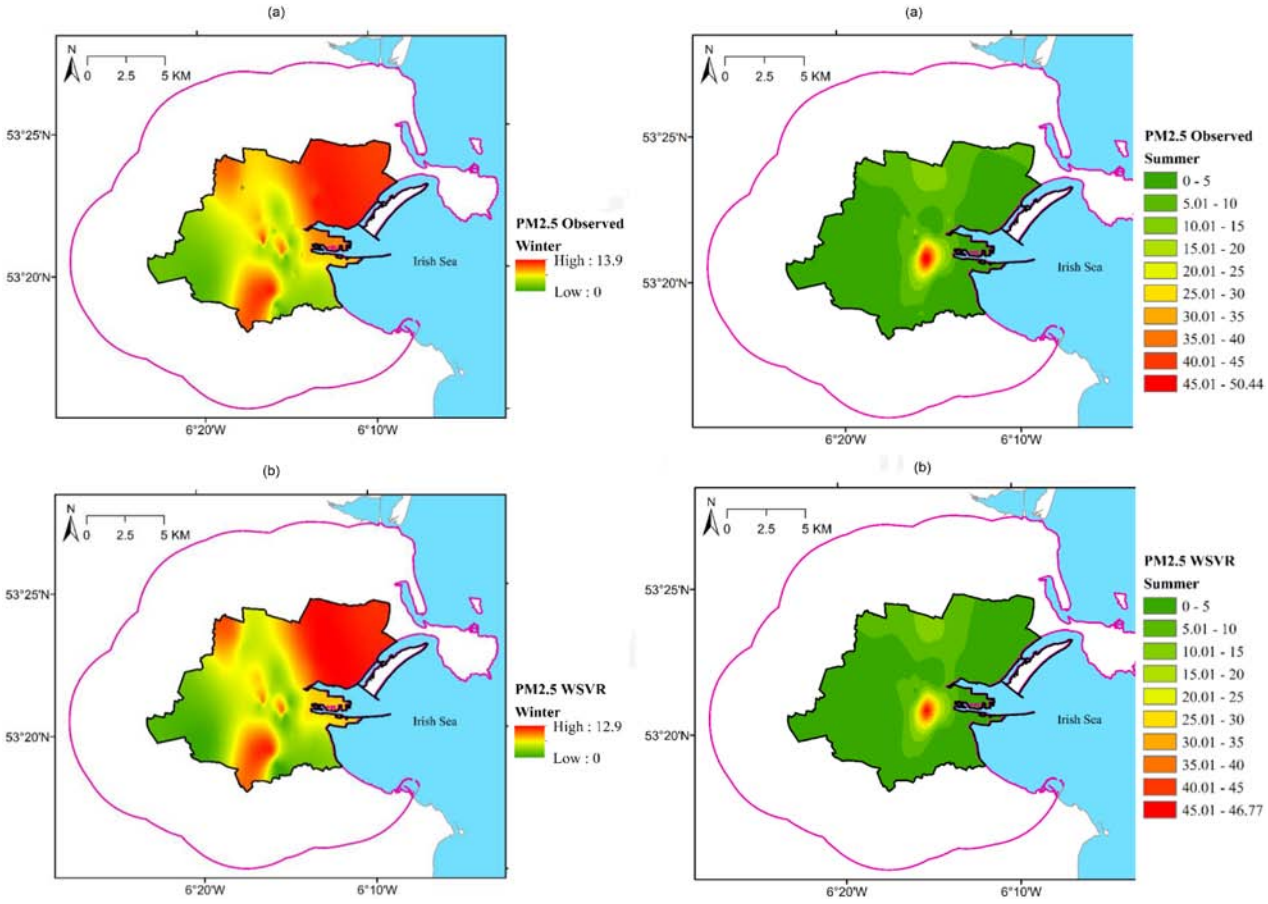

Figure 5.1. Spatial variation in $PM_{2.5}$ concentrations obtained using (a) observed data and (b) W-SVR-predicted data for winter and summer months.

years of life lost as a result of premature mortality (YLLs) and the years lived with disability (YLDs) need to be evaluated separately. To estimate the YLLs for different age groups, the number of deaths and the population in Dublin are required. The populations corresponding to different age groups in Dublin were obtained from the Census 2011 database (https://www.cso.ie/en/census/census2011smallareapopulationstatisticssaps/). Data on the number of deaths for different age groups were available for Ireland from the Central Statistics Office (CSO), but were not available for the study area. Estimates of the number of deaths due to diseases of the circulatory system (cardiopulmonary disease) and the respiratory system (lung cancer) for different age groups in the study area were estimated by using the same rate as for Ireland. The estimated YLLs because of diseases of the circulatory and respiratory systems are provided in Table 5.3.

Estimation of YLDs using the approach described in section 6.2.5 of the end-of-project Technical Report requires data on the number of incident cases of circulatory and respiratory system diseases in Dublin. As these data were not available for Ireland, estimates were obtained from the Global Health Estimates 2016 summary table prepared by the WHO (http://www.who.int/healthinfo/global_burden_disease/en/). The estimates of YLDs and DALYs for different age groups resulting from circulatory and respiratory system diseases in Dublin are provided in Table 5.4.

