A COMPARISON OF AIR POLLUTION IN DIFFERENT SOCIO-ECONOMIC AREAS

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Glossary

Term	Definition
CDRC – Customer Data Research Centre.	Data available for research purpose online
DEFRA – Department for Environment, Food and Rural Affairs.	Department of the UK government that overseas air quality issues among other issues.
GIS – Geographical Information Systems.	Is a system that can be used to manipulate and analyse data with spatial data.
IMD- Index of Multiple Deprivation.	A qualitative study of how deprived an area is in English councils undertaken by the UK government
WHO – World Health Organisation.	Is an agency of the United Nations that focus on public health

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Abstract

Air pollution has a significant impact on human health causing around 40,000 deaths annually in the United Kingdom (RCPCH, 2016). This thesis examines the variations in Particulate Matter concentration across areas of different socio-economic status. The research assesses air pollution concentration in different areas of deprivation to determine if communities with lower socio-economic status experience higher pollutant concentrations than areas with higher socio-economic status and consists of three linked studies. The first study was conducted in Greater Manchester across three study areas of high, medium and low deprivation. Three monitoring sites within each area were selected to allow inter-site comparison and comparison between study areas. Particulate matter data was collected using a Dustmate Particle monitor and analysis was undertaken using SPSS. Each monitoring event was analysed separately using descriptive statistics. To analyse the link between socio-economic characteristics and pollution levels all data collected was combined to calculate correlation and analysis of variance. The results demonstrated slight variance in pollution levels between study areas however with no significant link found between pollution and deprivation. The second research study analysed particulate matter concentration across the North West of England using the automatic urban and rural network data, which was analysed to determine descriptive statistics such as mean, maximum and minimum. To assess the link between pollution concentration and socio-economic status all data was combined to calculate correlations. The third research study analysed background modelled data for Greater Manchester. To analyse the data ArcMap was used to assess spatial relationships between PM_{10} levels and IMD ranking. Road type data was used to create map the road structure in the area and pollution. These two studies demonstrated no significant link between socio-economic status and pollution levels with the AURN study showing the strongest links. Higher concentrations of pollutants were no found to be in the areas of high road traffic. This reasons for the differences found in the link between socio-economic status could be due to limited data availability. It is suggested that for future studies a standardised deprivation level is decided upon.

Chapter 1: Introduction and Background

1.1 Introduction

Research has demonstrated that there is a link between air pollution concentration and socio-economic status (Briggs, Abellan & Fecht, 2008; Mitchell & Dorling, 2003; Li, Han, Lam, Zhu & Bacon-Shone, 2018, Morelli, Rieux, Cyrys, Forsberg & Slama 2016). This is an important link as it is also known that air pollution can cause health problems that can result in both premature death and increased morbidity (Namdea and Stringer, 2008; Boldo et al, 2006). The World Health Organisation (WHO) found that in 2016 an estimated 91% of the world's population were living in areas where WHO air quality guidelines were not met, and in 2016 it was estimated that ambient air pollution contributed 4.2 million premature deaths worldwide (World Health Organisation, 2018). Some of the 91% of premature death occurred in low- and middle-income countries (World Health Organisation, 2018). This suggests that air pollution is a worldwide problem, especially in low-income countries, which is having a great effect on people's health.

Early documented air pollution issues that occurred in the 1950's such as urban smog lead to the premature death of thousands of people causing governments of multiple countries to create environmental policies to reduce urban pollution levels (Gouveia & Fletcher, 2000). In the UK, historically air pollution became a major issue during the industrial revolution when the need and reliance on energy was increasing, and that need relied upon the burning of fossil fuels (DEFRA, n.d.). This resulted in urban smog events occurring which promoted the public's concern and government action to combat air pollution. This resulted in the UK's first Clean Air Act in 1956 (DEFRA, n.d.), which introduced smoke control areas to combat excessive air pollution in urban areas along with controls over boilers and furnaces to reduce pollution from industrial premises. The European Union (EU) also become an important part of regulating ambient air pollution levels with the first Air Quality Framework Directive being published in 1996 (European Commission, 2018). As well as setting air quality standards for numerous pollutants to lessen or stop the negative effects on people's health part of the aims also include controlling emissions from mobile sources, improving fuel quality and integrating environmental protection requirements into the transport and energy sector (European Commission, 2018). The WHO have also set health-based guidelines for different types of air pollution to help countries to reduce their pollution concentration. However, these are only guidelines that countries do not need to follow whereas member states of the EU are legally required to achieve a result set by a directive. Whilst these EU standards are informed by the WHO air quality guidelines, in some cases the standards applied in European legislation are less stringent than the guidelines.

After the problem of coal combustion had mostly been solved within the UK due to the reduction in heavy industry such as steel, textiles and an investment in cleaner fuel, emissions from road, air, rail and water transport have become some of the main contributors to air pollution (Colvile, Hutchinson, Mindell & Warren, 2001). Department for Transport (2018) figures show there was an 1.3% increase in miles driven in Great Britain from 2016 to 2017 and car traffic rose from 43% in 1949 to 78% in 2017. They also found in 2016 that 77% of households have access to a car and 62% of personal trips were made by car. While there are many contributions to urban air pollution it is widely accepted that one of the main causes is road traffic, particularly private cars and heavy vehicles making it a priority issue for transportation planners and public authorities (Catalano & Galatioto, 2017).

Since there is increasing evidence that exposure to air pollution causes negative health effects, and that people from lower socio-economic status have greater exposure to higher pollution levels, the understanding of the relationship between socio-economic status and pollution concentration has been the subject of major study (Harvard, Deguen, Zmirou-Navier, Schillinger & Bard, 2009). This is important to make sure that people do not face disadvantages due to their background and to address inequality in the sustainable development process. Deng, Deng, Lu, Li and Norback (2018) found that higher socio-economic stress was linked with higher cases of childhood asthma, and the association between exposure to air pollutants and childhood asthma was significant only in children from families with high parental stress. Many different association factors have been analysed in order to investigate the links between air pollution and socio-economic status, including income, housing, living environment and race such as in the study by Mikati, Benson, Luben, Sacks and Richmond-Bryant (2018). This can help our understanding about whether any particular factor contributes more to the association between socio-economic status and air pollution concentration, which can help to then tackle the issue in a more precise manner.

There have been many techniques used to investigate the spatial aspects of different socio-economic status; one of these techniques is Geographical Information Systems (GIS). This is useful as it allows a clear image to be created, which facilitates spatial comparisons to be made with air pollution of a particular area. It allows spatial patterns and distribution of air pollution to be analysed to help assess areas that may represent higher exposure to pollution. There is also the potential to analyse the spatial patterns in air pollution with other data sets representing both the causes of pollution and the populations affected.

GIS is also a clear way to share information with the public, as maps can be easier to interpret than other more traditional forms of data. Modelling has been used to simulate different pollutant concentrations using available data such as traffic counts (Kota, Ying & Zhang, 2013) and to assist in understanding how different conditions might affect pollution concentration, which can be done by running different scenarios through a model to see the effect on pollution concentration (Vienneau, de Hoogh & Briggs, 2009). This can then help policy makers decide what will be the best course of action to reduce air pollution.

Particulate Matter (PM) was chosen as the focus of this study as it has been shown to cause health problems at low concentrations and can therefore cause many negative consequences (Yang et al, 2019). These particles are of particular concern as due to their small size enabling them to penetrate deep into the sensitive regions of the respiratory tract and therefore have the potential to cause major health problems (Quah & Boon, 2003). Fine Particulate Matter ($PM_{2.5}$) has been found to cause health effects such as cancer, stroke, asthma and heart disease (Li, Han, Lam, Zhu & Bacon-Shone, 2018). Therefore, it is important to monitor particulate concentration to assess people's exposure, especially since this particular pollutant has not been researched in detail and the extent of the harm it can cause was not fully understood until fairly recently.

1.2 Aims and Objectives

The aim of this research is to assess air pollution concentration in different areas of social deprivation to determine if communities with lower socio-economic status experience higher pollutant concentrations than areas with higher socio-economic status.

This is an important area to study as air pollution has been shown to have negative health effects and if an already deprived group is facing more negative outcomes then others it heightens the need to be rectified.

The objectives to complete this research were:

A. To conduct a literature review surrounding the research topic to assess the strength of evidence on the link between socio-economic status and pollution concentration.
B. To identify suitable sampling sites according to the Index of Multiple Deprivation (IMD).
C. To carry out an assessment of the accuracy of the data collection equipment and to establish, test and carry out a sampling regime for the collection of air quality data.
D. To carry out a study of UK Government air pollution data which will analyse PM pollution across an area in the North of England to analyse if trends are found over a different spatial scale.
E. To assess modelled PM pollution data to examine if the same trend is found when different monitoring techniques are used.
F. To assess variations in air quality in areas of different socio-economic status and determine the relationship between air quality and socio-economic status

To complete these objectives three studies areas within Greater Manchester where selected using the Indices of Deprivation 2015 explorer, which is an interactive map of England showing the IMD ranking at a Ward level. This was then used to assess deprivation level and PM pollutants were then monitored at these locations using a DustMate® particle monitor. To assess air pollution levels in the North of England to $PM_{2.5}$ and PM_{10} data from government Automatic Urban and Rural Network (AURN) monitoring sites was collected and analysed. Modelled background concentration data was used to ascertain background PM_{10} pollution over a ward in Greater Manchester to assess if there was a difference found across different spatial scales of pollutant monitoring. Greater Manchester was chosen for a study site as it would allow for more data collection to be taken therefore allowing a more in-depth analysis to be conducted. Greater Manchester has a varied population throughout meaning it can be used to assess the hypothesis.

The thesis structure includes an analysis of the research literature to establish the boundaries of the study, a description and justification of the methodology that was chosen for each study along with a presentation of the results. A discussion of the findings with reference to previous literature and any differences or similarities between the studies followed by the conclusions that have been drawn from the research.

Chapter 2: Literature Review

2.1 Introduction

Poor air quality in the UK is harming both the environment and people's health, which has led to an estimated 40-50,000 early deaths a year (House of Commons Environment, Food & Rural Affairs Committee, 2016). It has also been observed that the health effects of air pollution are not equally distributed throughout society and that more deprived communities are exposed to higher concentrations of air pollutants and therefore experience higher cases of negative health effects (O'Lenick et al., 2017).

This chapter examines the sources of particulate matter, trends in emission monitoring and controls, the health effects of particulate matter, methods for monitoring pollutants and previous studies into the relationship between social deprivation and air quality.

2.2 Particulate Matter Sources

Particulate matter (PM) in ambient air is a complex mixture of organic and inorganic substances. It is derived from a wide variety of sources, both natural and anthropogenic (Harrison, Laxen, Moorcroft & Laxen, 2012). As a result, particulate matter emissions having multiple sources it can often be hard to monitor. There are two groups of Particulate Matter (PM), primary and secondary. Primary PM consists of dust, pollens, sea salt sprays and is mechanically emitted from the ground, plants and ocean along with particles emitted directly from combustion and mechanical activities whereas secondary PM is formed in the air from gas reactions (Guevara, 2016).

Three of the main sources of PM pollution are background dust, secondary aerosol and traffic (Bari & Kindzierski, 2017). Secondary aerosol is increased during the summer which is linked with photochemical activity as well as human and natural activity such as traffic exhaust, fossil fuel combustion and biogenic emissions (Grigoratos & Martini, 2014). Contributions from traffic have been shown to be seasonally affected with increases during winter, and that local roadway traffic was likely to be the biggest contributor (Bari & Kindzierski, 2017). While pollution is created from traffic exhausts it is also caused by non-exhaust traffic related sources and pre-existing deposited material (Grigoratos & Martini, 2014). One source of non-exhaust traffic pollution is break wear. As a result of use over time there is a break down in the components resulting in the release of debris some of which is particulate matter. Tyre wear also contributes to particulate matter pollution, which is generated by the friction between the tyre and pavement or the generation of fine particles through volatilization. An average passenger vehicle tyre is estimated to last between 40,000-50,000 km with between 10-30% of its tread rubber being emitted into the environment in that time (Grigoratos & Martini, 2014). The wear factor depends on tyre characteristics, vehicle characteristics, road surface characteristics and vehicle operation (Grigoratos & Martini, 2014). As well as traffic sources recent evidence suggests that in the UK domestic wood and coal burning is a major source of primary $PM_{2.5}$ contributing up to 38% of emissions (Defra, 2019).

2.3 Particulate Matter Trends

There are many different sources of Particulate Matter which can make it difficult to monitor. Over the years there has been a change in the pollutant sources which is mainly due to changes in industry and the tightening of emission standards for vehicles since 1993.

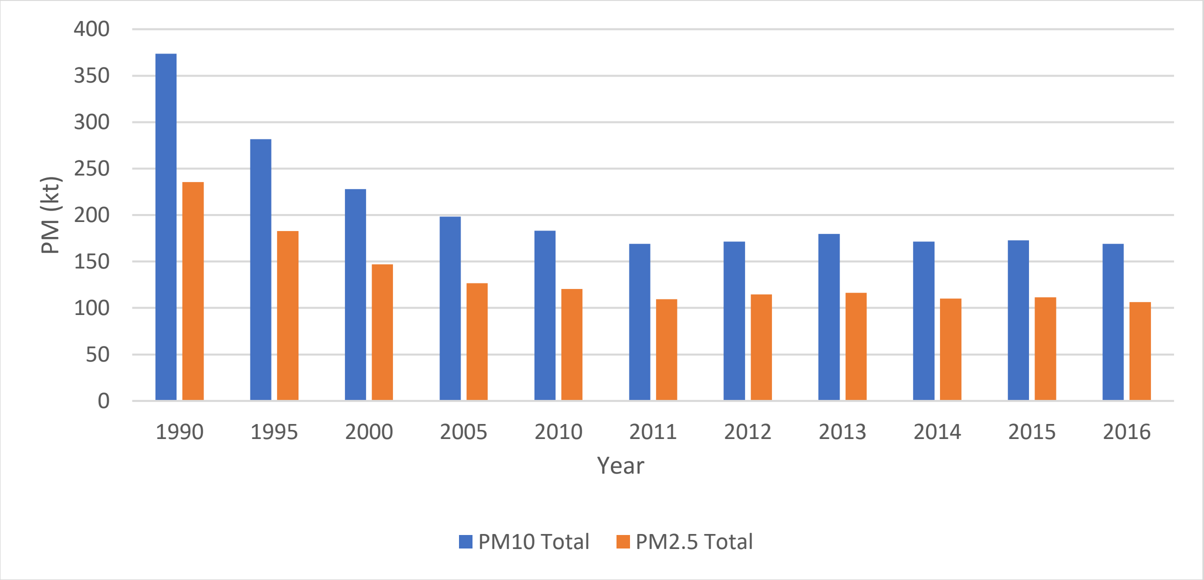

Figure 2.1: Graph showing the level of $PM_{2.5}$ and PM_{10} for each year for United Kingdom (Source: data from DEFRA, 2018).

Figure 2.1 shows the $PM_{2.5}$ and PM_{10} concentration for the United Kingdom since 1990. This shows that while there was a significant reduction at first, however from 2011 that has now slowed down. The first European Council Directive that specified measures against air pollution from motor vehicles was in 1970 (EU, 1970) which was then replaced by the 'Euro' emission standards, starting with the 'Euro 1' step, followed, generally, by successively stricter standards: Euro 2 to Euro 6 (European Environment Agency, 2016). However, one of the reasons that there is not as great a reduction in pollution emissions is how compliance with the Euro standards, under the New European Drive Cycle (NEDC) testing, is not consistent with real world driving conditions and the emissions produced. This is as a result of the NEDC being developed when vehicles were lighter and less powerful than those available today (European Environment Agency, 2016). Therefore, the emission values and fuel consumption measured in the laboratory largely understate the actual levels obtained under real-world driving conditions (European Environment Agency, 2016). Additionally, as technology advances it becomes harder to make faster progress therefore making it harder to cut down on the emissions produced.

There was a slight increase in pollutants from 2011 to 2013. One of the reasons for this could be an increase in the amount of coal used to produce electricity. From 2011 to 2012 there was an increase of 9% in coal use to generate electricity and a decrease of 12% in gas.