5.5.2 Diesel $PM_{2.5}$ health impact in Dublin

Table 5.5 summarises the overall estimated impact of the LUR-predicted $PM_{2.5}$ concentrations on health across Dublin, in terms of DALYs lost and expected number of deaths. Using the results of the source apportionment PMF study, Table 5.5 also summarises the resulting health impacts of diesel $PM_{2.5}$ concentrations, considering that diesel vehicles were shown to contribute 10–20% of the total $PM_{2.5}$ mass concentration in Dublin.

Table 5.2. Expected deaths from cardiopulmonary disease and lung cancer due to long-term exposure to $PM_{2.5}$, obtained by considering 5 µg/m³ as the threshold $PM_{2.5}$ concentration in winter and summer months in Dublin

			Cardiopulmonary mortality and long-term exposure to $PM_{2.5}$				Lung cancer mortality and long-term exposure to $PM_{2.5}$			
$PM_{2.5}$	Division	Population	Risk factor	IF	Expected deaths (*n*)	Expected death rate (%)	Risk factor	IF	Expected deaths (*n*)	Expected death rate (%)
Winter										
6.7	0	22,994	1.039	0.037	7	0.03	1.059	0.055	4	0.02
6.6	1	42,247	1.037	0.035	13	0.03	1.055	0.052	7	0.02
7.1	2	21,423	1.048	0.046	8	0.04	1.073	0.068	5	0.02
5.9	3	50,183	1.022	0.022	9	0.02	1.034	0.033	5	0.01
5.5	4	138,143	1.013	0.013	15	0.01	1.020	0.020	9	0.01
9.1	5	51,760	1.084	0.078	34	0.07	1.129	0.114	19	0.04
5.0	6	52,367	0.999	0.000	0	0.00	0.999	0.000	0	0.00
5.1	7	52,979	1.003	0.003	1	0.00	1.005	0.005	1	0.00
5.1	8	18,904	1.003	0.003	1	0.00	1.005	0.005	0	0.00
6.2	9	160,974	1.029	0.028	38	0.02	1.044	0.042	22	0.01
1.7	10	71,614	0.884	0.000	0	0.00	0.832	0.000	0	0.00
2.0	11	67,130	0.900	0.000	0	0.00	0.854	0.000	0	0.00
2.7	12	97,656	0.928	0.000	0	0.00	0.894	0.000	0	0.00
12.6	13	133,254	1.136	0.120	133	0.10	1.210	0.174	73	0.06
11.4	14	83,164	1.120	0.107	75	0.09	1.185	0.156	42	0.05
8.8	15	57,768	1.079	0.073	36	0.06	1.120	0.107	20	0.03
					Total: 372				**Total: 207**	
Summer										
3.3	0	22,994	0.948	0.000	0	0.00	0.923	0.000	0	0.00
5.7	1	42,247	1.017	0.016	6	0.01	1.025	0.024	3	0.01
12.9	2	21,423	1.139	0.122	22	0.10	1.215	0.177	12	0.06
1.7	3	50,183	0.881	0.000	0	0.00	0.828	0.000	0	0.00
4.4	4	138,143	0.985	0.000	0	0.00	0.977	0.000	0	0.00
4.3	5	51,760	0.982	0.000	0	0.00	0.973	0.000	0	0.00
0.8	6	52,367	0.830	0.000	0	0.00	0.756	0.000	0	0.00
2.9	7	52,979	0.936	0.000	0	0.00	0.906	0.000	0	0.00
25.1	8	18,904	1.257	0.204	32	0.17	1.407	0.289	18	0.09
3.3	9	160,974	0.951	0.000	0	0.00	0.928	0.000	0	0.00
1.9	10	71,614	0.895	0.000	0	0.00	0.847	0.000	0	0.00
1.9	11	67,130	0.891	0.000	0	0.00	0.841	0.000	0	0.00
0.2	12	97,656	0.777	0.000	0	0.00	0.686	0.000	0	0.00
4.5	13	133,254	0.988	0.000	0	0.00	0.982	0.000	0	0.00
3.4	14	83,164	0.953	0.000	0	0.00	0.931	0.000	0	0.00
8.4	15	57,768	1.072	0.067	33	0.06	1.109	0.098	18	0.03
					Total: 93				**Total: 51**	

IF, impact fraction.

5.5.3 Impacts of omitting Pearse Street data on land use regression model results

As highlighted previously, in Chapter 4, $PM_{2.5}$ concentrations recorded at Pearse Street were considerably higher than at all other monitoring stations and therefore may not be representative of typical air quality in urban areas of Dublin. Figure 5.2 illustrates the impacts of re-running the LUR modelling

Table 5.3. Estimates of YLLs as a result of circulatory and respiratory system diseases in Dublin

			Diseases of the circulatory system			Diseases of the respiratory system		
Age group (years)	Population	L (years)	Deaths (*n*)	YLLs	YLLs/capita	Deaths (*n*)	YLLs	YLLs/capita
0–4	30,250	83	89	2720.7	0.090	33	1008.8	0.033
5–14	49,779	75.5	18	537.7	0.011	7	209.1	0.004
15–24	76,620	65.5	62	1777.0	0.023	24	687.9	0.009
25–34	119,300	55.5	125	3378.4	0.028	47	1270.3	0.011
35–44	76,790	45.5	205	5088.2	0.066	78	1936.0	0.025
45–54	61,202	35.5	427	9326.7	0.152	163	3560.3	0.058
55–64	47,181	25.5	863	15,380.6	0.326	329	5863.5	0.124
65–74	34,892	15.5	1593	19,746.0	0.566	606	7511.7	0.215
75–84	23,705	5.5	2607	13,218.0	0.558	993	5034.7	0.212
85+	7893	0	2910	0.0	0.000	1108	0.0	0.000
Total	527,612	–	8899	71,173.3	1.820	3388	27082.3	0.691

L, the number of years remaining in the expected lifetime of the age groups (not applicable for the overall totals).

Table 5.4. Estimates of YLDs and DALYs lost as a result of circulatory and respiratory system diseases in Dublin

		Diseases of the circulatory system per capita			Diseases of the respiratory system per capita		
Age group (years)	Population	YLLs	YLDs	DALYs lost	YLLs	YLDs	DALYs lost
0–4	30,250	0.090	0.011	0.101	0.033	0.000	0.033
5–14	49,779	0.011	0.043	0.054	0.004	0.000	0.004
15–24	76,620	0.023	0.170	0.193	0.009	0.001	0.01
25–34	119,300	0.028	0.747	0.775	0.011	0.014	0.025
35–44	76,790	0.066	1.324	1.39	0.025	0.028	0.053
45–54	61,202	0.152	1.617	1.769	0.058	0.057	0.115
55–64	47,181	0.326	2.685	3.011	0.124	0.139	0.263
65–74	34,892	0.566	6.420	6.986	0.215	0.135	0.35
75–84	23,705	0.558	9.379	9.937	0.212	0.078	0.29
85+	7893	0.000	0.000	9.379	0.000	0.000	0.000
Total	527,612	1.820	22.396	24.216	0.693	0.452	1.145

Table 5.5. Summary of the estimated health impact of total $PM_{2.5}$ and diesel $PM_{2.5}$ in Dublin

Health impact measure	Total $PM_{2.5}$	Diesel $PM_{2.5}$
Cardiopulmonary mortality	465 expected deaths	46–93 expected deaths
Lung cancer mortality	258 expected deaths	25–51 expected deaths
DALYs: circulatory system	24.216 years	2.42–4.84 years
DALYs: respiratory system	1.145 years	0.11–0.23 years

exercise without the inclusion of the Pearse Street data from Site A and with the inclusion of some data from the EPA's new monitoring station at this location. Running the LUR models without the inclusion of Pearse Street data resulted in a small improvement in the accuracy of the predictions using the multiple linear regression approaches in general. However, all of these remain inferior to the W-SVR approach, which resulted in no notable change in predictive performance with this omission.

The new data were collected in the winter period (from 1 November 2019 to 29 January 2020) from the