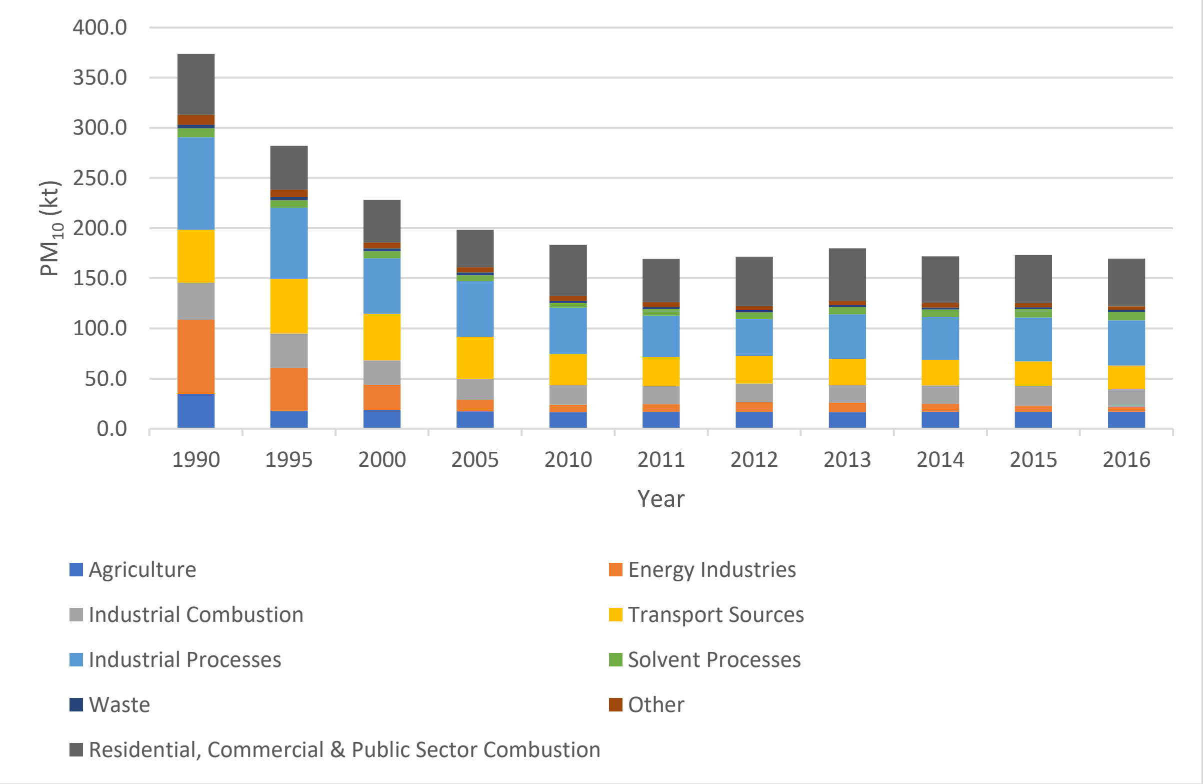

Figure 2.2: Graph showing the contribution of PM_{10} sources for each year for the United Kingdom (Source: data from DEFRA, 2018).

Since 1990 PM_{10} levels have been decreasing with an overall reduction of 54% from 1990 to 2016 (DEFRA, 2018). Figure 2.2 shows there is a wide range of sources for PM_{10} pollution, with transport sources, residential commercial and public sector combustion, industrial combustion and industrial process being the largest contributes in 2016 (DEFRA, 2018). Figure 2.2 also shows that the sector with the largest reduction in PM_{10} emissions was the energy sector which is a result of the reduction in coal-fired energy and an increase in natural gas (DEFRA, 2018). This is shown by the United Kingdom Department of Energy Statistics (2018) that states that the UK produced 39 Million tonnes of oil equivalent natural gas but consumed 75 Million tonnes of oil equivalent natural gas in 2018. There has also been a reduction in PM_{10} emissions from vehicle exhausts due to the decrease in emissions from diesel vehicles as a result of emission standards becoming firmer over time (DERFA, 2018). The only sectors to have had an increase in PM_{10} levels since 2007 is the residential and combustion from unclassified industries, which is likely due to an increase in the use of wood as fuel (DEFRA, 2018).

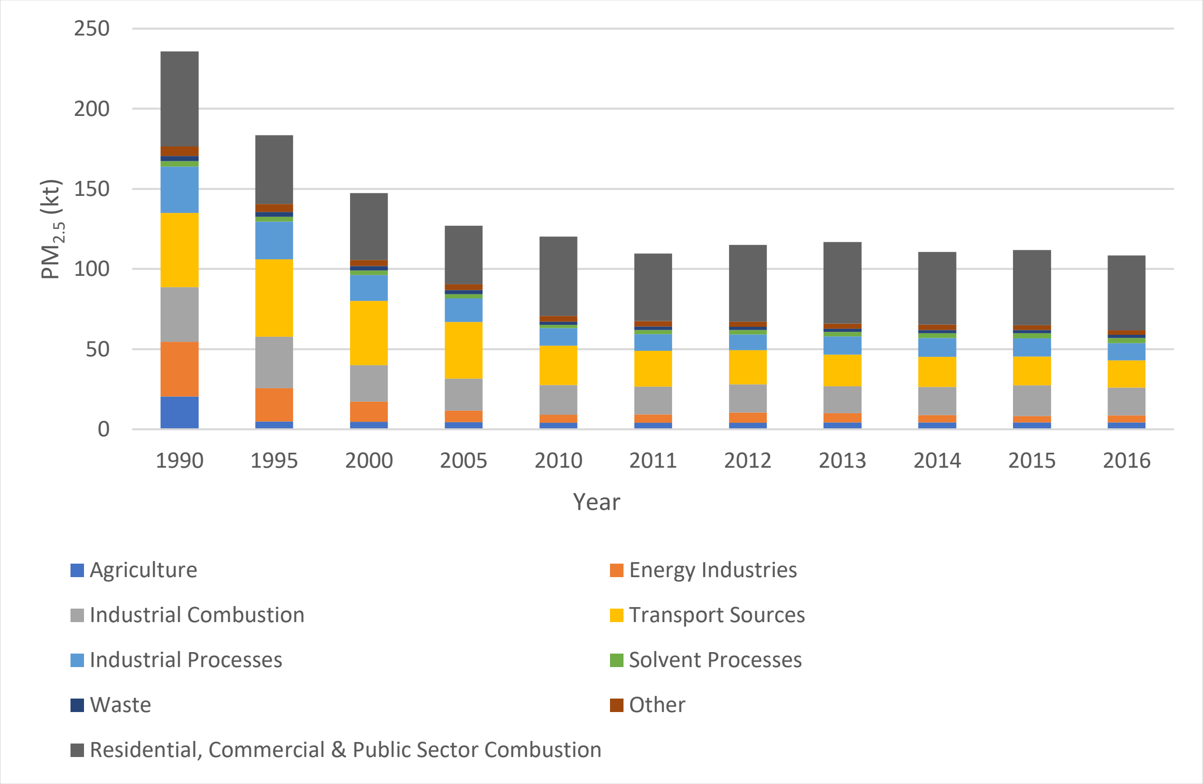

Figure 2.3: Graph showing the contribution of $PM_{2.5}$ sources for each year for the United Kingdom (Source: data from DEFRA, 2018)

$PM_{2.5}$ emissions have also decreased since 1990 with a reduction of 53% from 1990 to 2016 (DEFRA, 2018). Figure 2.1 shows $PM_{2.5}$ emission also has numerous sources with residential, commercial and public sector combustion, energy industries and industrial combustion and transport sources being the largest contributors (DEFRA, 2018). It also shows the main cause for the decline in pollution levels is a reduction in the use of coal and increase in the use of natural gas in energy production (DERFA, 2018). However, since 2005 there has been an increase in emissions from the residential sector mostly as a result of an increase in the combustion of wood (DEFRA, 2018).

As discussed earlier, wood burning in homes has increased, which is an issue as it is one of the largest contributors of particulate matter. One of the ways that the government plans to target this issue is to limit or ban the sale of wet wood, as it is known it releases more pollutants then dry wood (Institute for Public Policy Research, 2018). However, one of the issues is that there is little research into the area of domestic wood burning so it will be difficult for the government to regulate (Institute for Public Policy Research, 2018).

2.4 Health Effect of Particulate Matter

One of the reasons air pollution is a concern is the negative health effects it can cause. One of the earliest major air pollution incidents was the London Smog of 1952 which at the time was estimated to have caused 4,000 deaths. Analysis was conducted in 2001 to assess the effect of air pollution on the direct and indirect indicators of respiratory morbidity and mortality, with longer lag periods to reflect the fact that often the health effects of air pollution are long term (Bell, Davis & Fletcher, 2004). The calculated that 12,000 excess deaths occurred between December 1952 and February 1953 (Bell, Davis & Fletcher, 2004). This indicates the severe effects that can occur from high pollution episodes, but there is increasingly persuasive evidence that life time exposure to lower levels of air pollution also have the potential to significantly influence rates of mortality and morbidity in exposed populations.

There is a significant body of research that indicates a causal link between air pollutants and respiratory and coronary morbidity. Particulate Matter has been shown to trigger asthma in young children (César, Nascimento, Mantovani & Vieira, 2016; Jung, Chen, Tang & Hwang, 2019). It has also been found to increase the likelihood of lung cancer (Raaschou-Nielsen et al, 2016; Li et al, 2018).

More recent research in this field suggests a wider range of links between exposure to air pollutants and health effects. Recent studies have also found a link between exposure to particulate matter and development of Attention Deficit Hyperactivity Disorder (ADHD) in children (Markevych, Tesch, Datzman, Romanos, 2018; Agehaei, Janjani, Yousefian, Jamal & Yunesian, 2019).

A link has also been found between $PM_{2.5}$ and dementia incidence (Chen et al, 2017). Chen et al (2017) conducted a population-based study in Ontario, Canada that included residents who were 55-85 years old, Canadian-born and free of diagnosed dementia. They found there was a positive correlation between $PM_{2.5}$ and dementia incidence with a hazard ratio of 1.04% for every interquartile-range with increased exposure to $PM_{2.5}$. This equates to around 6.1% of dementia cases being attributable to $PM_{2.5}$.

2.5 Air Quality Regulations

One of the first major pollution incidents in the UK was the London Smog that occurred in December 1952 that lasted for 4 days and is estimated to have caused the deaths of 4,000 people (Bell, Davis & Fletcher, 2004). This resulted in the government setting a committee with the aim of coming up with a solution to smoke pollution. This resulted in them recommending introducing legislation to eliminate particulate emissions such as smoke, dust and grit. To meet this aim, the Clean Air Act was introduced in 1956 which was the first-time controls where introduced to limit the production of smoke, grit and dust from commercial as industrial activities as well as domestic fires.

From the 1970's the problems of smoke, dirt and dust and grit reduced due to changes in the industrial process lead to a gradual improvement in air quality (DEFRA, n.d). However other issues started to arise, and this led to a new direction needed to combat air quality issues (DEFRA, n.d).

The first Clean Air Act was introduced by the UK government in 1956 and the world's first co-ordinated national air pollution monitoring network was created in 1961 (DEFRA, n.d). This was called the National Survey which monitored black smoke and sulphur dioxide. As the main source of pollution in the UK changed to vehicular emissions over industry the Automatic Urban Network was developed to monitor air pollution in compliance with emerging European Commission Directive limit values on air quality in 1987 (European

Commission, 2018.) In 1992 the Department of Environment then created the Enhanced Urban Network (EUN) and then in 1995 all statutory and other urban monitoring was consolidated into one comprehensive programme (DEFRA, n.d). In 1998 all UK urban and rural networks where combined to create the current Automatic Urban and Rural Network (AURN) which is now the most important and comprehensive automatic national monitoring network in the country, which is made up of 127 sites across the UK (DEFRA, n.b).

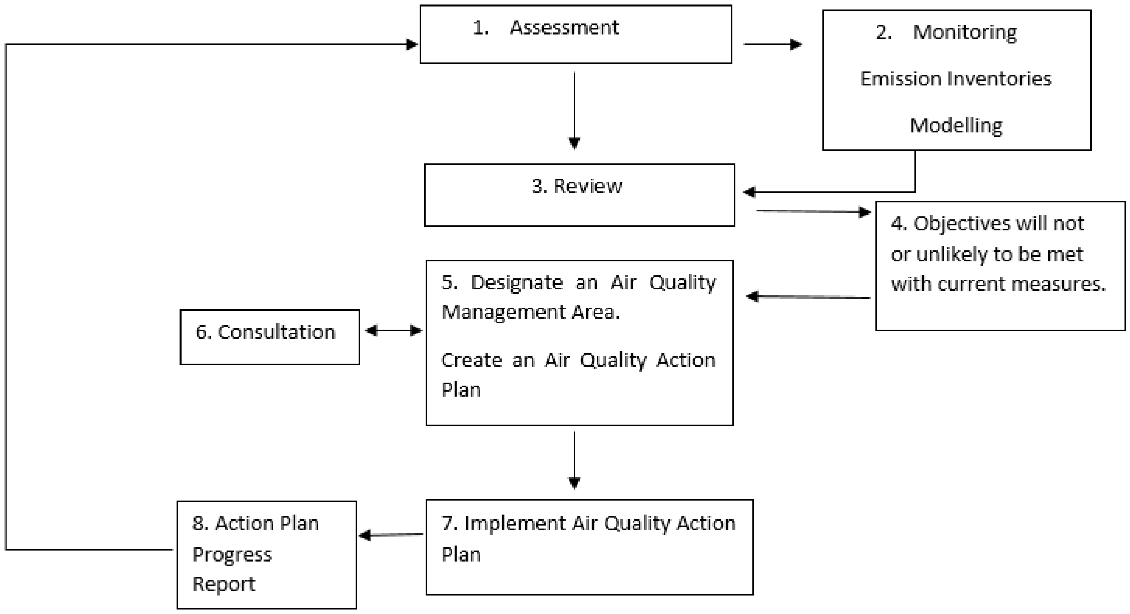

Figure 2.4: Flow chart showing local authority process for air pollution management.

Local Authority are responsible for monitory and reporting air pollutant levels and reporting this to DEFRA (DEFRA, 2018). In England this is done by submission of a single of Annual Status Report, the stages to this are shown in figure 2.4 (DEFRA, 2018). This should be tailed to each region specific to the area's needs (DEFRA, 2018). Pollutants that are mandatory to monitor and report on are NO_2, PM_{10}, $PM_{2.5}$ and SO_2 with other pollutants only being necessary if there is an issue in the area (DEFRA, 2018).

Figure 2.3 shows the first stage is to carry out an assessment of the pollution levels in the area (DEFRA, 2018). This will enable local authorities to identify the areas where air quality objectives are or likely to be exceeded (DEFRA, 2018). This should provide information on key pollutant sources, the nature and extent of exceedance, the number and location of receptors and the degree of population that will be exposed (DEFRA, 2018). As shown by box 2 in figure 2.4 this should be done by a combination of monitoring and modelling pollution levels as well as emission inventories (DEFRA, 2018).

The information from the air monitoring and assessment can then be used to review the pollution as shown by box 3 which then leads to assessing if the objectives are likely to be met (DEFRA, 2018). Area that are not going to meet the objectives should be designated an Air Quality Management Areas (DEFRA, 2018). Each of these areas is required to have an Air Quality Action Plan (AQAP) (DEFRA, 2018). This should develop measures that will ensure emissions reduction to reach air quality objectives within the necessary time scales (DEFRA, 2018). The information from the air monitoring and assessment can then be used to determine what effort is needed to reduce the pollutant emissions to the necessary levels to reach the objectives (DEFRA, 2018). When assessing ways to reduce pollution levels there are measures across government policy areas such as national air quality plans and sustainability strategies (DEFRA, 2018). During this process local authorities should also consult with local organisation and bodies that may be affected be the plan (DEFRA, 2018). Statutory bodies such as DEFRA, environment agency should also be consulted (DEFRA, 2018). This should then lead to an Action Plan Progress Plan report which updates on the pollution levels and then this should be used to make an assessment to see if enough progress has been made to meet the objectives (DEFRA, 2018).

The 1997 National Air Quality Strategy was legislated by the 1995 Environment Act which provides a corresponding approach throughout the whole UK for air quality management to ensure the population has access to outdoor air without significant health risk (Bell & McGillivray, 2006). This strategy was developed to include national measures which would be able to tackle larger scale issues that has arisen (Bell & McGillivray, 2006). This included vehicle fuel quality, engine technology standards and emissions from combustion processes (Bell & McGillivray, 2006). It aimed to manage air quality and reduce the chances of negative health effects through national and local-level action to comply with Air Quality Objectives for the relevant pollutants (Bell & McGillivray, 2006). Air Quality Objectives, which are in the UK Air Quality Regulations, are set at levels below which negative health effects are unlikely, or small, even in high-risk groups (Bell & McGillivray, 2006).

Since 1997, relevant European Air Quality Directives have been consolidated as the European Ambient Air Quality Directive 2008/50/EC and three revisions of the UK National Air Quality Strategy have been published (Bell & McGillivray, 2006). The Air Quality Strategy 2000 recognised that clean air is important to the population is they are going to be able to have a good quality of life (Bell & McGillivray, 2006). The most recent Air Quality Strategy for England, Scotland, Wales and Northern Ireland was published in 2007 whilst the last update to the UK Air Quality Regulations was published in 2010 (Longhurst, Barnes, Chatterton, Hayes &Williams, 2016). Some process-reporting streamlining and modifications of AQO timescales, values and/or exceedance limits, LAQM's two-stage effects-based approach of air quality assessment in the context of public exposure followed, where necessary, by an AQMA declaration and development of an action plan, has remained largely unchanged since its inception (Longhurst et al., 2016).

While in the European Union the UK government must report compliance with European Limit Values to the European Commission. In 2013 the UK exceeded the EU limit value for NO_2 annual mean at 31 of its 43 zones and agglomerations and the government predicts it will not be met until 2025 (Longhurst et al., 2016). In April 2015, following a legal challenge by Client Earth, the Supreme Court ruled that the UK is in breach of the European Air Quality Directive, and insisted that the government draw up a plan for compliance by the end of this year (Longhurst et al., 2016). In 2015, the UK Government consulted on its proposals and in late 2015 published its plan to comply with the European Air Quality Directive (Longhurst et al., 2016). This is published by the Department of Environment, Food and Rural Affairs in the December of 2015 and was titled 'Improving air quality in the UK. Tackling nitrogen dioxide in our towns and cities'. it included new assessments of air quality in the UK and acknowledges that full compliance will not be met till 2025 however exceedances are still expected to occur after 2020 in Birmingham, Leeds, Southampton, Nottingham Derby and London (Longhurst et al., 2016). The government intends the Local Authorities of these areas to implement a new approach to pollution management through designation of a Clean Air Zone (CAZ) (Longhurst et al., 2016). Table 2.1 shows the limit values that are set for 24 hours mean and annual average from different organisations. The limits set by the UK are the same as those from the EU. The WHO guidelines are based on what levels will not impact the public health from scientific research that's conducted (Krzyzanowski & Cohen, 2008). European Union guidelines take into account health effects however they are deciding politically and decided to be more manageable to achieve.