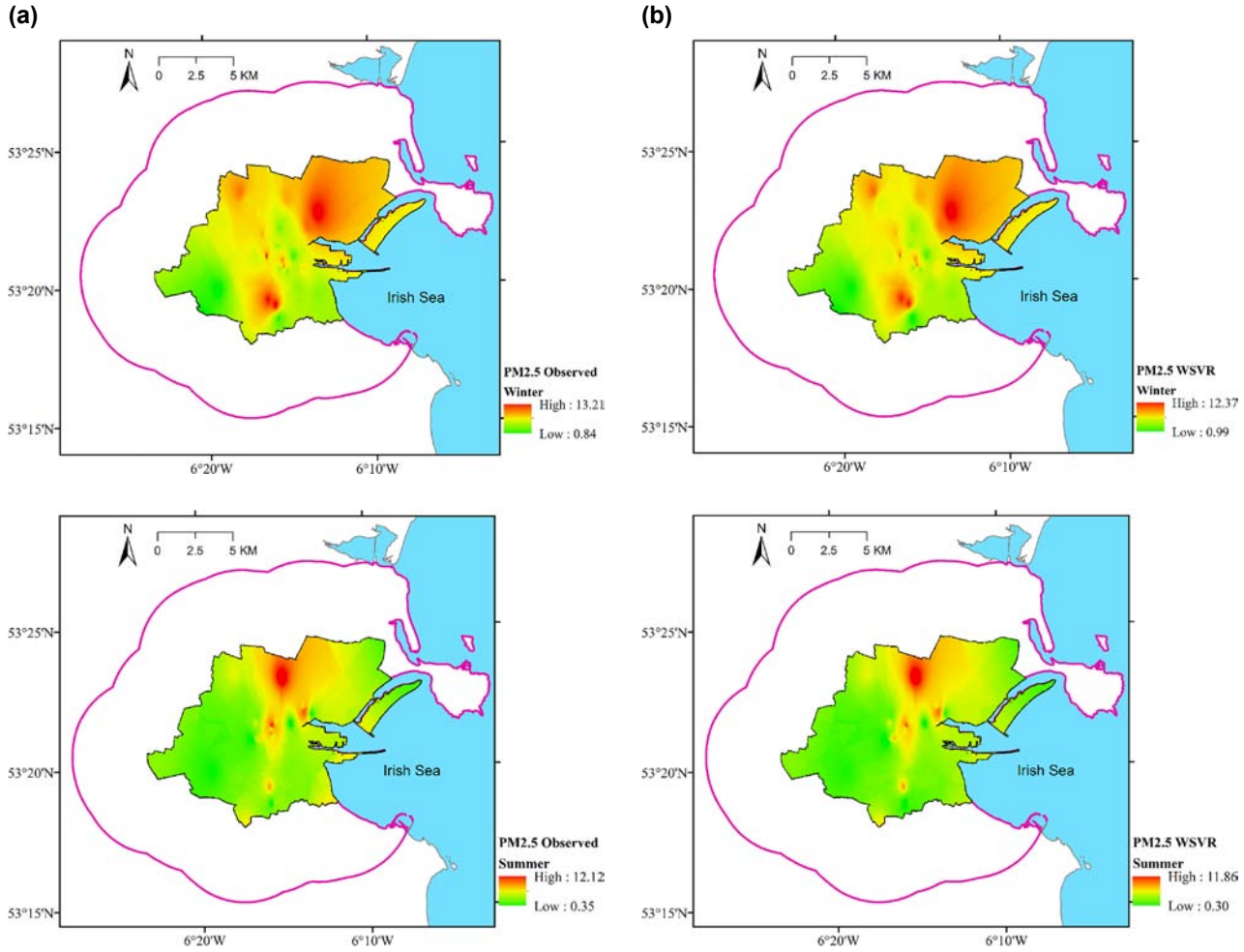

Figure 5.2. Spatial variation in $PM_{2.5}$ concentrations obtained using (a) observed data and (b) W-SVR-predicted data for winter and summer months, excluding data from the Pearse Street monitoring station.

EPA's new monitoring station; therefore, the results for the summer period did not change. The LUR model performance results for the winter period are provided in Table 5.1. Note that Pearse Street had been selected as an outlier station during the winter period (outlier selection depends not on pollutant concentrations, but on other attributes affecting the pollutants). Hence, when both fixed and mobile stations are considered, changes in concentration at Pearse Street do not alter the results.

Note also that the datasets used to estimate the performance for Sets A and B in Table 5.1 are different. In Set A, only nine stations (after discarding the Pearse Street data) were considered to estimate model performance, whereas, for Set B, 62 (winter) or 61 (summer) stations were considered (nine fixed stations – excluding Pearse Street – and the remainder mobile stations). Therefore, it would be unrealistic to compare the results obtained for Sets A and B.

The spatial variation in $PM_{2.5}$ concentrations obtained using the W-SVR model with the Pearse Street data omitted was also used to assess the impacts of omitting these data on the estimated environmental burden of disease in terms of mortality as a result of long-term exposure, corresponding to mortality caused by cardiopulmonary disease and lung cancer. The corresponding expected number of deaths and the expected death rates for cardiopulmonary disease and lung cancer corresponding to different Dublin divisions (divisions 0 to 15 – not postcodes) for the winter and summer months are provided in Table 5.6. The population in each of the Garda divisions was obtained from Census 2016 data acquired from the CSO database (https://www.cso.ie/en/census/census2016reports/census2016smallareapopulationstatistics/).

Table 5.6. Expected deaths from cardiopulmonary disease and lung cancer as a result of long-term exposure to $PM_{2.5}$, obtained by considering 5 µg/m³ as the threshold $PM_{2.5}$ concentration (omitting the Pearse Street data)