Table 2.1: Table showing particulate matter air quality standards from different organisations.

Pollutant	Average Period	UK	EU	WHO
$PM_{2.5}$	Hourly	n/a	n/a	25 µg/m^3
	Annual	25 µg/m3	25 µg/m^3	10 µg/m^3
PM_{10}	Hourly	50 µg/m3	50 µg/m^3	50 µg/m3
	Annual	40 µg/m3	40 µg/m3	20 µg/m3

As has been discussed air quality has been shown to have negative health effects with pollution levels and this has led to research being conducted into the link between pollution levels and socio-economic status.

2.6 Pollutant Concentration Calculation Methods

To calculate pollutant concentration for each ward in Britain the coordinates and corresponding ward identifier were imported into a relational database along with an NO_2 coordinate and value data which allowed the wards central coordinates to be paired with the nearest concentration data point. This is a method could lead to less accurate rural area pollution concentration therefore to avoid the biased estimates of pollution estimates due to area weighting mean concentration Briggs, Abellan and Fecht (2008) used postcode headcount weighting to calculate pollution levels for each area. This will allow for a more accurate representation of pollution levels that the population is exposed to. However, both methods assume a person’s expose is the same as an area’s pollution level. Therefore Tonne et al. (2018) used individual-level data and calculated exposure using the London Hybrid Exposure model (LHEM) which estimated pollution exposure based on the individual’s residential location, trips, mode of transport and time spent in non-residential locations between trips.

2.7 The Link between Socio-economic Status and Pollution Concentration

The link between socio-economic status has been studied to gain an understanding into the relationship between pollution and pollution concentration in areas of different deprivation. Understanding the problem is key to being able to create effective solutions to combat the problem as it is unjust for a group of the population to be exposed to higher pollution levels than others. Environmental justice is the principle that regardless of socio-economic status or ethnicity no group should bear the brunt of environmental hazards and the benefits of environmental amenities should be shared fairly (Mitchell, Norman & Mullin, 2015). Studies into this area where developed by activist groups in the USA with the focus on toxic waste facilities and industrial sites and emissions (Mitchell, Norman & Mullin, 2015). In the 1990s research started taking place the UK with a broader range of issues including industrial sites, landfills, air quality, flooding and traffic accidents (Mitchell, Norman & Mullin, 2015).

2.8 Determining Socio-economic Status

When conducting research into the link socio-economic status and air pollution in Britain the Index of Multiple Deprivation (IMD) is often used. This is been used in such studies as Briggs, Abellan and Fecht (2008) and Tonne et al. (2018). The IMD has an overall ranking and is also split into seven domains which Lower Layer Super Output Area from most deprived to least deprived. Briggs, Abellan and Fecht (2008) used all domains to assess the link between pollution concentration whereas Tonne et al. (2018) only used the income domain.

Census data has also been used to determine socio-economic status such as Loizeau et al. (2018) used yearly income from the 1996 Census of Population by Statistics Canada to determine socio-economic status. Only using income as an indicator of socio-economic status is not highly accurate therefore using more indictors is suggested such as Li at al. (2018) which used low income, low education and non-professional occupation data being used from the 2011 HK population census.

2.9 Data Analysis

Correlation is often used to assess the link between socio-economic status and pollution concentration Briggs, Abellan and Fecht (2008) and Li et al. (2018) used a Spearman rank correlation and Briggs, Abellan and Fecht (2008) also used a Pearson’s product moment correlation. This is useful as it shows if the link is strong or weak as well as positive or negative. Li et al. (2018) also used an ANOVA which can also show if there is a significant difference between pollutant levels and socio-economic status.

Tonne et al. (2018) used summary statistics and quantile regression to assess the links between socio-economic status and pollution levels. Using a quantile regression is more accurate as it makes no assumptions about the distribution of the data.

2.10 Findings

Most studies found a link between socio-economic status and pollution concentration however there was differences in the strength of the link found. Briggs, Abellan and Fecht (2008) found there was a strong positive correlation between income, employment, education, health and overall IMD domains. However, this is contradicted by Tonne et al. (2018) who found that there was a weak correlation between income and pollution exposure. This could suggest that by using area level pollution it is overestimating people's exposure.

Mitchell and Dorling (2003) found that there the most deprived wards were exposed to NO_2 concentration being 17% above the national average however the least deprived wards had concentrations 7% above the national average. This suggest that the link between socio-economic status and pollution concentration is not linear.

Lin et al. (2018) also found there was a difference in pollution levels experienced by people in different socio-economic status and through both the correlation and ANOVA.

2.11 Conclusion

Previous studies have proven that there is a health risk with being exposed to high level of particulate matter pollution. It has also been shown that people of lower socio-economic status have been exposed to higher levels of pollutants and that they may even be more susceptible to the effects of these pollutants. This shows that this is an important area to study.

Chapter 3: Research Overview

3.1 Introduction

In order to explore the relationship between air quality and socio-economic status the research adopts a three-pronged approach to the subject matter. This chapter will provide a brief overview of the three studies, why they were undertaken and how they link together. Chapters 4, 5 and 6 will then provide more detailed information on each study methodology and results.

As shown by figure 3.1 this project had three separate research studies undertaken. The studies were designed to examine the links at different spatial and temporal scales utilising data from a number of different sources. These studies involved the use and analysis pre-existing data sources together with the collection of new data. The three-pronged approach involved a primary data collection study, a monitored data study and modelled data study.

Figure 3.1: Diagram showing the separate research studies and the order they take place in.

The reason for having three studies was to be able to assess pollutant concentrations and the link between socio-economic status and pollution levels at different spatial and temporal scales. Another reason for this is to assess the differences in pollution concentration over different periods of time. The primary data study collects pollution concentration at a neighbourhood scale over short periods of time to examine peak concentrations and changes that may occur over minutes and hours. The AURN data study uses permanent monitoring stations which are placed in specific strategic locations such as roadsides and urban background areas and data is collected over long periods of time. This allows for to temporal analysis which can be used to evaluate longer term trends over months and years. The modelled data study uses background PM_{10} concentrations for lower super output areas in Greater Manchester. Background pollution shows the lowest level of ambient air pollution that the population is regularly exposed to (Gomoz-Losada, Pires & Pino-Mejias, 2018).

As well as assessing differences in pollution concentration over different temporal and spatial scales it will enable comparison of how the design of a study may have an impact on the link found between socio-economic status and pollution concentration.

3.2 Study Areas

Part of the overall aim of this study was to assess if the same trends in pollution levels were found over different spatial scales therefore the study areas for each location were different sizes. While the locations of each study were different, they were still chosen with aim of having similar characteristics to make them comparable and there was overlap in study areas throughout the three studies. The primary data study took place in three areas within Greater Manchester with three study sites in each area. This would allow for spatial analysis between both the areas and sites.

The AURN data study took place across the North West of Britain with Government permanent monitoring being selected that monitored the correct pollutants.

The modelled data study took place across Greater Manchester which the data being for lower super output areas.

All the study includes Greater Manchester and the AURN study took place in the north west to maintain a similarity. As one of the aims is to assess pollution concentration across different socio-economic areas it was important to have comparable study sites. By having different spatial sizes throughout the different studies, the link between socio-economic status and pollution levels could be compared and see if it is affected.

3.3 Pollution Collection Methods

All three studies had different ways of measuring particulate matter concentration with different temporal scales. One of the aims was to carry out a sampling regime for collecting air quality data therefore for the primary data study DustMate® environmental dust detector was used to collection pollution levels at the three monitoring sites within three different areas. Data would be collected for between thirty minutes and an hour at a time which would allow for changes in pollution concentration to be seen over minutes.

Another aim was to study UK Government air pollution data across an area in the North of England. To complete this aim the AURN data study would use government permanent monitoring stations data within the selected study area that monitored the correct pollutants (PM_{10} and $PM_{2.5}$). The monitoring stations are placed in strategic locations to monitor pollutants every hour all year around which allows long term trends to be assessed. This would allow insight into long term pollution trends in these areas.

A further aim was to assess modelled PM pollution data therefore a modelled data study would take place. The modelled pollution data used was annual background PM_{10} concentration for Greater Manchester at a Lower Super Output level. This would allow comparison between what the lowest pollution concentration and what is experienced on a more daily basis.

By using a permanent monitoring station were data can be seen for a large time period and primary monitoring data over a short period and annual background averages allows assessment in the temporal variations in the pollution levels. It will determine see if the link between socio-economic status is dependent on the time period data is collected from.

3.4 Socio-economic Status

One of the aims was to assess the link between socio-economic status and pollution concentration therefore a deprivation level had to be assigned to the study areas.

To determine socio-economic status for both the primary and AURN data study the Index of Multiple Deprivation was used to assign a deprivation to each study location. This is in the spatial unit of a Lower Layer Super Output Area. This has been used in previous studies that have taken place in the UK such as Briggs, Abellan and Fecht (2008) and Tonne et al. (2018).

For the modelled data study, the Access to Health Assets and Hazard (AHAH) Index was used to assign the deprivation to an area. This was also in the spatial unit of a Lower Layer Super Output Area. The index measures how healthy an area is and assigns a risk level to it. This one done to assess the differences in deprivation and risk that may be in an area and if risk is always equal to deprivation. As there is no standard for studies for determining deprivation this could result in the differences in the link found between socio-economic status.

Chapter 4: Primary Data Collection

4.1 Introduction

Primary data collection was used to provide detailed information on pollutant concentrations in specific areas. Monitored data is useful as it provides accurate data from the location but has some limitations as it only provides data for a small spatial area. Another issue is that monitoring would normally need to occur over a long period of time as otherwise the data might not provide an accurate representation of the usual pollutant concentrations of the area.

To determine if there is an identifiable relationship between socio-economic status and air pollution, primary data collection took place within Salford and Manchester, which was chosen as the case study area. There were three areas of different socio-economic status selected from which pollution data would be collected. This study set out to assess if there was any variation in pollution concentration in a small spatial area, so there were three different monitoring sites selected from each area.

This chapter discusses the aim and objectives, the methods used and the justification for their choice with reference to previous studies and the results found.

4.2 Aims and Objectives

The aim was to assess the relationship between socio-economic status and pollution levels through collecting primary data based on pollution monitoring.

The aim was achieved through fulfilling the following objectives:

A. To select appropriate study sites.
B. To design a method for data collection.
C. To conduct data analysis assessing the relationship between socio-economic status and pollution concentration.

By collecting data from three areas of different socio-economic status it would allow comparison of pollution concentration between these areas to determine if there is a statistically significant difference. Pollution levels can also be compared between each site within the area to ascertain if there was any spatial variation.

Salford and Manchester were chosen as the study area as it would allow time for adequate data collection in the time available. The two cities also have areas of varying IMD ranking which was needed to allow comparison.

4.3 Socio-Economic Status

To select the study areas the IMD 2015 explorer was used, which is an interactive online map showing the IMD ranking of all wards within the UK. The overall IMD domain ranking was used to ascertain socio-economic status; however, other domains such as living environment and income were also used when conducting data analysis.

For each study area three sites were identified of broadly similar character. All areas chosen were residential areas so that they could be compared. Three wards were chosen as the areas with one of high (decile 1), medium (decile 5) and low (decile 7) deprivation and within them three sites chosen to monitor pollution.

Each of the monitoring sites had different characteristics to allow comparison of pollution concentration within each area. One close to the main source of pollution (roadside), one background site and one close to a residential area. This would enable assessments of any spatial variation of pollution concentration within the area. Monitoring was undertaken at a background site as according to the Local Air Quality Management Technical Guidance (TG16) it is needed to obtain a representation of pollution concentration in the area. This can then be used to ascertain variations in pollution levels as a result of local sources. For the sites in this study the most common factor would be changes in traffic levels.

4.4 Description of the Study Sites.

Tables 4.1 to 4.4 show what the study areas (Table 4.1) and sites (Tables 4.2-4.4) for each location. The area refers to the ward chosen, and the site refers to the location in which monitoring was undertaken. From this point the areas and sites will be referred to by their code (table 4.1-4.4).

Table 4.1: Table showing study area names and code which they will be referred to.

Area Name	Area Code
Hulme	1
Irwell Riverside	2
City Centre	3

Table 4.2: Table showing monitoring sites for Area 1 and code which they will be referred to.

Site Names for Area 1	Site Code
St Wilfrid’s	1A
Chevassut Street	1B
Chorlton Road	1C

Table 4.3: Table showing monitoring sites and the code they will be referred to for area 2.

Site Name for Area 2	Site Code
St Stephen Street	2A
Trinity Way -Green Wall	2B
Trinity Way	2C

Table 4.4: Table showing monitoring sites and the code they will be referred to for area 3.

Site Name for Area 3	Site Code
Potato Wharf 1	3A
Potato Wharf 2	3B
Liverpool Road	3C

Figure 4.1 shows the monitoring sites for Area 1. Area 1 is ranked 1,563 out of 32,844 Lower Super Output Areas (LSOAs) in England, where 1 is the most deprived LSOA. Therefore, this was selected as an area of high deprivation. Hulme is a ward in Manchester with a population of 16,907 according to the 2011 UK census (Office for National Statistics, 2016). It is primarily a residential area with a small park nearby as well as a being close to a major road, the A50. Site 1A was next to a school and residential area, site 1B was next to busy side street and residential area and site 1C was next to a main road, Chorlton Road, which was also close to residential properties.

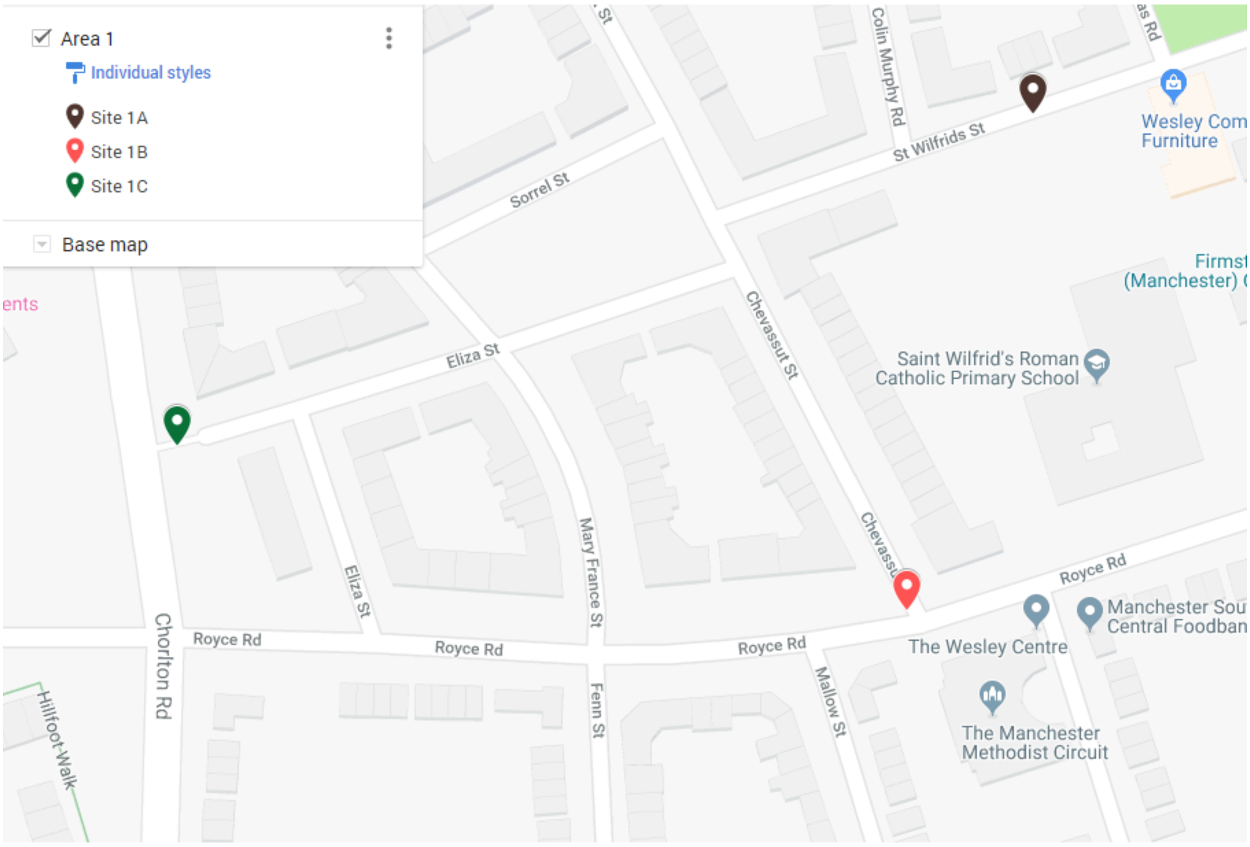

Figure 4.1: Map showing the sites for Area 1. (Google Earth, n.d.-1)

Figure 4.2 shows the location of the sites in Area 2. Area 2 is ranked 14,628 out of 32,844 LSOAs in England and was chosen to represent an area of middle deprivation. Irwell Riverside is a ward in Salford and has a population of 12,734 (Office for National Statistics, 2016). Site 2A is a residential area with small area of green space and is close to a major road, Trinity Way. Site 2B is next to Trinity Way being next to the road but behind a green wall with Site 2C being right next to the road. This would be used to determine how effective the green wall is in reducing the pollution levels.

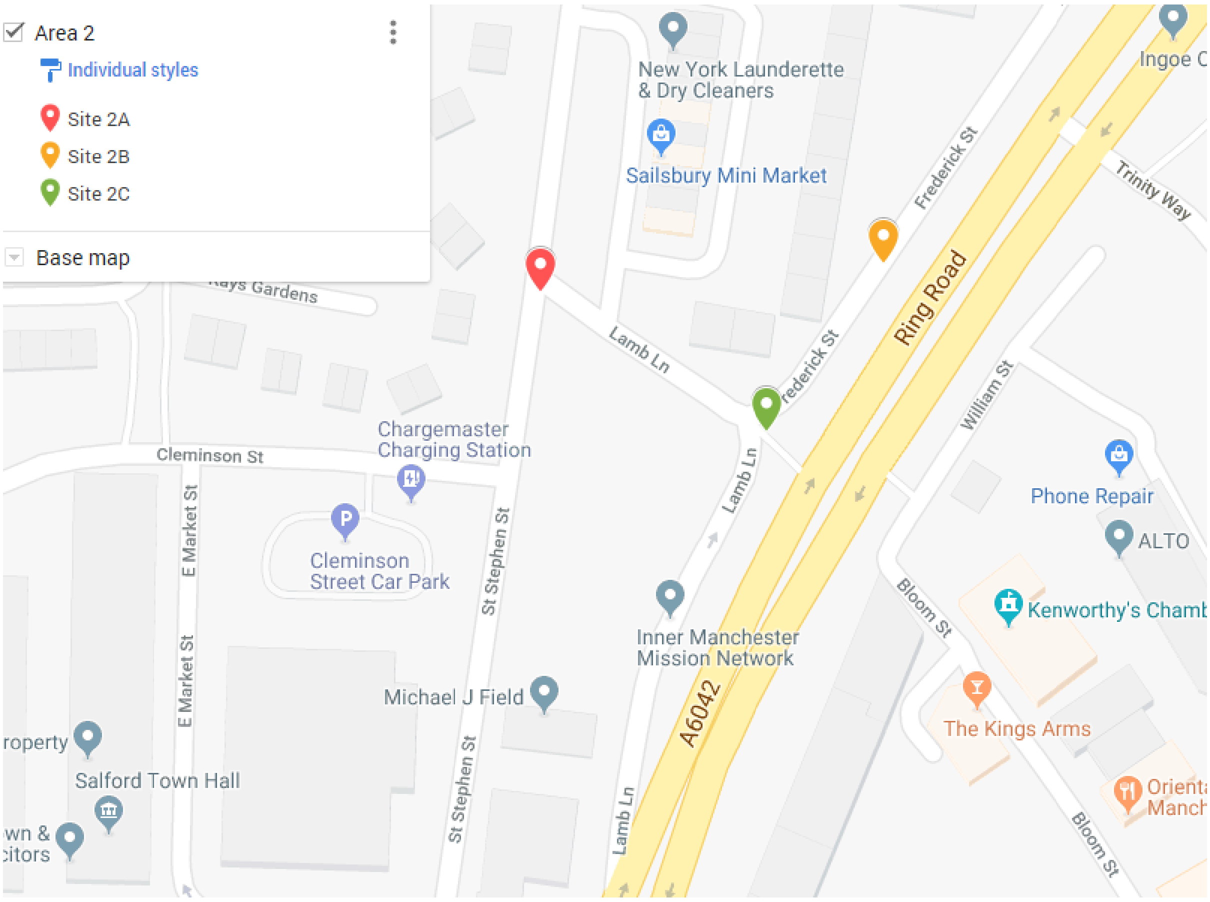

Figure 4.2: Map showing the monitoring sites at Area 2. (Google Earth, n.d.-2)

Figure 4.3 shows the sites where the monitoring had taken place in Area 3. Area 3 is ranked 20,221 out of 32,844 LSOAs in England and was chosen to present an area of low deprivation. It is located in Manchester's city and has a population of 17,861 according to the 2011 census (Office for National Statistic, 2016). The area is largely residential with some business close by and is a small distance from Manchester city centre. Site 3A was next to residential area and a quiet road, site 3B was next to a busier side street and residential area and Site 3C was next to a main road which leads into Manchester city centre.

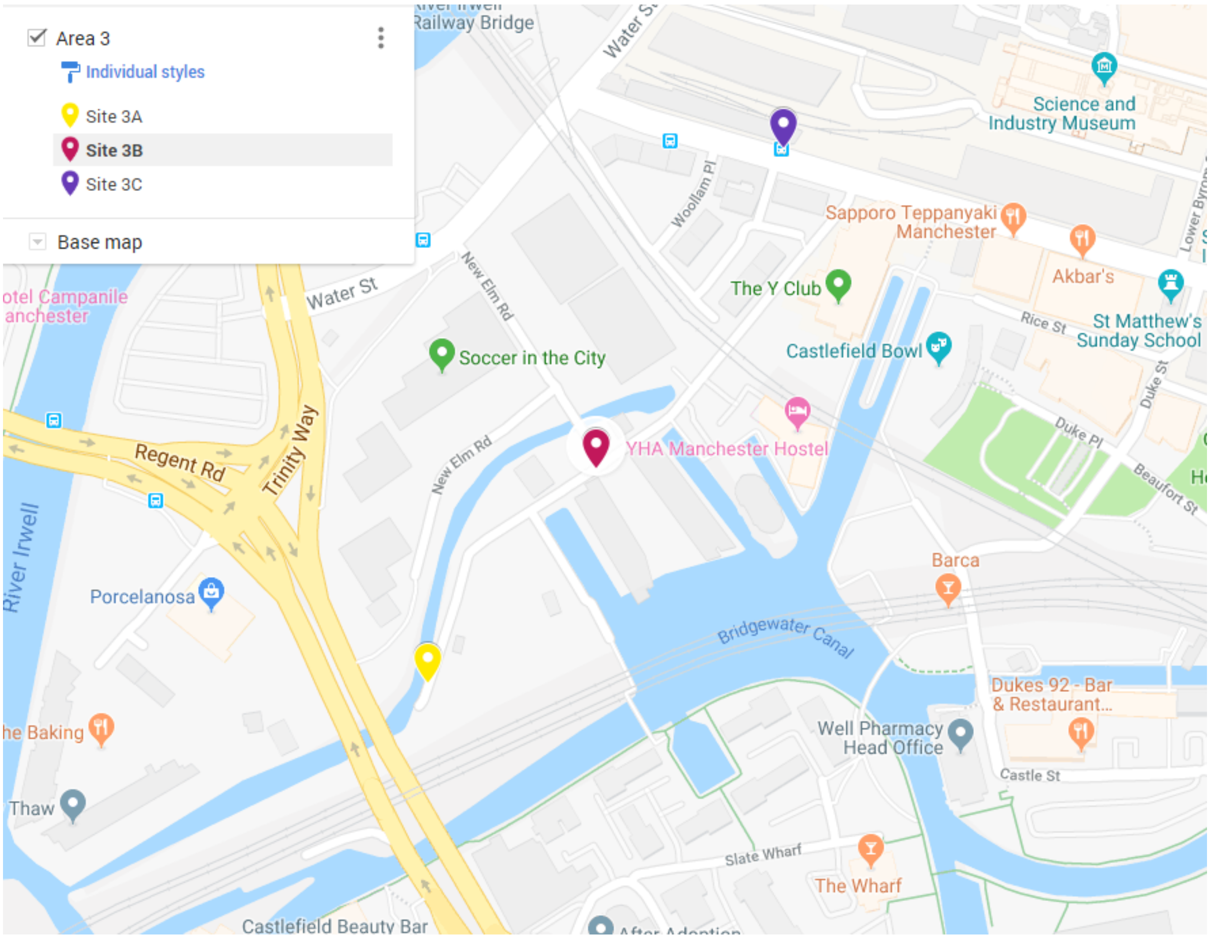

Figure 4.3: Map Showing study sites in Area 3. (Google Earth, n.d.-3)

4.5 Methods

This section will discussion the methods for data collection and analysis.

4.5.1 Monitoring Equipment and Data Collection

Tables 4.5 to 4.7 show the date and time of when the monitoring undertaken. These tables illustrate the number of site visits, and the dates and times of the monitoring events.

Table 4.5: Table showing the visits to monitor pollution at Area 1.

Area 1	Visit 1 17/05/2018	Visit 2 23/07/2018	Visit 3 01/08/2018	Visit 4 07/08/2018	Visit 5 14/08/2018
Site 1A	09:58 – 10:30	10:43-11:44	11:40-12:40	10:12-11:13	n/a
Site 1B	09:58-10:30	10:38-11:39	11:33-12:34	10:29-11:30	11:22-11:52
Site 1C	10:43-11:39	12:00-12:59	12:52-13:53	11:31-12:31	11:21-12:21

Table 4.6: Table showing the visits to monitor pollution at Area 2.

Area 2	Visit 1 21/05/2018	Visit 2 26/07/2018	Visit 3 30/07/2018	Visit 4 08/08/2018
Site 2A	11:10-10:40	09:53-10:54	12:19-13:20	09:44-10:45
Site 2B	10:45-11:15	11:05-12:06	11:08-12:09	10:56-11:56
Site 2C	11:18-11:47	11:02-12:02	11:09-12:09	10:53-11:53

Table 4.7: Table showing the visits to monitor pollution at Area 2.

Area 3	Visit 1 27/07/2018	Visit 2 03/08/2018	Visit 3 06/08/2018	Visit 4 15/08/2018
Site 3A	10:05-11:05	12:23-13:23	10:27-11:27	11:51-12:21
Site 3B	10:07-11:07	12:22-13:23	10:22-11:23	11:51-12:04
Site 3C	11:26 - 12:25	11:12-12:13	11:39-12:39	11:11 – 11:42

To conduct the primary data collection a DustMate® environmental dust detector was used which would monitor TSP, PM_{10}, $PM_{2.5}$ and PM_1 levels. Other studies that have used this equipment include Deary, Bainbridge, Kerr, McAllister and Shrimpton (2016) who used the machine to monitor PM_{10} and $PM_{2.5}$ and map their concentrations on a city-wide scale. Liu, Chen, Shen and Mao (2004) used the machine to assess indoor Particulate Matter concentration. For this study pollutant concentration was recorded once a minute. Two machines were used to concurrently monitor at each area with the same machine used at the same site for each monitoring event. This would allow pollution concentrations to be measured at two sites at the same time which would rule out time of day as the cause of difference in pollution levels. Unfortunately, all three sites would not be able to be monitored concurrently due to a limit on the number of monitors available during each monitoring event. To reduce the likelihood of differences in pollution levels due to time of day the third site would be monitored straight after the first stage of monitoring.

Sites were visited on different days of the week to determine if that resulted in different pollution levels; however, they were visited at similar times of day to establish if that resulted in a difference in pollution levels.

According to the Local Air Quality Management Technical Guidance (TG16) published by DERFA when monitoring air pollution, the equipment should be placed close to the dominate pollution source. Since in the case of all the monitoring sites in this study the main source of PM pollution was a major road this was the location of the equipment when monitoring.

4.5.2 Comparison of Monitors.

Both machines being used were calibrated before data collection took place. An assessment of if the equipment would produce the same pollution concentration was undertaken. To do this both machines where set up next to each other near a roadside, which was the main source of pollution for the area and run for a total of 30 minutes. This would give insight into how similar the pollution level recordings from both machines where. This is important as both machines would be used concurrently to monitor at different sites therefore if the results from the machine are significantly different the analysis undertaken will not be as accurate. It is also important as the difference in the pollutant concentration could be a result of the machines and not the issues being studied.

4.5.3 Traffic Counts

Traffic counts would be taken at each monitoring event at each site. The traffic counts would be done for duration of each monitoring event with types of vehicles split into car, vans, HGV’s, buses and motorcycles. The traffic count would be taken while the monitoring was taken place using a tally. This would be used to give an indication of how much traffic contributes to pollution in each area. In certain studies, such as Steinberga, Sustere, Bikse, Bikse Jr and Kleperis (2019) traffic levels where used to model pollution levels of street canyons in Latvia.

4.5.4 Other Data Used

IMD ranking was used to determine socio-economic status, which is the official measure of relative deprivation for Lower-layer Super Output Areas (LSOA) in England. These areas are designed to be of similar population size to enable comparison between different areas. There are 7 domains of deprivation: income, employment, education, health, crime, barriers to housing and services, and living environment, which are then combined to create an overall level of deprivation. This has been used to in previous studies (Tonne *et al.*, 2018; Chalabi *et al.*, 2017) in the UK to determine socio-economic status.

Traffic counts from the Department of Transport were used as well as the traffic counts taken during the monitoring events. This would allow assessments to be made about the relationship between traffic flow and air pollution. According to TG16, traffic flow data must be in a 24-hour Annual Average Daily Traffic (AADT) format, it is also preferable to have traffic counts that are manually or automatically/continuously collected. Therefore, to supplement Department of Transport traffic counts, manual traffic counts were undertaken at each monitoring events as discussed in 4.3.4.

4.5.5 Data Analysis

Descriptive analysis was initially undertaken with each monitoring event being analysed separately. This included mean, variance, minimum and maximum. This gave an insight into pollution concentration over time in each site as well as provide information on any spatial variation between the sites.

Statistical analysis was undertaken to assess if there was a meaningful relationship between pollution levels and socio-economic status. This was performed using a Pearson Correlation Analysis as well as an ANOVA with IMD ranking being used to signify socio-economic status. ANOVA determines whether two groups have the same mean.

To assess the differences between the pollutants measured from both DustMate® machines statistical analysis was used which included mean, standard deviation, minimum, maximum and variance. Line graphs were also used to assess the pollutant concentrations over the monitoring event for both machines. This was intended to demonstrate whether there was a significant difference between the pollution concentrations recorded by the machines. A regression analysis was used to determine the differences in pollution concentrations were the same for each event as this would show if the differences were consistent.   This was done to determine whether there was a need for normalisation of data collected from the data.

4.6 Problems

While both machines had been calibrated and checked by the manufacturer before data collection took place, after the sites had been visited a few times an issue with the batteries for both machines developed. This resulted in not being able to monitor pollution levels for the planned time period for each monitoring event as shown by tables 4.5, 4.6 and 4.7. It also resulted in not being able to visit the sites an equal number of times with Areas 2 and 3 being visited four times and Area 1 being visited five times as shown by tables 4.5, 4.6 and 4.7. There was enough data collected to conduct analysis and determine if there where socio-economic status and pollution levels.

4.7 Results

For the results comparing the Dustmate® machines a graph showing the mean pollutant concentration and standard deviation for both machines. The tables showing the statistics and regression comparing the pollutants recorded by the machines are in the appendices.

The results of the pollution data collected at the monitoring sites will be shown in several different ways, the first being graphs that show the maximum pollution levels and standard deviation for each site in an area and graphs showing similar sites across each of the three study areas.

The results for the correlation performed to assess the link between socio-economic status and pollutant concentration will also be discussed and any ANOVA significant values will be discussed with the tables being available in the appendix.

4.7.1 Comparison of DustMate® Machines

Figure 4.4 shows that there was not a notable difference recorded for all pollutants and standard by both the machines. Appendices A to D show that there was also not a notable difference in the minimum and mean recorded for all pollutants. Appendices E to H show that there was no significant difference found in pollutant levels recorded when using a regression. For TSP the R^2 was -0.029, for PM_{10} the R^2 was -0.025, for $PM_{2.5}$ the R^2 was 0.022 and for PM_1 the R^2 was 0.057. This suggests that both machines are comparable and therefore can be used to concurrently monitor at different sites.