			Cardiopulmonary mortality and long-term exposure to $PM_{2.5}$				Lung cancer mortality and long-term exposure to $PM_{2.5}$			
$PM_{2.5}$	Division	Population	Risk factor	IF	Expected deaths (*n*)	Expected death rate (%)	Risk factor	IF	Expected deaths (*n*)	Expected death rate (%)
Winter										
7.0	0	24,745	1.046	0.044	9	0.04	1.070	0.066	5	0.02
6.5	1	44,816	1.036	0.035	13	0.03	1.054	0.051	7	0.02
6.7	2	24,135	1.040	0.039	8	0.03	1.061	0.057	4	0.02
4.8	3	53,011	0.994	0.000	0	0.00	0.990	0.000	0	0.00
5.4	4	144,955	1.011	0.011	13	0.01	1.016	0.016	7	0.01
7.2	5	57,212	1.050	0.048	23	0.04	1.076	0.070	13	0.02
5.5	6	53,791	1.013	0.013	6	0.01	1.020	0.019	3	0.01
5.8	7	66,923	1.020	0.020	11	0.02	1.030	0.029	6	0.01
6.6	8	22,600	1.037	0.035	7	0.03	1.055	0.052	4	0.02
7.1	9	165,979	1.047	0.045	63	0.04	1.071	0.067	35	0.02
3.8	10	71,299	0.967	0.000	0	0.00	0.951	0.000	0	0.00
4.8	11	64,240	0.994	0.000	0	0.00	0.991	0.000	0	0.00
4.8	12	102,472	0.994	0.000	0	0.00	0.991	0.000	0	0.00
9.4	13	144,051	1.090	0.082	99	0.07	1.137	0.120	58	0.04
8.8	14	87,544	1.079	0.073	54	0.06	1.120	0.107	30	0.03
8.1	15	56,138	1.067	0.062	30	0.05	1.101	0.092	17	0.03
				Total	**336**			**Total**	**189**	
Summer										
3.7	0	24,745	0.962	0.000	0	0.00	0.943	0.000	0	0.00
5.4	1	44,816	1.011	0.011	4	0.01	1.017	0.016	2	0.01
5.3	2	24,135	1.008	0.008	2	0.01	1.012	0.012	1	0.00
3.1	3	53,011	0.943	0.000	0	0.00	0.915	0.000	0	0.00
4.8	4	144,955	0.995	0.000	0	0.00	0.993	0.000	0	0.00
4.7	5	57,212	0.992	0.000	0	0.00	0.987	0.000	0	0.00
4.9	6	53,791	0.997	0.000	0	0.00	0.995	0.000	0	0.00
3.2	7	66,923	0.947	0.000	0	0.00	0.921	0.000	0	0.00
5.0	8	22,600	0.999	0.000	0	0.00	0.999	0.000	0	0.00
4.1	9	165,979	0.976	0.000	0	0.00	0.965	0.000	0	0.00
3.2	10	71,299	0.947	0.000	0	0.00	0.922	0.000	0	0.00
4.0	11	64,240	0.973	0.000	0	0.00	0.960	0.000	0	0.00
5.9	12	102,472	1.023	0.022	18	0.02	1.034	0.033	11	0.01
5.2	13	144,051	1.005	0.005	6	0.00	1.007	0.007	3	0.00
5.4	14	87,544	1.009	0.009	7	0.01	1.014	0.013	4	0.00
7.9	15	56,138	1.063	0.060	28	0.05	1.096	0.088	16	0.03
				Total	**65**			**Total**	**37**	

IF, impact fraction.

The data shown in Tables 5.4 and 5.5 from the previous analysis, which include the Pearse Street data, do not change as a result. Since data on the number of deaths for different age groups were available for Ireland from the CSO, but were not available for the study area, estimates of the number

of deaths as a result of diseases of the circulatory system (cardiopulmonary disease) and the respiratory system (lung cancer) for different age groups in the study area were estimated by using the same rate as for Ireland. The $PM_{2.5}$ concentration in Dublin can provide only an estimate of the death rates for all age groups, but not individual age groups. Hence, we used the average values for Ireland.

Similarly, the numbers of incident cases of circulatory and respiratory system diseases in Dublin were needed to estimate YDLs. As this information is not available for Ireland, the estimates were obtained from the Global Health Estimates 2016 summary table prepared by the WHO (https://www.who.int/healthinfo/global_burden_disease/en/).

6 Conclusions and Recommendations

The following conclusions and recommendations have been drawn from the final report:

- *Analysis.* LA-ICP-MS is currently the only known methodology that can measure all of the trace element species analysed in this study. However, LA-ICP-MS cannot measure the major mass-bearing species such as carbon, because this method requires analysis of $PM_{2.5}$ samples collected on (carbon-rich) Teflon filters. As mentioned above, previous investigations suggest that the measurement of both trace elements and major mass-bearing species could yield successful separation of diesel vehicle emissions. In the design of the current study, it was felt that measuring a larger number of species at a greater level of accuracy using LA-ICP-MS could identify a diesel source without measuring carbon. However, because source apportionment models such as PMF require knowledge of the major mass-bearing species present in the $PM_{2.5}$ samples (e.g. OC, elemental carbon, nitrate and sulfate), in order to refine the approach these major organic compounds would have to be measured in addition to the species that are present at trace levels in future studies. Thus, parallel sampling on Teflon filters (for trace element species) and on glass microfibre or quartz filters (for major species) as well as chemical analysis of both of these filter types would be required should this method be adopted routinely. However, the analytical costs of such a study would be 5–10 times that of the current project.
- *Diesel and other emissions.* The indirect breakdown of the $PM_{2.5}$ sources measured in Dublin using the PMF and CMB models revealed a contribution from diesel vehicles of 28.6% ± 6.5% and 8.1% ± 1.8% to ambient $PM_{2.5}$ levels at Sites A and B, respectively. Diesel vehicles were the second largest source of $PM_{2.5}$ at the roadside location but only the fourth largest at the urban background location. Solid fuel combustion was the largest source of $PM_{2.5}$ in both cases by a considerable margin (see Table 4.4). Road dust was also a significant source of $PM_{2.5}$ and was shown to contain a number of toxic metals. Considering the major pressures on the environment at both study locations, a reduction in emissions from solid fuel stands to make the largest contribution to human health protection in Dublin at present. Reductions in diesel vehicle numbers (to address the contribution of road dust to $PM_{2.5}$ emissions of 19.1% and of diesel exhaust to $PM_{2.5}$ emissions of 22.1%) stand to make a comparable reduction in $PM_{2.5}$ concentrations at roadside locations. However, mitigating measures must address travel demand as well as emission rate and fuel type.
- *Direct source sampling.* Sampling of the exhaust emissions of a number of diesel and petrol vehicles to determine the characteristic element concentrations revealed a large difference between Euro classes, between diesel and petrol vehicles, between old and new vehicles, and between vehicles within the same Euro class. Older Euro 3 and Euro 4 diesel vehicles were typically much more polluting than newer Euro 5 or Euro 6 diesel vehicles. The difference between well-maintained new petrol and new diesel vehicles was markedly reduced. Furthermore, the contribution of road dust to $PM_{2.5}$ emissions was notable for its toxic content, including high concentrations of many toxic elements, e.g. Cd, Mo, Se and As. Future work should include a detailed examination of non-exhaust emissions in the transport sector in Ireland, considering its high contribution to roadside emissions and toxic content.
- *$PM_{2.5}$ mass concentrations.* Levels of $PM_{2.5}$ mass concentration at Site B were in line with the measurements published in the other four EPA monitoring stations in Dublin and the four Transport Infrastructure Ireland monitoring stations. All were in accordance with EU concentration limit values. However, levels of $PM_{2.5}$ at the roadside location on Pearse Street exceeded the EU limit values consistently across a > 1-year period of monitoring. The differences between Site A and all other monitoring stations gives rise to concerns about