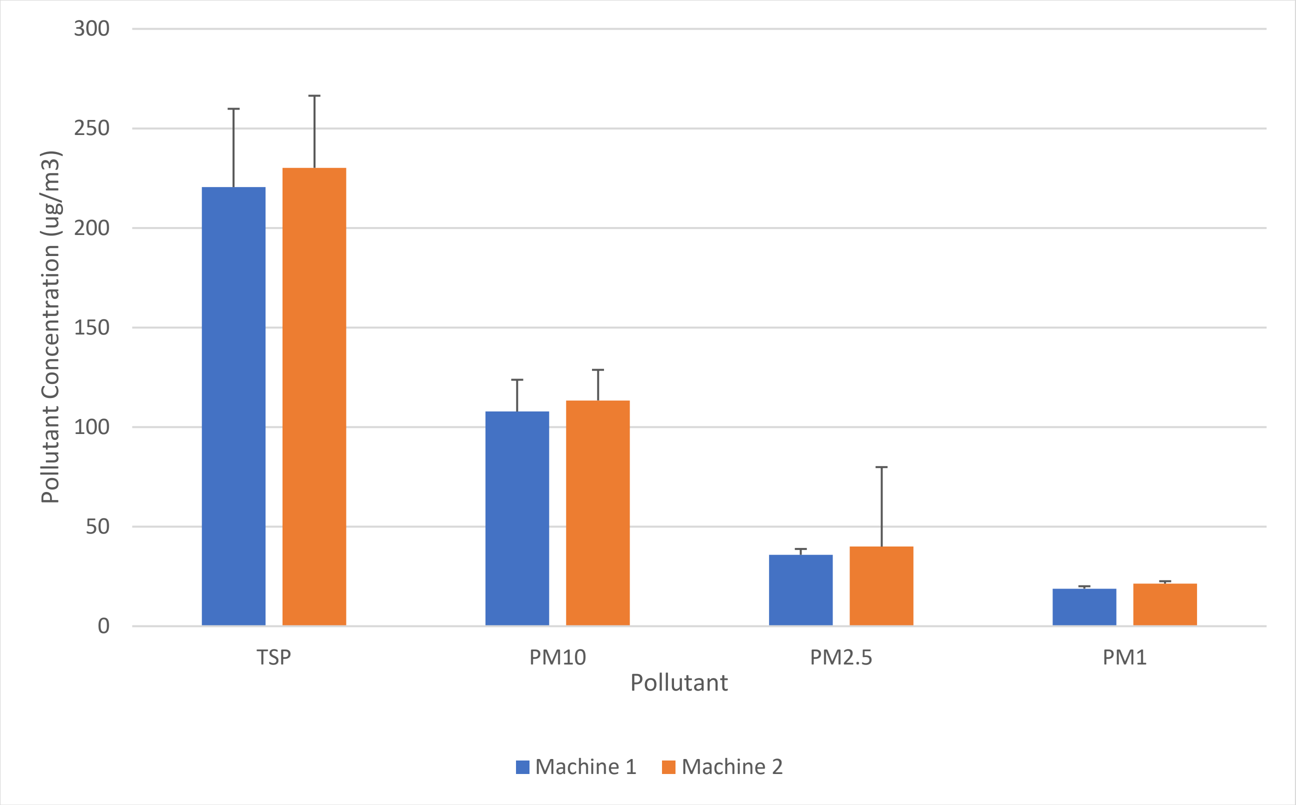

Figure 4.4: Graph showing the standard deviation and mean pollutant concentration for all pollutants recorded by both machines.

4.7.2 Analysis of Pollutant Concentrations Across Areas and Sites

To be able to assess for similarities and differences in pollution concentration graphs are shown that display the mean pollution levels and standard deviation for the study sites and areas.

Figure 4.5 shows that Site 1C had the highest levels of PM pollution and the greatest of standard deviation, which suggests that there is a higher level of variation. For instance, TSP at Site 1C had a standard deviation of 52.02 with a mean of 40.63 ug/m^3 suggesting high values of 92.65. The mean of PM$_{10}$ at Site 1C reaches the annual limit set by the WHO as shown by table 2.1. However, it is important to note that a years' worth of data is needed to generate a true annual average for the limits therefore it is not completely comparable.

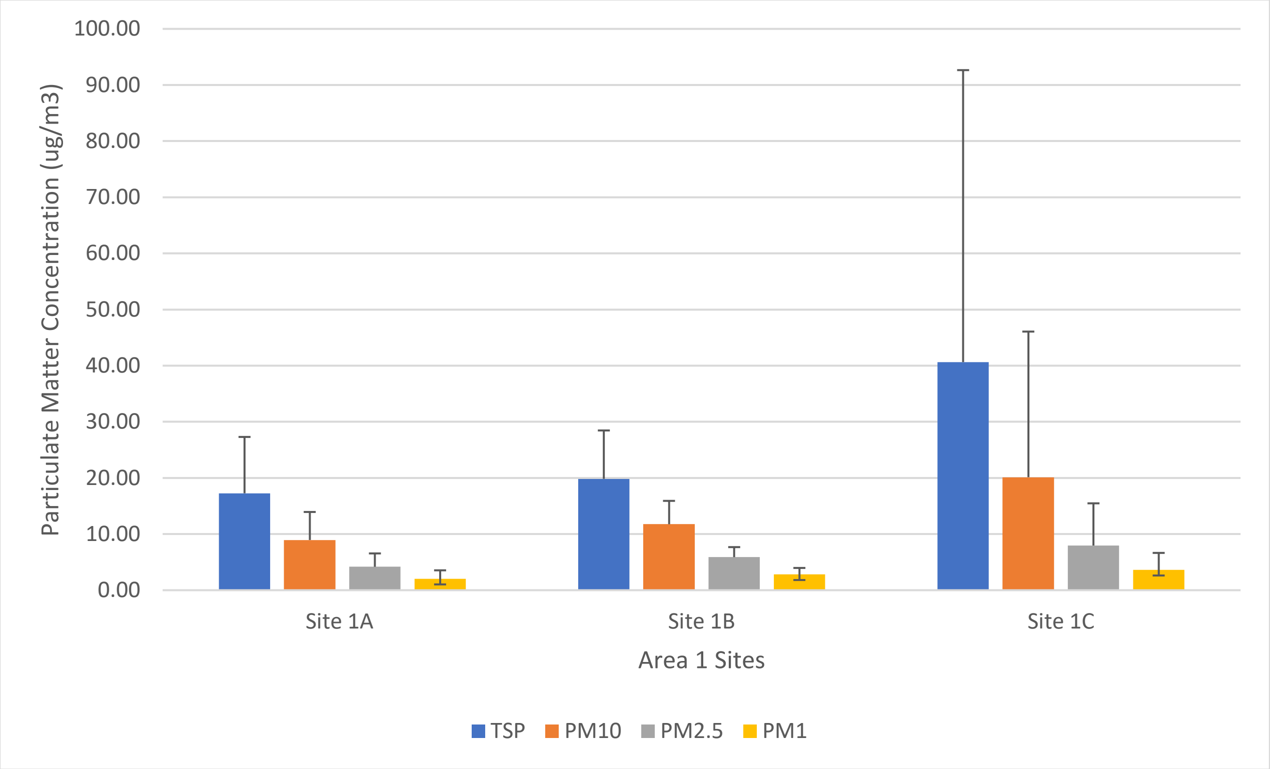

Figure 4.5: Graph showing the mean PM pollution levels across all sites at Area 1.

Figure 4.6 shows that Site 2C had the highest pollution levels expect PM_1 where Site 2B had the highest mean concentration. All sites had high standard deviation for TSP and PM_{10} and Site 2B also had high standard deviation for $PM_{2.5}$ and PM_1. Since Site 2C had a standard deviation of 22.40 with a mean pollution concentration of 44.42 ug/m^3 suggesting a high level of 66.82 ug/m^3 which suggest that a population are exposed to high levels of pollution. This suggest high levels of variation in pollution levels at all sites particularly at Site 2B. Both Site 2B and Site 2C reach the annual limit set by the WHO as shown by table 2.1. However, it is important to note that a years' worth of data is needed to generate a true annual average for the limits therefore it is not completely comparable.

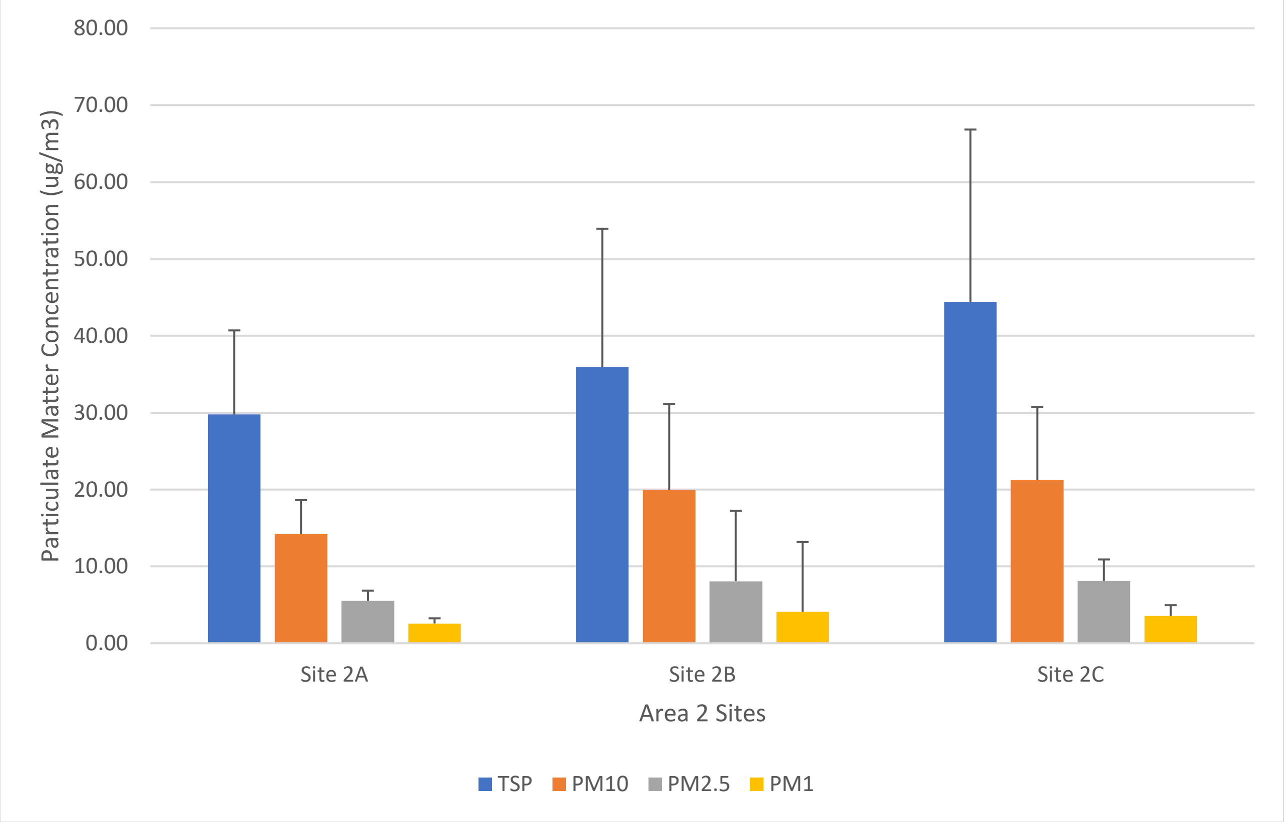

Figure 4.6: Graph showing the mean PM pollution levels across all sites at Area 2.

Figure 4.7 shows that Site 3A has the highest levels of all pollutants as well as the highest standard deviation for all pollutants. This suggest there was a high level of variation in pollution levels in this area. Sites 3B and 3C also had large standard deviation for TSP and a fairly high standard deviation for PM_{10}. This indicates that these pollutants had higher levels of variation at these sites then the other monitored pollutants.

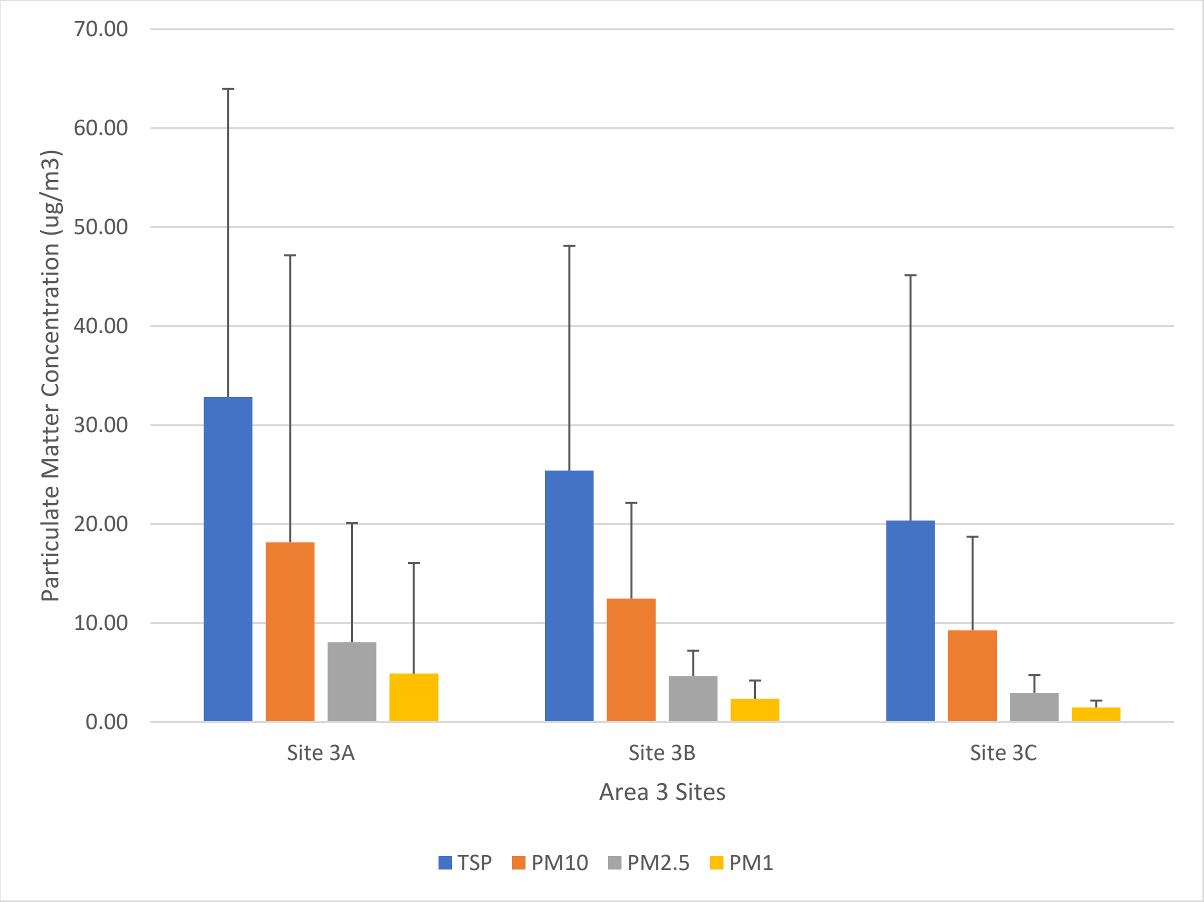

Figure 4.7: Graph showing the mean PM pollution levels across all sites at Area 2.

Figure 4.8 shows that Area 3 had the highest pollution levels out of all study areas. It also had a lot higher standard deviation for all pollutants than the other study areas indicating a higher variation in pollution concentration.

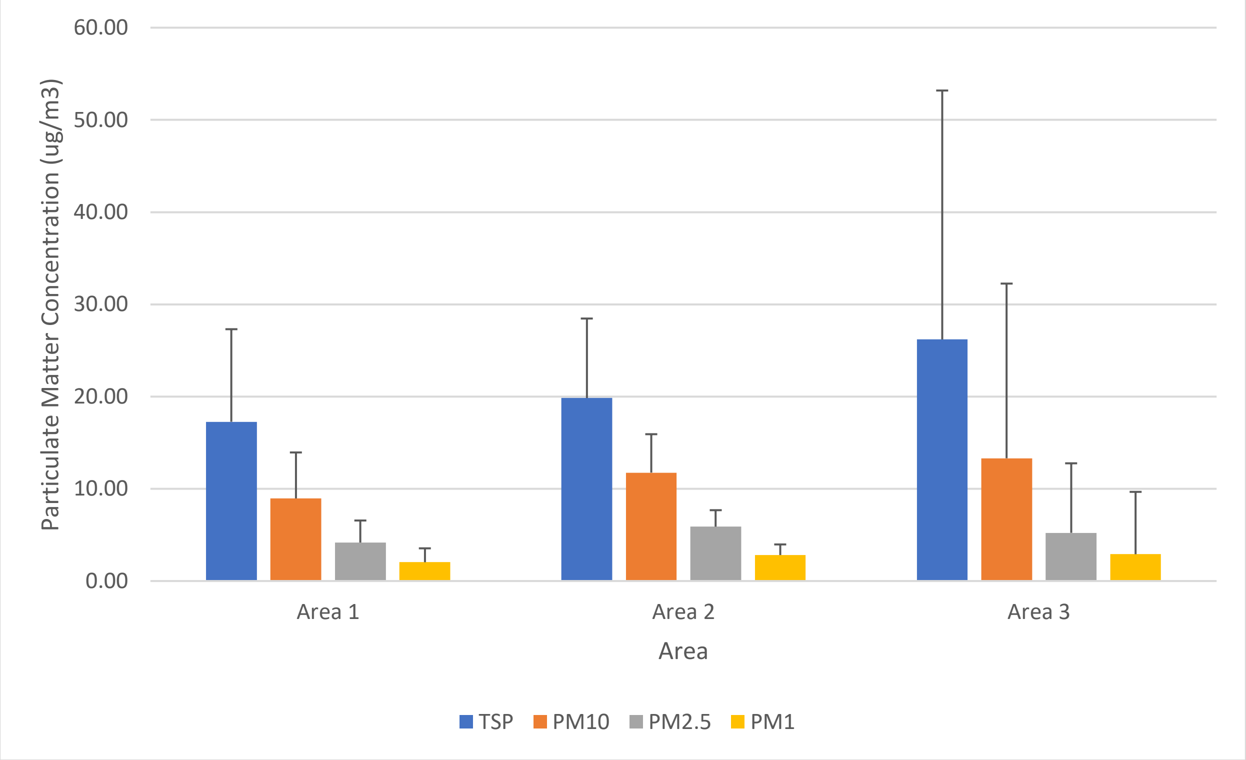

Figure 4.8: Graph showing the mean PM pollution levels for each Area.

Figure 4.9 shows that their Site 3A had the highest pollution levels and Site 1A had the lowest out of all A Sites. Site 3A was in Area 3 which was the least deprived area and Site 1A was in Area 1 in the most deprived area. This observation that the least deprived area has the highest observed pollutant concentrations while the most deprived has the lowest pollution consternations appears to the obverse of the relationship determined by other studies. Site 3A also had the highest standard deviation suggesting a high level of variation in the pollution levels at this site.

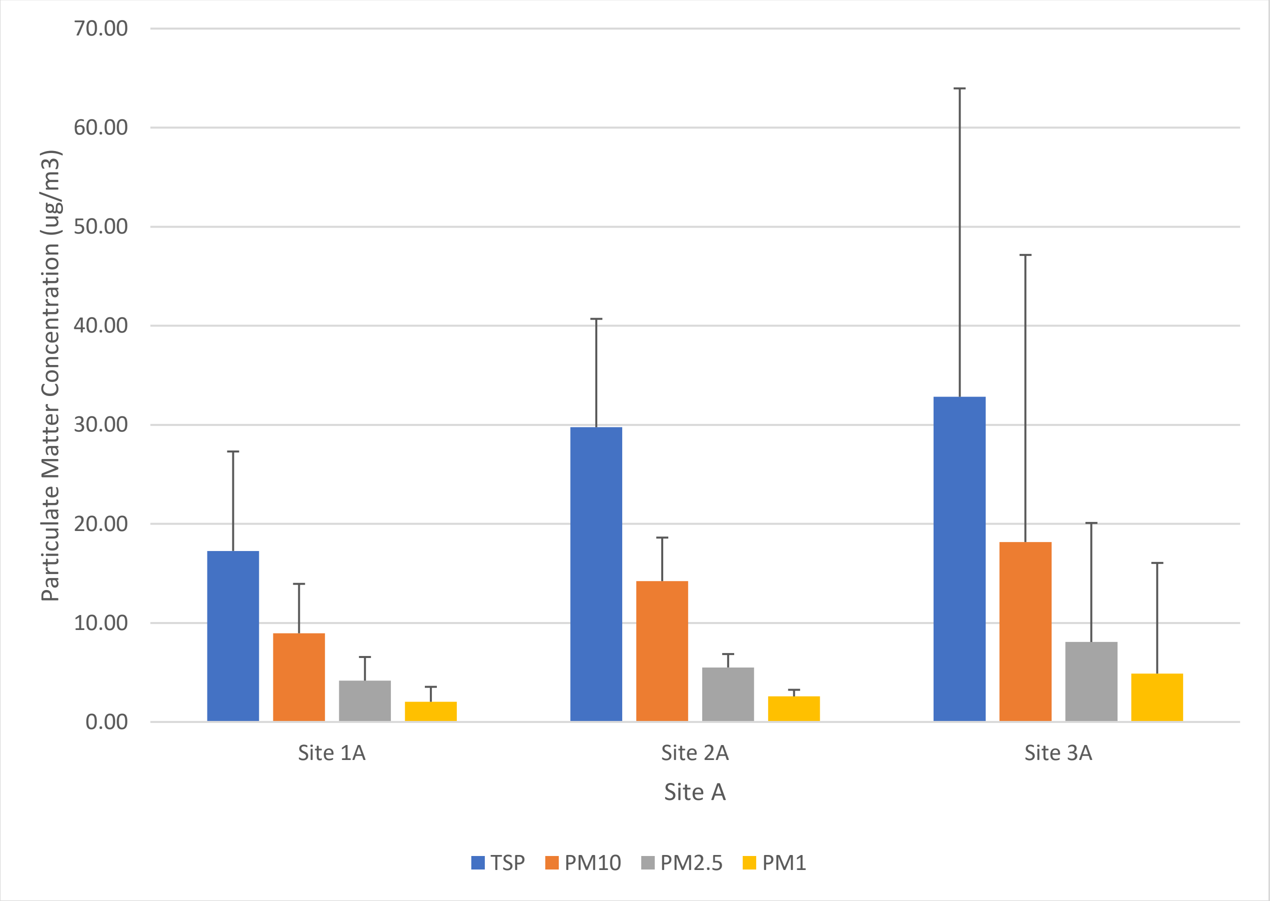

Figure 4.9: Graph showing the mean PM pollution levels for each Site A at each area.

Figure 4.10 shows that Site 2B had the highest pollutant concentration and standard deviation out of the all B sites. However, Site 3B also had high standard deviation for TSP and PM_{10}. Site 2B also reached the WHO annual limit for PM_{10}. However, it is important to note that a years' worth of data is needed to generate a true annual average for the limits therefore it is not completely comparable.

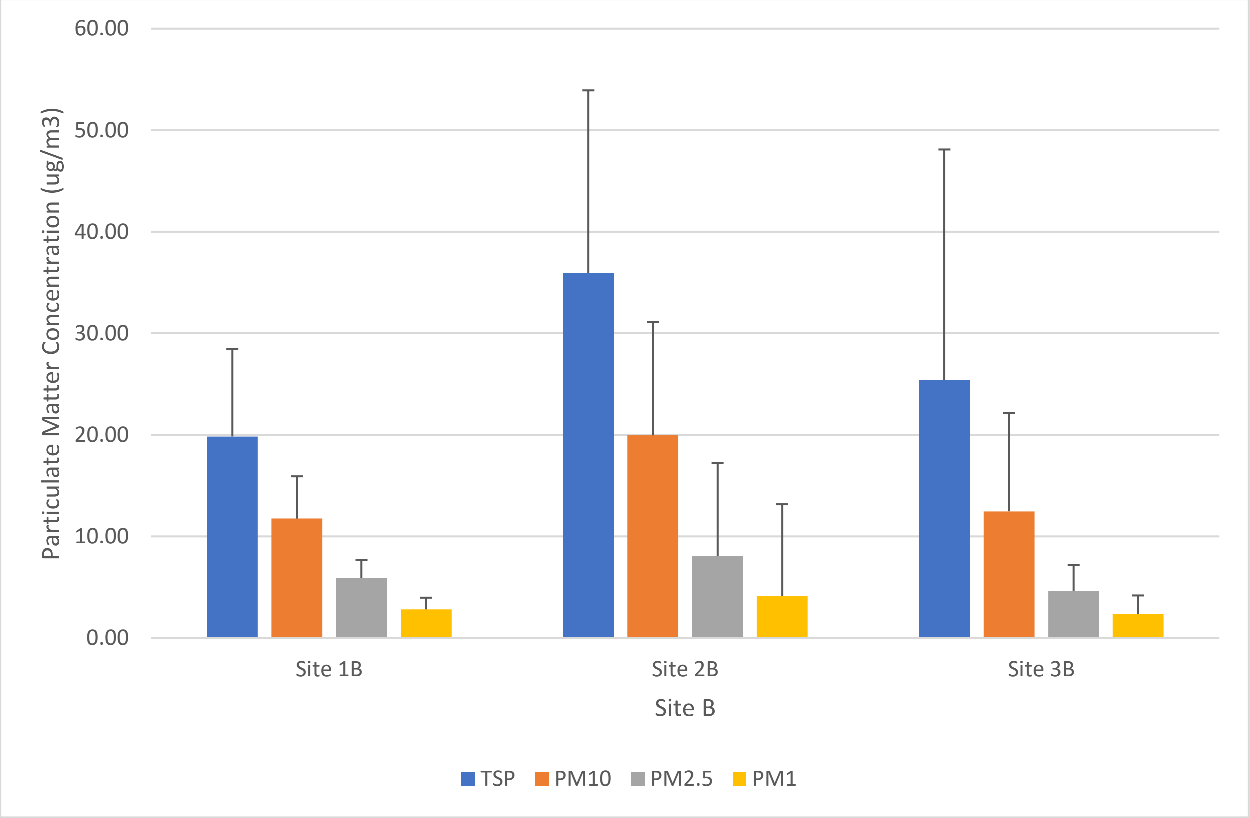

Figure 4.10: Graph showing the mean PM pollution levels for each Site B at each area.

Figure 4.11 shows that Sites 1C and 2C had the highest pollution levels with similar levels. All sites had a high level of standard deviation for TSP and PM_{10}.

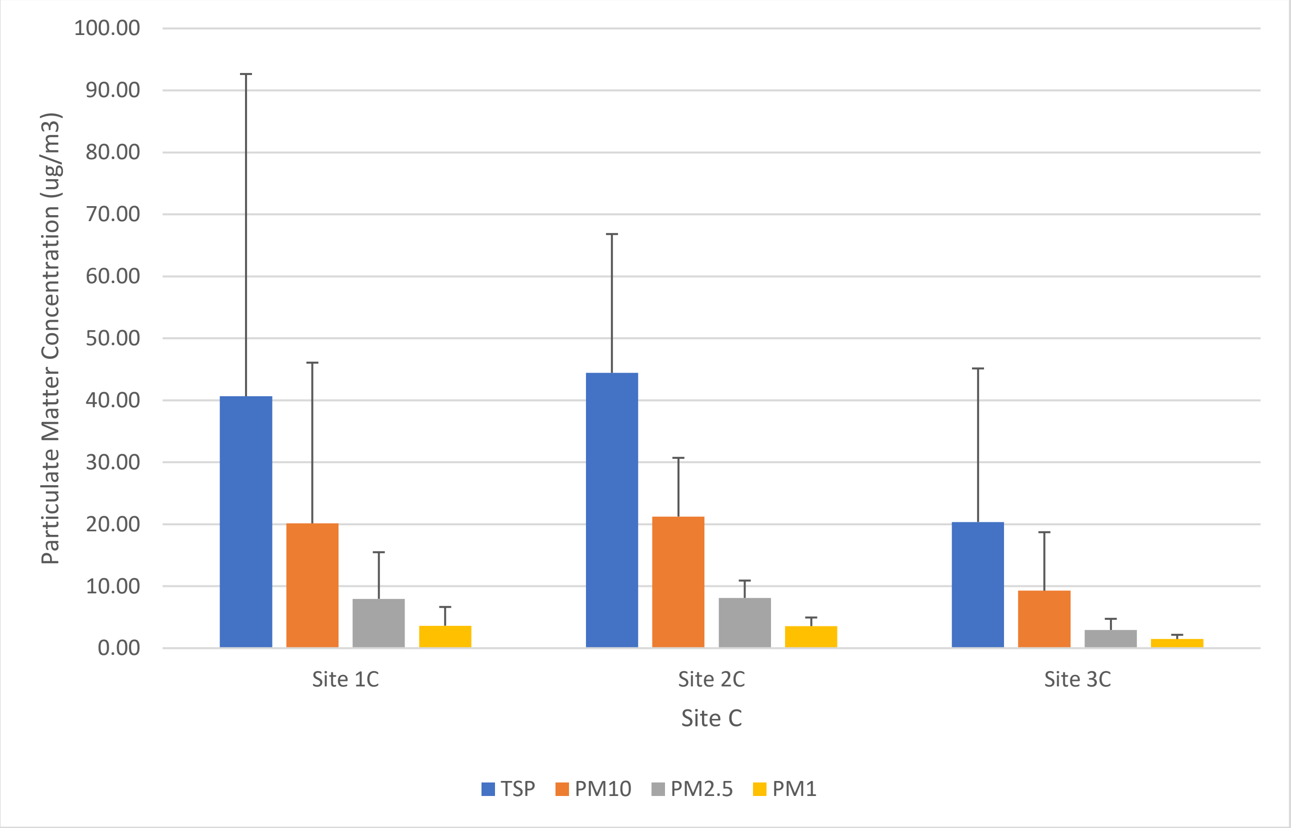

Figure 4.11: Graph showing the mean PM pollution levels for each Site B at each area.

Graphs 4.4 to 4.10 show that there was high standard deviation across all areas and sites for TSP and PM_{10}. This suggests that there is a high amount of variation the pollution levels the public is being exposed to. There were also three sites 1C, 2B and 2C that reached the annual PM_{10} limit set by the WHO however as stated before an annual average must be collected from a years' worth of data. The graphs also show that for areas 1 and 2 site C had the highest mean pollution levels.

4.7.3 Descriptive Statistics Comparing Sites

Table 4.8 shows that all sites had similar level of pollutants with Site 1A generally having slighter higher levels. The standard deviation for was higher Site 1C then the others suggesting that there was a higher level of variation in the pollution concentration in that area.

Table 4.8: Table showing statistics for monitoring event 1 at area 1.

	Site 1A				Site 1B				Site 1C			
ug/m^3	TSP	PM$_{10}$	PM$_{2.5}$	PM$_1$	TSP	PM$_{10}$	PM$_{2.5}$	PM$_1$	TSP	PM$_{10}$	PM$_{2.5}$	PM$_1$
Mean	31.46	18.21	8.49	3.05	26.80	16.44	8.47	3.17	33.43	17.78	8.20	3.10
Std. Deviation	9.28	3.79	0.80	0.29	5.53	1.66	0.46	0.15	12.52	4.39	0.89	0.31
Relative Std. Deviation (%)	29.49	20.81	9.42	9.51	20.63	10.10	5.34	4.73	37.45	24.69	10.85	10.00
Variance	86.05	14.35	0.64	0.08	30.54	2.74	0.21	0.02	156.73	19.28	0.79	0.10
Minimum	16.40	12.60	6.99	2.65	16.80	12.50	7.73	2.91	16.00	11.60	6.88	2.58
Maximum	52.30	28.60	10.35	3.81	43.60	19.80	9.44	3.56	78.90	31.70	9.80	3.65

Table 4.9 shows that Site 1C had the highest levels of pollutants however there was also high standard deviation for all pollutants suggesting that the population of the area are not always exposed to the higher levels of pollutants. Site 1B had the lowest pollutant concentration out of all the sites.

Table 4.9: Table showing statistics for monitoring event 2 at area 1.

	Site 1A				Site 1B				Site 1C			
ug/m^3	TSP	PM10	PM$_{2.5}$	PM$_1$	TSP	PM$_{10}$	PM$_{2.5}$	PM$_1$	TSP	PM$_{10}$	PM$_{2.5}$	PM$_1$
Mean	19.13	9.03	4.18	2.25	12.36	7.75	4.12	1.92	60.15	29.17	9.94	4.10
Std. Deviation	7.14	1.53	0.40	0.22	4.80	2.31	1.22	1.07	96.89	48.82	12.73	3.83
Relative Std. Deviation (%)	37.32	16.94	9.57	9.78	38.83	29.81	29.61	55.73	164.41	167.36	128.07	93.41
Variance	50.97	2.35	0.16	0.05	23.14	5.35	1.48	1.15	9388.04	2383.43	162.07	14.70
Minimum	10.30	6.60	3.56	1.86	6.30	5.10	3.25	1.47	15.10	6.70	3.79	1.98
Maximum	57.50	14.00	6.25	3.34	31.90	17.90	12.08	9.82	614.80	314.00	86.49	27.34

Table 4.10 shows that Site 1C had the highest pollutant concentration and had high relative standard deviation at this monitoring event suggesting that high variation in the pollution

levels pollutants are experienced at this location. Site 1A had the lowest pollution levels out of all the sites.

Table 4.10: Table showing statistics for monitoring event 3 at area 1.

	Site 1A				Site 1B				Site 1C			
ug/m^3	TSP	PM$_{10}$	PM$_{2.5}$	PM$_1$	TSP	PM$_{10}$	PM$_{2.5}$	PM$_1$	TSP	PM$_{10}$	PM$_{2.5}$	PM$_1$
Mean	9.71	5.09	2.59	1.50	14.35	9.63	6.78	4.24	18.99	11.32	7.13	4.12
Std. Deviation	5.81	3.20	2.66	2.67	3.73	1.62	0.90	0.41	6.80	2.56	0.91	0.49
Relative Std. Deviation (%)	59.84	62.87	102.70	178.00	23.48	16.82	13.27	9.67	35.81	22.61	12.76	11.89
Variance	33.76	10.23	7.10	7.13	13.94	2.63	0.81	0.17	46.27	6.58	0.82	0.24
Minimum	3.30	2.70	1.35	0.59	9.30	7.20	5.71	3.66	10.70	8.00	5.52	3.30
Maximum	30.90	25.70	22.87	21.92	28.70	18.00	12.72	6.77	42.80	21.20	9.83	5.62

Table 4.11 shows that Site 1C had the highest and Site 1A had the lowest pollutant levels. All sites had a high level of relative standard deviation suggesting that there was high variation in the pollution concentration at all sites.

Table 4.11: Table showing statistics for monitoring event 4 at area 1.

	Site 1A				Site 1B				Site 1C			
ug/m^3	TSP	PM$_{10}$	PM$_{2.5}$	PM$_1$	TSP	PM$_{10}$	PM$_{2.5}$	PM$_1$	TSP	PM$_{10}$	PM$_{2.5}$	PM$_1$
Mean	15.75	8.04	3.55	1.83	27.57	15.56	6.39	2.78	45.51	22.07	8.79	4.25
Std. Deviation	7.96	2.99	0.55	0.18	7.54	3.50	0.87	0.43	25.31	14.51	8.08	4.40
Relative Std. Deviation (%)	50.54	37.19	15.49	9.84	27.35	22.49	13.62	15.47	55.61	67.57	91.92	103.53
Variance	63.34	8.96	0.30	0.03	56.89	12.24	0.76	0.18	640.73	210.58	65.32	19.38
Minimum	6.30	4.90	2.93	1.53	13.00	9.90	4.83	2.17	13.50	10.20	5.05	2.55
Maximum	46.90	22.80	6.08	2.48	49.60	24.10	8.69	3.71	154.10	104.70	65.72	35.94

Table 4.12 shows that Site 1C had the highest levels of pollutants and extremely high relative standard deviation suggesting a high level of variation of pollutant levels at the site.