the representativeness of these concentrations of general urban air quality in Dublin.

- *Modelling.* The present study showed that LUR modelling could be easily adapted to predict air pollution concentrations on a city scale in Dublin with very promising levels of accuracy. This process was carried out within a short period of time in this project and could therefore be readily rolled out to the extrapolation of measurement data across other Irish towns and cities. The method combines long-term fixed-site data with short-term mobile-station data. These data were used to augment the limited set of statutory long-term fixed-site monitors available in Dublin. In a further attempt to improve model performance, the study developed a W-SVR-based LUR model to quantify the non-linear relationship between the set of predictors influencing pollution and the air pollution concentration. Results indicated that the use of a combination of fixed- and mobile-station data improved model performance significantly. Another important observation was that a non-linear W-SVR equation-based LUR performs better than the multiple linear regression-based LUR model. Furthermore, the different weights considered for long-term and short-term data improved model performance. The difference between predicted and observed $PM_{2.5}$ concentrations was very low for the W-SVR-based LUR model, which can be used to obtain $PM_{2.5}$ concentrations at any spatial location inside the city. The difference in maximum values of $PM_{2.5}$ concentration was found to be less than 1 $\mu g/m^3$ for winter months and less than 4 $\mu g/m^3$ for summer months. It is recommended that the W-SVR-based LUR methodology is adopted for all major towns and cities in Ireland in future and that this is conducted in a relatively short period, subject to a minimum amount of existing monitoring data being available. In addition, removing the high concentration of data found at Site A from the LUR model did not alter the superior performance of the W-SVR approach.
- *Health impact.* Based on the results obtained using the W-SVR model, the expected number of deaths in the study area was estimated along with the number of DALYs lost. The overall number of deaths associated with $PM_{2.5}$ pollution is expected to be approximately 723 in Dublin (627 if the Pearse Street data are excluded) and the number of DALYs lost is expected to be approximately 25 years (Table 5.5). These figures compare with a predicted 1100 premature deaths as a result of $PM_{2.5}$ exposure in the entire country, according to the most recent EEA assessment (EEA, 2020). The numbers of expected deaths and DALYs lost because of $PM_{2.5}$ pollution contributed from diesel vehicles are in the ranges of 46–93 deaths and 2.53–5.07 years, respectively. It is recommended that measures to address both travel demand and emission type are put in place in Dublin to address this.

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Abbreviations

BC	Black carbon
CAFE	Clean Air for Europe
CMB	Chemical mass balance
CSO	Central Statistics Office
DALY	Disability-adjusted life year
EPA	Environmental Protection Agency
EU	European Union
GDA	Greater Dublin Area
LA-ICP-MS	Laser-ablation inductively coupled plasma mass spectrometry
LUR	Land use regression
OC	Organic carbon
OLS-MLR	Ordinary least squares multiple linear regression
PM	Particulate matter
$PM_{2.5}$	Particulate matter < 2.5 µm in aerodynamic diameter
PMF	Positive matrix factorisation
RMSE	Root mean square error
R^2	Coefficient of determination
SVR	Support vector regression
TII	Transport Infrastructure Ireland
WHO	World Health Organization
WLS-MLR	Weighted least squares multiple linear regression
W-SVR	Weighted support vector regression
YLD	Year lived with disability
YLL	Year of life lost as a result of premature mortality

AN GHNÍOMHAIREACHT UM CHAOMHNÚ COMHSHAOIL
Tá an Ghníomhaireacht um Chaomhnú Comhshaoil (GCC) freagrach as an gcomhshaol a chaomhnú agus a fheabhsú mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ó éifeachtaí díobhálacha na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialú: *Déanaimid córais éifeachtacha rialaithe agus comhlíonta comhshaoil a chur i bhfeidhm chun torthaí maithe comhshaoil a sholáthar agus chun díriú orthu siúd nach gcloíonn leis na córais sin.*