Table 4.12: Table showing statistics for monitoring event 5 at area 1.

	Site 1B				Site 1C			
ug/m^3	TSP	PM_{10}	$PM_{2.5}$	PM_1	TSP	PM_{10}	$PM_{2.5}$	PM
Mean	22.94	11.39	3.92	1.44	42.32	19.40	5.78	2.19
Std. Deviation	5.35	1.83	0.44	0.26	36.73	17.58	4.46	2.10
Relative Std. Deviation (%)	23.32	16.07	11.22	18.06	86.79	90.62	77.16	95.89
Variance	28.65	3.34	0.18	0.07	1349.30	309.18	19.93	4.39
Minimum	12.60	8.70	3.20	1.12	14.00	8.30	3.30	1.26
Maximum	31.50	15.60	5.15	2.09	280.90	137.40	36.14	16.18

Table 4.13 shows that Site 2C had the highest mean and Site 2B had the lowest mean pollutant concentrations. All sites had high relative standard deviation suggesting high level of variation of pollutant levels at the site.

Table 4.13: Table showing statistics for monitoring event 1 at area 2.

	Site 2A				Site 2B				Site 2C			
ug/m^3	TSP	PM_{10}	$PM_{2.5}$	PM_1	TSP	PM_{10}	$PM_{2.5}$	PM_1	TSP	PM_{10}	$PM_{2.5}$	PM_1
Mean	42.24	20.04	7.09	2.69	37.90	18.33	6.00	2.35	59.35	26.38	9.10	3.52
Std. Deviation	10.51	3.10	0.71	0.19	16.73	6.34	1.56	0.57	32.46	12.66	3.21	1.23
Relative Std. Deviation (%)	24.88	15.47	10.01	7.06	44.14	34.59	26.00	24.26	54.69	47.99	35.27	34.94
Variance	110.41	9.64	0.50	0.04	279.98	40.24	2.45	0.33	1053.94	160.18	10.29	1.52
Minimum	25.80	13.40	6.09	2.42	18.00	11.10	4.16	1.72	17.70	10.20	5.08	2.10
Maximum	66.40	29.70	9.83	3.26	84.70	36.60	9.87	3.82	180.90	75.50	18.42	7.18

Table 4.14 shows that Site 2C had the highest mean concentration of pollutants. All sites had high relative standard deviation however Site 2B's were exceedingly high especially for PM$_{2.5}$ and PM$_1$. This suggests a high level of variation in pollutant concentration at these sites.

Table 4.14: Table showing statistics for monitoring event 2 at area 2.

	Site 2A				Site 2B				Site 2C			
ug/m^3	TSP	PM$_{10}$	PM$_{2.5}$	PM$_1$	TSP	PM$_{10}$	PM$_{2.5}$	PM$_1$	TSP	PM$_{10}$	PM$_{2.5}$	PM$_1$
Mean	31.12	14.81	5.45	2.40	30.17	20.70	9.88	6.49	38.50	18.00	6.58	2.84
Std. Deviation	6.25	2.62	0.44	0.18	17.61	17.00	16.64	16.67	12.64	5.71	2.47	1.07
Relative Std. Deviation (%)	20.08	17.69	8.07	7.5	58.37	82.31	168.42	256.86	32.83	31.72	37.54	37.68
Variance	39.04	6.85	0.19	0.03	310.08	289.09	276.82	277.72	159.66	32.56	6.12	1.15
Minimum	18.60	11.20	4.62	2.17	14.80	10.70	4.09	1.71	20.20	10.10	3.95	1.81
Maximum	50.70	26.60	7.13	3.34	128.60	122.00	112.67	110.14	88.80	38.60	15.12	6.73

Table 4.15 shows that Site 2C had the highest pollutant concentration and Site 2A had the lowest pollutant concertation. All sites had a high relative standard deviation particularly Site 2C suggesting a lot of variation of the pollution concentration at these sites.

Table 4.15: Table showing statistics for monitoring event 3 at area 2.

	Site 2A				Site 2B				Site 2C			
ug/m^3	TSP	PM$_{10}$	PM$_{2.5}$	PM$_1$	TSP	PM$_{10}$	PM$_{2.5}$	PM$_1$	TSP	PM$_{10}$	PM$_{2.5}$	PM$_1$
Mean	24.45	10.62	3.91	1.82	35.30	17.77	6.52	2.87	47.95	22.65	8.45	3.62
Std. Deviation	7.18	2.51	0.62	0.22	15.67	7.19	2.14	0.86	23.03	10.04	2.95	1.85
Relative Std. Deviation (%)	29.37	23.63	15.86	12.09	44.39	40.46	32.82	29.97	48.03	44.33	34.91	51.10
Variance	51.51	6.30	0.39	0.05	245.51	51.70	4.58	0.74	530.19	100.82	8.72	3.44
Minimum	10.60	6.30	2.71	1.36	15.80	7.80	3.21	1.66	22.20	10.60	4.97	2.17
Maximum	44.60	17.30	5.66	2.39	105.00	48.70	12.90	5.83	138.20	64.20	19.68	15.81

Table 4.16 shows that Site 2A had the lowest pollution concentration and Site 2B and 2C had the similar pollution levels. All areas had a high relative standard deviation suggesting high levels of variation in the pollution concentration at these sites.

Table 4.16: Table showing statistics for monitoring event 4 at area 2.

	Site 2A				Site 2B				Site 2C			
ug/m^3	TSP	PM$_{10}$	PM$_{2.5}$	PM$_1$	TSP	PM$_{10}$	PM$_{2.5}$	PM$_1$	TSP	PM$_{10}$	PM$_{2.5}$	PM$_1$
Mean	27.44	14.31	6.36	3.45	41.48	22.21	8.81	3.85	39.26	20.48	8.81	4.23
Std. Deviation	12.81	4.45	1.01	0.33	19.63	8.23	2.26	0.74	19.46	8.89	2.07	0.75
Relative Std. Deviation (%)	46.68	31.10	15.88	9.57	47.32	37.06	25.65	19.22	49.57	43.41	23.50	17.73
Variance	164.15	19.77	1.03	0.11	385.19	67.70	5.09	0.55	378.80	78.98	4.29	0.56
Minimum	13.50	9.10	4.90	2.88	17.50	11.40	4.99	2.34	11.90	8.60	5.01	2.83
Maximum	76.70	31.30	9.71	4.41	124.20	50.50	15.74	6.30	147.30	73.60	16.37	6.14

Table 4.17 shows that Site 3A had the highest pollutant concentrations and Site 3C had the lowest pollutant concentrations. Sites 3B and 3C had extremely high relative standard deviation and Site 3A also did for pollutants $PM_{2.5}$ and PM_1. This suggest a high level of variation for these pollutants at these sites.

Table 4.17: Table showing statistics for monitoring event 1 at area 3.

	Site 3A				Site 3B				Site 3C			
ug/m^3	TSP	PM_{10}	$PM_{2.5}$	PM_1	TSP	PM_{10}	$PM_{2.5}$	PM_1	TSP	PM_{10}	$PM_{2.5}$	PM_1
Mean	48.81	19.94	5.33	3.17	26.47	11.35	3.20	1.41	32.63	12.71	2.68	1.08
Std. Deviation	18.52	14.99	13.89	13.77	20.93	8.94	1.32	0.29	29.79	9.58	1.15	0.40
Relative Std. Deviation (%)	37.94	75.18	260.60	434.48	79.07	78.77	41.25	20.57	91.30	75.37	42.91	37.04
Variance	343.16	224.75	193.02	189.53	438.27	79.99	1.76	0.09	887.66	91.77	1.32	0.16
Minimum	23.10	8.80	2.62	1.00	9.50	4.10	2.11	.99	6.00	3.60	1.74	0.67
Maximum	158.90	130.90	111.89	108.90	164.70	74.00	12.12	2.44	163.50	52.30	9.29	3.76

Table 4.18 shows that Site 3A had the highest pollutant concentration and all sites had extremely high relative standard deviation suggesting a large amount of variation in pollution levels at these sites.

Table 4.18: Table showing statistics for monitoring event 2 at area 3.

	Site 3A				Site 3B				Site 3C			
ug/m^3	TSP	PM_{10}	$PM_{2.5}$	PM_1	TSP	PM_{10}	$PM_{2.5}$	PM_1	TSP	PM_{10}	$PM_{2.5}$	PM_1
Mean	24.33	15.63	6.12	4.57	21.12	10.34	4.05	1.91	24.37	11.15	3.45	1.43
Std. Deviation	50.72	51.39	14.98	14.99	25.14	10.47	3.17	2.65	29.31	12.85	2.86	0.85
Relative Std. Deviation (%)	208.47	328.79	244.77	328.01	119.03	101.26	78.27	222.69	120.27	115.25	82.90	59.44
Variance	2572.07	2640.48	224.41	224.81	632.20	109.67	10.03	7.04	858.87	165.03	8.20	0.72
Minimum	5.30	3.80	1.93	0.87	6.10	3.50	2.16	0.96	4.90	3.50	1.80	0.88
Maximum	409.40	407.20	110.51	109.02	197.00	79.80	23.08	21.67	232.30	102.60	23.58	7.19

Table 4.19 shows that Site 3A had the highest pollutant concentration and Site 3C had the lowest pollutant concentration. Site 3C had extremely high relative standard deviation for TSP and PM_{10} suggesting that there was a high level of variation in pollution levels.

Table 4.19: Table showing statistics for monitoring event 3 at area 3.

	Site 3A				Site 3B				Site 3C			
ug/m^3	TSP	PM_{10}	$PM_{2.5}$	PM_1	TSP	PM_{10}	$PM_{2.5}$	PM_1	TSP	PM_{10}	$PM_{2.5}$	PM_1
Mean	33.19	23.76	14.69	8.01	30.44	16.31	6.61	3.59	7.39	4.73	2.13	1.37
Std. Deviation	7.21	5.33	5.64	3.67	23.26	9.56	1.70	1.15	8.30	4.61	0.61	0.36
Relative Std. Deviation (%)	21.72	22.43	38.39	45.82	76.41	58.61	25.72	32.03	112.31	97.46	28.64	26.28
Variance	51.98	28.36	31.83	13.44	540.97	91.32	2.89	1.32	68.81	21.23	0.37	0.13
Minimum	18.70	14.90	8.35	3.85	9.50	7.60	4.24	2.21	2.20	2.00	1.32	0.71
Maximum	52.10	32.20	24.40	14.16	110.60	53.30	10.90	5.68	66.50	38.00	4.52	2.15

Table 4.20 shows that Site 3A had the highest pollutant concentrations and Site 3C had the lowest pollutant concentrations. All sites had high relative standard deviation suggesting that there was a high level of variation in pollution concentrations.

Table 4.20: Table showing statistics for monitoring event 4 at area 3.

	Site 3A				Site 3B				Site 3C			
ug/m^3	TSP	PM$_{10}$	PM$_{2.5}$	PM$_1$	TSP	PM$_{10}$	PM$_{2.5}$	PM$_1$	TSP	PM$_{10}$	PM$_{2.5}$	PM$_1$
Mean	17.37	8.65	4.28	2.70	17.26	9.75	4.95	2.68	13.89	7.70	3.95	2.45
Std. Deviation	6.02	1.55	0.32	0.18	6.48	2.41	0.56	0.19	3.90	1.41	0.38	0.16
Relative Std. Deviation (%)	34.66	17.92	7.48	6.67	37.54	24.72	11.31	7.90	28.08	18.31	9.62	6.53
Variance	36.26	2.42	0.10	0.03	42.05	5.81	0.32	0.03	15.21	1.99	0.15	0.03
Minimum	10.20	5.60	3.68	2.31	7.80	6.40	4.32	2.43	5.80	4.90	3.34	2.09
Maximum	39.50	12.60	5.02	3.11	27.00	13.10	6.27	3.10	22.40	10.90	5.49	2.99

Table 4.21 shows that there were extremely high maximum levels of pollutants found at area 1. There was also exceedingly high relative standard deviation for all pollutants suggesting a high level of variation in pollutants levels across the whole area.

Table 4.21: Table showing statistics for all monitoring events in Area 1.

	Minimum	Maximum	Mean	Std. Deviation	Relative Std. Deviation (%)
TSP	3.30	614.80	26.73	34.07	127.46
PM$_{10}$	2.70	314.00	14.01	16.82	120.06
PM$_{2.5}$	1.35	86.49	6.15	5.09	82.76
PM$_1$	0.59	35.94	2.88	2.21	76.74

Table 4.22 show that the maximum levels of all pollutants were high however the minimum concentration of pollutant was low. All pollutants also had a high relative standard deviation which suggests a high level of variation in the pollutant levels.

Table 4.22: Table showing statistics for all monitoring event in Area 2.

	Minimum	Maximum	Mean	Std. Deviation	Relative Std. Deviation (%)
TSP	10.60	180.90	36.70	18.71	50.98
PM_{10}	6.30	122.00	18.45	9.31	50.46
$PM_{2.5}$	2.71	112.67	7.22	5.68	78.67
PM_1	1.36	110.14	3.41	5.30	155.43

Table 4.23 show that the maximum levels of all pollutants were high, however the minimum concentration of pollutant was low. All pollutants also had an extremely high relative standard deviation which suggests a very high level of variation in the pollutant levels.

Table 4.23: Table showing statistics for all monitoring event in Area 3.

Pollutant	Minimum	Maximum	Mean	Std. Deviation	Relative Std. Deviation (%)
TSP	2.20	409.40	26.19	26.99	103.05
PM_{10}	2.00	407.20	13.31	18.94	142.30
$PM_{2.5}$	1.32	111.89	5.23	7.54	144.17
PM_1	0.67	109.02	2.90	6.76	233.10

Tables 4.8 to 4.23 show that site C had the highest pollutants for area 1 and 2 and site A had the highest for area 3.

Table 4.24 shows that there was no significant link between $PM_{2.5}$ concentration between different sites in the same area expect for between Sites 2B and 2C were there was an t-value of 0.95. This suggest there was an equal variance.

Table 4.24: Table showing T-Test results comparing $PM_{2.5}$ concentration between sites in the same area.

Sites	T-Test	Mean Difference	Significant (2 tailed)	Degrees of Freedom
Site 1A/1C	-7.135	-3.80	0.00	485
Site 1A/1B	-8.87	-1.72	0.00	464
Site 1B/1C	-4.25	-2.07	0.00	519
Site 2A/2C	12.35	2.605	0.00	431
Site 2A/2B	-4.07	-2.56	0.00	427
Site 2B/2C	-0.07	-0.046	0.95	426
Site 3A/3C	-6.214	-5.14	0.00	428
Site 3A/3B	-3.94	-3.42	0.00	411
Site 3B/3C	-7.97	-1.72	0.00	413

4.7.4 Socio-economic Status and Pollution Concentration

Table 4.25 shows that there was no consistent correlation between pollutant levels and IMD ranking. There was a weak negative correlation between $PM_{2.5}$ concentration and Employment rank and a strong negative correlation between $PM_{2.5}$ and health rank.

Table 4.25: Table showing the Pearson correlation for each pollutant and IMD ranking.

IMD Category	TSP	PM_1	$PM_{2.5}$	PM_{10}
Overall	0.037	0.014	-0.03	0.019
Employment	0.034	0.13	-0.32	0.016
Health	-0.028	-0.004	-0.074	-0.035
Income	0.041	0.015	-0.027	0.022
Living Environment	0.086	0.021	0.11	0.082

4.8 Conclusion

The results show that for Areas 1 and 2, Site C had the highest pollution levels. Site C was closest to the main pollution source which in both areas was a road with heavy traffic. As discussed in chapter 2 section 2.2, exhaust and non-exhaust pollution from traffic is a major contributor to particulate matter pollution. Site 3A had the highest pollution levels for area 3, this was the residential area. As discussed in chapter 2 section 2.2 and 2,3 there are numerous contributors to particulate matter pollution. Since Area 3 was situated in Manchester city centre it may be likely that there was a larger number of contributors to pollution resulting in residential areas experiencing higher levels. There was shown to be no significant link between socio-economic status and pollution levels.

Chapter 5 AURN data analysis

5.1 Introduction.

A study was conducted to examine patterns in pollution concentration in relation to socio-economic status across a large spatial area. This study enabled assessments to be made as to whether a link between socio-economic status and pollution levels across a large spatial area could be established. The primary data collection used for the study described in Chapter 4 used spot sampling whereas here automatic stations which monitor constantly are used, enabling a comparison between those results and the data reported in this chapter. This enables the research to assess if a difference in the temporal scale influences the results found in chapter 4 and 5. It is also can be used to assess if spatial scale as an effect on the results as the primary data study was over a local scale whereas the AURN data is over the North West with monitoring stations placed in strategic locations.

This research entailed a desktop study that analysed secondary data from the UK government's air pollution monitoring stations called the Automatic Urban and Rural Network (AURN). AURN is operated by local authorities in order to fulfil their air quality management duties under the Environment Act 1995. There was a large volume of data available to analyse which allowed for trends to be assessed over several years. Having a wide range of data enabled an assessment of the links between socio-economic status and pollution concentrations and if the link was consistent over the years.