Eolas: *Soláthraímid sonraí, faisnéis agus measúnú comhshaoil atá ar ardchaighdeán, spriocdhírithe agus tráthúil chun bonn eolais a chur faoin gcinnteoireacht ar gach leibhéal.*

Tacaíocht: *Bímid ag saothrú i gcomhar le grúpaí eile chun tacú le comhshaol atá glan, táirgiúil agus cosanta go maith, agus le hiompar a chuirfidh le comhshaol inbhuanaithe.*

Ár bhFreagrachtaí

Ceadúnú
Déanaimid na gníomhaíochtaí seo a leanas a rialú ionas nach ndéanann siad dochar do shláinte an phobail ná don chomhshaol:
- saoráidí dramhaíola *(m.sh. láithreáin líonta talún, loisceoirí, stáisiúin aistrithe dramhaíola)*;
- gníomhaíochtaí tionsclaíocha ar scála mór *(m.sh. déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta)*;
- an diantalmhaíocht *(m.sh. muca, éanlaith)*;
- úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe *(OGM)*;
- foinsí radaíochta ianúcháin *(m.sh. trealamh x-gha agus radaiteiripe, foinsí tionsclaíocha)*;
- áiseanna móra stórála peitril;
- scardadh dramhuisce;
- gníomhaíochtaí dumpála ar farraige.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil
- Clár náisiúnta iniúchtaí agus cigireachtaí a dhéanamh gach bliain ar shaoráidí a bhfuil ceadúnas ón nGníomhaireacht acu.
- Maoirseacht a dhéanamh ar fhreagrachtaí cosanta comhshaoil na n-údarás áitiúil.
- Caighdeán an uisce óil, arna sholáthar ag soláthraithe uisce phoiblí, a mhaoirsiú.
- Obair le húdaráis áitiúla agus le gníomhaireachtaí eile chun dul i ngleic le coireanna comhshaoil trí chomhordú a dhéanamh ar líonra forfheidhmiúcháin náisiúnta, trí dhíriú ar chiontóirí, agus trí mhaoirsiú a dhéanamh ar leasúchán.
- Cur i bhfeidhm rialachán ar nós na Rialachán um Dhramhthrealamh Leictreach agus Leictreonach (DTLL), um Shrian ar Shubstaintí Guaiseacha agus na Rialachán um rialú ar shubstaintí a ídíonn an ciseal ózóin.
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Uisce
- Monatóireacht agus tuairisciú a dhéanamh ar cháilíocht aibhneacha, lochanna, uiscí idirchriosacha agus cósta na hÉireann, agus screamhuiscí; leibhéil uisce agus sruthanna aibhneacha a thomhas.
- Comhordú náisiúnta agus maoirsiú a dhéanamh ar an gCreat-Treoir Uisce.
- Monatóireacht agus tuairisciú a dhéanamh ar Cháilíocht an Uisce Snámha.

Monatóireacht, Anailís agus Tuairisciú ar an gComhshaol
- Monatóireacht a dhéanamh ar cháilíocht an aeir agus Treoir an AE maidir le hAer Glan don Eoraip (CAFÉ) a chur chun feidhme.
- Tuairisciú neamhspleách le cabhrú le cinnteoireacht an rialtais náisiúnta agus na n-údarás áitiúil *(m.sh. tuairisciú tréimhsiúil ar staid Chomhshaol na hÉireann agus Tuarascálacha ar Tháscairí)*.

Rialú Astaíochtaí na nGás Ceaptha Teasa in Éirinn
- Fardail agus réamh-mheastacháin na hÉireann maidir le gáis cheaptha teasa a ullmhú.
- An Treoir maidir le Trádáil Astaíochtaí a chur chun feidhme i gcomhair breis agus 100 de na táirgeoirí dé-ocsaíde carbóin is mó in Éirinn.

Taighde agus Forbairt Comhshaoil
- Taighde comhshaoil a chistiú chun brúnna a shainaithint, bonn eolais a chur faoi bheartais, agus réitigh a sholáthar i réimsí na haeráide, an uisce agus na hinbhuanaitheachta.

Measúnacht Straitéiseach Timpeallachta
- Measúnacht a dhéanamh ar thionchar pleananna agus clár beartaithe ar an gcomhshaol in Éirinn *(m.sh. mórphleananna forbartha)*.

Cosaint Raideolaíoch
- Monatóireacht a dhéanamh ar leibhéil radaíochta, measúnacht a dhéanamh ar nochtadh mhuintir na hÉireann don radaíocht ianúcháin.
- Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha.
- Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta.
- Sainseirbhísí cosanta ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Faisnéis Inrochtana agus Oideachas
- Comhairle agus treoir a chur ar fáil d'earnáil na tionsclaíochta agus don phobal maidir le hábhair a bhaineann le caomhnú an chomhshaoil agus leis an gcosaint raideolaíoch.
- Faisnéis thráthúil ar an gcomhshaol ar a bhfuil fáil éasca a chur ar fáil chun rannpháirtíocht an phobail a spreagadh sa chinnteoireacht i ndáil leis an gcomhshaol *(m.sh. Timpeall an Tí, léarscáileanna radóin)*.
- Comhairle a chur ar fáil don Rialtas maidir le hábhair a bhaineann leis an tsábháilteacht raideolaíoch agus le cúrsaí práinnfhreagartha.
- Plean Náisiúnta Bainistíochta Dramhaíola Guaisí a fhorbairt chun dramhaíl ghuaiseach a chosc agus a bhainistiú.

Múscailt Feasachta agus Athrú Iompraíochta
- Feasacht chomhshaoil níos fearr a ghiniúint agus dul i bhfeidhm ar athrú iompraíochta dearfach trí thacú le gnóthais, le pobail agus le teaghlaigh a bheith níos éifeachtúla ar acmhainní.
- Tástáil le haghaidh radóin a chur chun cinn i dtithe agus in ionaid oibre, agus gníomhartha leasúcháin a spreagadh nuair is gá.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil
Tá an ghníomhaíocht á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóirí. Déantar an obair ar fud cúig cinn d'Oifigí:
- An Oifig um Inmharthanacht Comhshaoil
- An Oifig Forfheidhmithe i leith cúrsaí Comhshaoil
- An Oifig um Fianaise is Measúnú
- Oifig um Chosaint Radaíochta agus Monatóireachta Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag comhaltaí air agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

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Particulate Matter from Diesel Vehicles: Emissions and Exposure

Authors: Meabh Gallagher, Bidroha Basu, Bidisha Ghosh, Md. Saniul Alam, Laurence Gill, Balz Kamber and Aonghus McNabola

Identifying Pressures

Clean air is considered a basic requirement of human health preservation and well-being. Epidemiological studies have shown that even low levels of air pollution in industrialised societies are linked to adverse health outcomes. The Environmental Protection Agency (EPA) reports that the most problematic pollutants in Ireland are particulate matter (PM, including PM < 2.5 µm in aerodynamic diameter – $PM_{2.5}$ – and PM < 10 µm in aerodynamic diameter – PM_{10}) and oxides of nitrogen (NO_x). In Ireland in 2015 and 2016, more than 70% of new cars sold were diesel-fuelled cars, whereas the average in the European Union was 50%. Diesel vehicles are known to be a significant source of particulate air pollution, emitting more PM than other vehicle types. Owing to the recent growth in private diesel vehicles in Ireland since 2008, this vehicle category may represent a significant pressure on the quality of the urban environment in Ireland and requires investigation to quantify these potential impacts.

Informing Policy

A 2-year research project was conducted in Dublin to assess the contribution of diesel vehicle emissions to the concentrations of $PM_{2.5}$ that the population is exposed to (2016–2018). $PM_{2.5}$ was monitored for over 1 year at two locations in Dublin. Source apportionment sampling and analysis, and positive matrix factorisation (PMF) modelling were conducted to determine the major sources of $PM_{2.5}$ in Dublin. The major source of $PM_{2.5}$ identified at the two sites was solid fuel burning, contributing 46–50% of the total $PM_{2.5}$ mass recorded. The second largest contributor at Site A (roadside location in the city centre) was diesel vehicle emissions (22%), followed closely by road dust (19%). Other sources made minor contributions at Site A (sea salt, soil and petrol vehicles were all < 4%). The second largest source at Site B (urban background location in a residential neighbourhood) was soil (20%) followed closely by sea spray (14%). Road dust and diesel exhaust emissions, 8% and 9% respectively, contributed significantly less at Site B. The resulting predicted number of deaths and disability-adjusted life years (DALYs) lost associated with diesel $PM_{2.5}$ pollution are expected to be in the ranges of 46–93 deaths and 2.53–5.07 years, respectively.

Developing Solutions

The breakdown of the $PM_{2.5}$ sources measured in Dublin using the PMF model revealed a contribution from diesel vehicles of 22% and 9% of ambient $PM_{2.5}$ at Sites A and B. In comparison, emissions from petrol vehicles accounted for 3.2% and 1.4% at Sites A and B, respectively. Diesel vehicles were the second largest source of $PM_{2.5}$ at the roadside location but only the fourth largest at the urban background location. Solid fuel combustion was the largest source of $PM_{2.5}$ in both cases by a considerable margin. Road dust was also a significant source of $PM_{2.5}$ and was shown to contain a number of toxic metals. Considering the major pressures on the environment at both study locations, a reduction in emissions from solid fuel stands to make the largest contribution to human health protection in Dublin at present. Reductions in diesel vehicle numbers (to address the contribution of road dust to $PM_{2.5}$ emissions of 19% and of diesel exhaust to $PM_{2.5}$ emissions of 22%) stand to make a comparable reduction in $PM_{2.5}$ concentrations at roadside locations. However, mitigating measures must address travel demand as well as emission rate and fuel type in order to reduce both exhaust and non-exhaust emissions.

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