This study was designed to fulfil the overall aim and objective to assess air pollution across the North of England. This was achieved by determining the relationship between air pollution and socio-economic status by assessing if there is a link by using IMD rankings and PM pollution data.

5.2 Aim and Objectives

The aim was to assess trends in air pollution concentration across a larger spatial area and to assess the link between air pollution and socio-economic status within the North of England.

The objectives were:

A. To select an appropriate study area across the North of England.
B. To find all monitoring stations within that area that fit into the requirements and collect all the data from the selected period.
C. To conduct data analysis to determine any trends.
D. To assess the relationship between pollution concentrations and socio-economic status.

These objectives were selected to ensure that on completion it would allow for assessments to be made about pollution levels in the North West and links that may be present between socio-economic status and pollution levels.

5.3 Methodology.

5.3.1 Selecting Study Sites

The first stage of the study was to select an area across England to analyse PM concentration data. It was decided that the North of England was a suitable area as the wards in this location have a similar socio-economic profile according to the Index of Multiple Deprivation (IMD) making them comparable. However, the whole of the North of England was too large an area to complete analysis in the time frame of this study so a 20km area north and south of Manchester (as this is the central location being studied) was chosen as the study location as this was a manageable area for which to collect and analyse data. It would also allow for comparison as often cities in the North West of England of a similar background and demographics.

All the government air pollution data collection points within that area were then found using the DEFRA Air Quality Archive webpage. There were 34 monitoring stations within the study area with 19 stations monitoring the necessary pollutants and what years data is available for as shown by table 5.1.

Table 5.1: Table showing the monitoring stations used with pollutants monitored and what years data is available for. (Source: Defra, n.d.)

Station name	Pollutants monitored	Years data available
Wirral Tirran	$PM_{2.5}$	2013,2014,2015,2016,2017
Blackpool Marton	$PM_{2.5}$	2014, 2015,2016,2017
Liverpool Speke	$PM_{2.5}$ and PM_{10}	2013,2014,2015,2016,2017
Warrington	$PM_{2.5}$ and PM_{10}	2013,2014,2015,2016,2017
Wigan Centre	$PM_{2.5}$	2013,2014,2015,2016,2017
Salford Eccles	$PM_{2.5}$ and PM_{10}	2013,2014,2015,2016,2017
Manchester Piccadilly	$PM_{2.5}$	2013,2014,2015,2016,2017
Bury Whitefield Roadside	PM_{10}	2015,2016,2017
Sheffield Devonshire Green	$PM_{2.5}$ and PM_{10}	2013,2014,2015,2016,2017
Chesterfield Roadside	$PM_{2.5}$ and PM_{10}	2013,2014,2015,2016,2017
Chesterfield Loundsley Green	$PM_{2.5}$ and PM_{10}	2014,2015,2016,2017
Scunthorpe	PM_{10}	2013,2014,2015,2016,2017
Preston	$PM_{2.5}$	2013,2014,2015,2016,2017
Leeds Centre	$PM_{2.5}$ and PM_{10}	2013.2014,2015,2016,2017
Leeds Headingly Kerbside	$PM_{2.5}$ and PM_{10}	2013,2014,2015,2016,2017
Hull Freetown	$PM_{2.5}$	2013,2014,2015,2016,2017
Hull Holderness Road	PM_{10}	2015,2016,2017
Stoke-on-Trent A50 roadside	PM_{10}	2015,2016,2017
Stoke-on-Trent Centre	$PM_{2.5}$	2013,2014,2015,2016,2017

5.3.2 Data Collection and Analysis

Fine particle ($PM_{2.5}$) and course particle (PM_{10}) concentrations were analysed for this study as they were collected during the primary data collection in chapter 4, therefore it was deemed that other pollutants would not be relevant in the aims of the study. As discussed in the literature review section 2.3, PM was chosen as health effects can be caused even at a limited exposure as $PM_{2.5}$ is able to enter the lungs and blood due to their small size (DEFRA, 2019).

Data for the location of the monitoring stations and air pollution concentration were both derived from the UK Department for Environment and Rural Affairs (DEFRA) website. The monitoring network used by DEFRA is the Automatic Urban and Rural Monitoring Network (AURN). Air pollution data is recorded hourly and is readily available to the public through the Air Quality Archive.

Data for the 19 stations was collected for the months March, June, September and December from the years 2013-2017. This resulted in a month from each season being analysed which would allow judgment to be made if that influenced pollution levels. This is because there has been research to suggest that particulate matter is impacted to the seasons such as Jung et al (2019) found that high PM_{10} levels were occurred at a maximum frequency during the cold seasons. The whole year worth of data for 2013-2017 was also collected for each station to allow a more accurate assessment of the pollution concentration and pollution trends in the area. However, not all stations had started collecting data from 2013 meaning that not all locations could be analysed for all years. Sometimes there were periods of variable time lengths when data was not being collected due to problems with monitoring stations, resulting in gaps in data. Table 5.1 shows the data availability for each monitoring station.

For each of the months selected the mean and standard deviation were calculated and a graph showing the results each year shown. This allowed analysis to be made regarding any patterns in pollution levels across the timeframe of the study. This was done for each day and the whole month of March, June, September and December to assess how common large variances in pollution concentration across different periods of time were analysed and allowed insight into levels of pollution experienced by people living in those areas.

For each year a correlation analysis was performed against the seven IMD domains and overall IMD ranking. IMD rankings were chosen to show deprivation levels in these areas and has been used to show socio-economic status as many previous studies in the UK had also used this such as Briggs, Abellan and Fecht (2008) and Tonne et al. (2018). These rankings were chosen as they demonstrate important indicators of deprivation and could be linked to high concentration of air pollution. This was done to assess the link between deprivation and pollution levels and see if there is a factor that is a greater contributor than others.

5.4 Limitations

As already discussed, there was data unavailable for certain years and data missing for variable lengths of time. This could have affected the results however since there was a large amount of data available it should ensure that the pollution levels where representative.

The monitoring stations are not situated in similar locations meaning that some areas may be exposed to levels of higher pollutants due to location and not socio-economic status. However, councils use the Technical Guidance LAQM.TG (16) when deciding where to place monitoring stations which was also used in the primary data study when deciding monitor placement.

5.5 Results

The first results shown are graphs for the $PM_{2.5}$ and PM_{10} for each month studied will all years studied. The Pearson correlation results for between $PM_{2.5}$ and PM_{10} and IMD ranking are then shown.

5.5.1 Analysis of the Pollutant Concentrations Across Different Areas

Figure 5.1 shows that for the majority of locations for March 2013 had the highest $PM_{2.5}$ pollutant levels and 2017 had the lowest levels. As discussed in chapter 2 section 2.3 there has been a decline in particulate matter concentration in the UK since 1990. All locations reached the WHO hourly limit, 25 ug/m^3, in 2013. In 2014 Warrington, Wigan, Salford, Manchester, Sheffield Devonshire Green, Chesterfield Roadside, Preston, Leeds Centre, Leeds Headingly Kerbside, Hull Freetown and Stoke-on-Trent Centre reached the WHO annual limit, 10 ug/m^3. In 2015 Salford, Manchester, Leeds Headingly Kerbside, Hull Freetown and Stoke-on-Trent Centre. In 2016 Manchester, Bury Whitefield, Leeds Headingly Kerbside and Stoke-on-Trent Centre. All locations across all years studied had significantly high levels of standard deviation ranging from 9.51 (Leeds Headingly Kerbside, 2017) to 22.17 (Leeds Headingly Kerbside, 2013), between suggesting a lot of variation in pollution levels across all sites.

Figure 5.2 shows that for June 2013 had the highest pollution levels in the locations; Wirral, Blackpool, Liverpool Speke, Warrington, Wigan, Salford Eccles. However, for the rest of the locations either 2015 or 2016 had the highest pollutant concentration. Manchester had an extremely high average pollution level for 2016. Salford Eccles reached the WHO annual limit value in 2013 and 2014, Manchester did in 2016, Leeds Headingly Kerbside did in 2015 and 2017 and Stoke-On-Trent Centre did in 2014 and 2016. All locations had medium levels standard deviation for instance from 3.59 (Warrington, 2017) to 7.45 (Warrington, 2016) for all years suggesting slight variation in pollutant concentration.

Figure 5.3 shows that for all location in September 2014 had the highest average $PM_{2.5}$ concentration and 2016 had the lowest except for Hull Freetown where 2015 had the lowest average pollutant concentration. Wigan had the highest average $PM_{2.5}$ level, 25 ugm^3 which as shown by table 2.1 this is the annual limit value for the UK, EU and the annual limit for the WHO. In 2013 Salford Eccles and Stoke-on-Trent Centre reached WHO annual limit value. In 2014 all locations reached WHO annual limit value and in 2015 Leeds Headingly Kerbside and Stoke-on-Trent Centre reached the limit. The standard deviation was high for all study periods for instance, from 6.17 (Wirral, 2015) to 13.25 (Wirral, 2014) suggesting high levels of variation in the pollution levels.

Figure 5.4 shows that for most locations in December 2016 had the highest average $PM_{2.5}$ concentration expect for Blackpool and Wigan where 2014 had the highest pollutant concentration. in 2013 Salford Eccles reaches the WHO annual limit value. In 2014 Blackpool, Warrington, Wigan and Salford Eccles did. In 2016 all locations expect for Wigan and Blackpool reached the WHO annual limit value. Across all locations in the study period there were high levels of standard deviation, for instance 15.04 for Leeds Headingly Kerbside in 2016, suggesting high levels of variation in pollution levels.

In general pollution levels where higher in the later part of the years, in the Autumn and winter months September and December. Previous studies such as De Lange, Garland and Dyson (2019) and Li, Ma, Wang, Liu and Hong (2017) have found that this has been the case mainly as a result of strong wind speeds which encourage the dispersion of pollution and wet deposition.

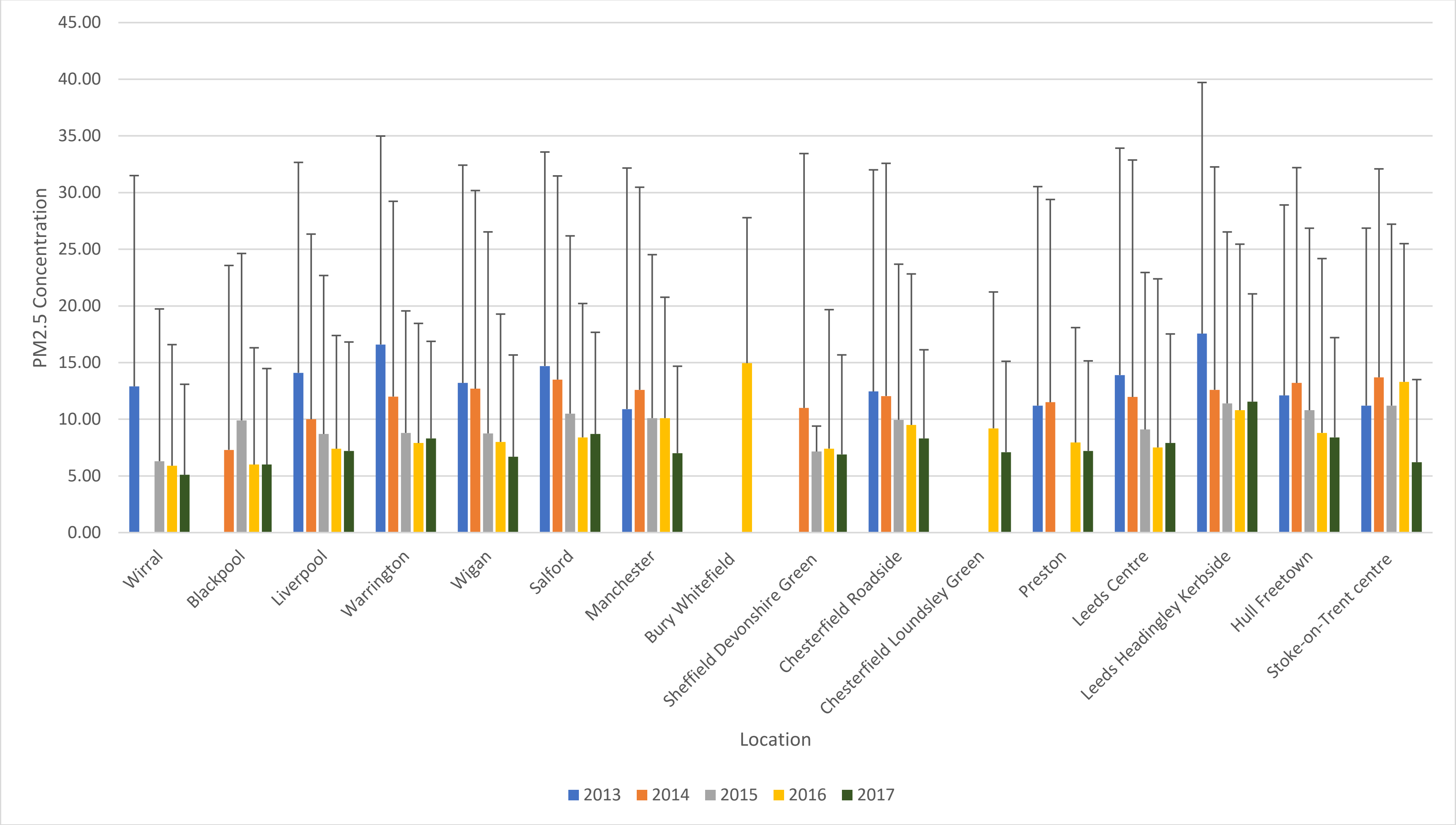

Figure 5.1: Graph showing $PM_{2.5}$ concentration for all locations across all study years for March.

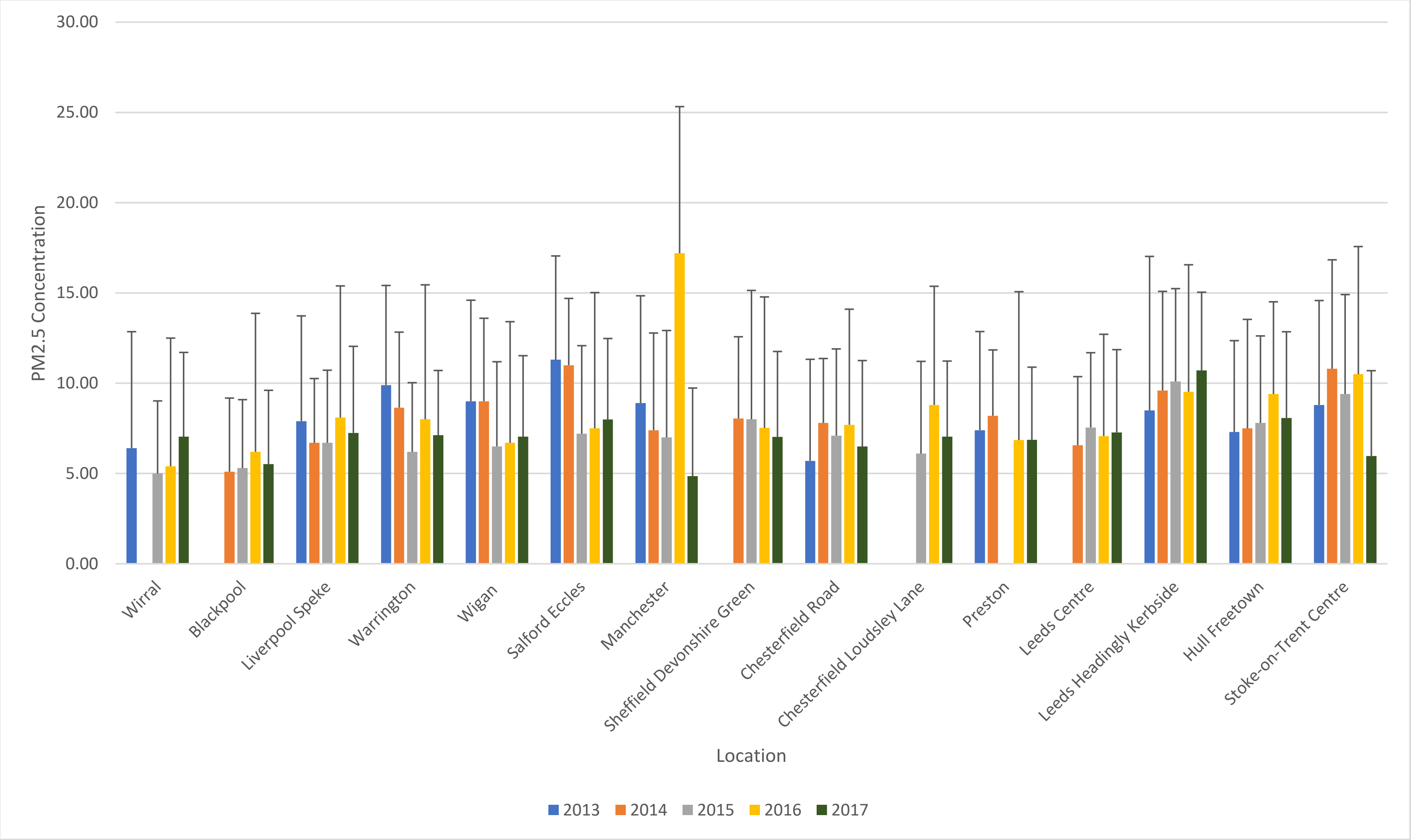

Figure 5.2: Graph showing $PM_{2.5}$ concentration for all locations across all study years for June

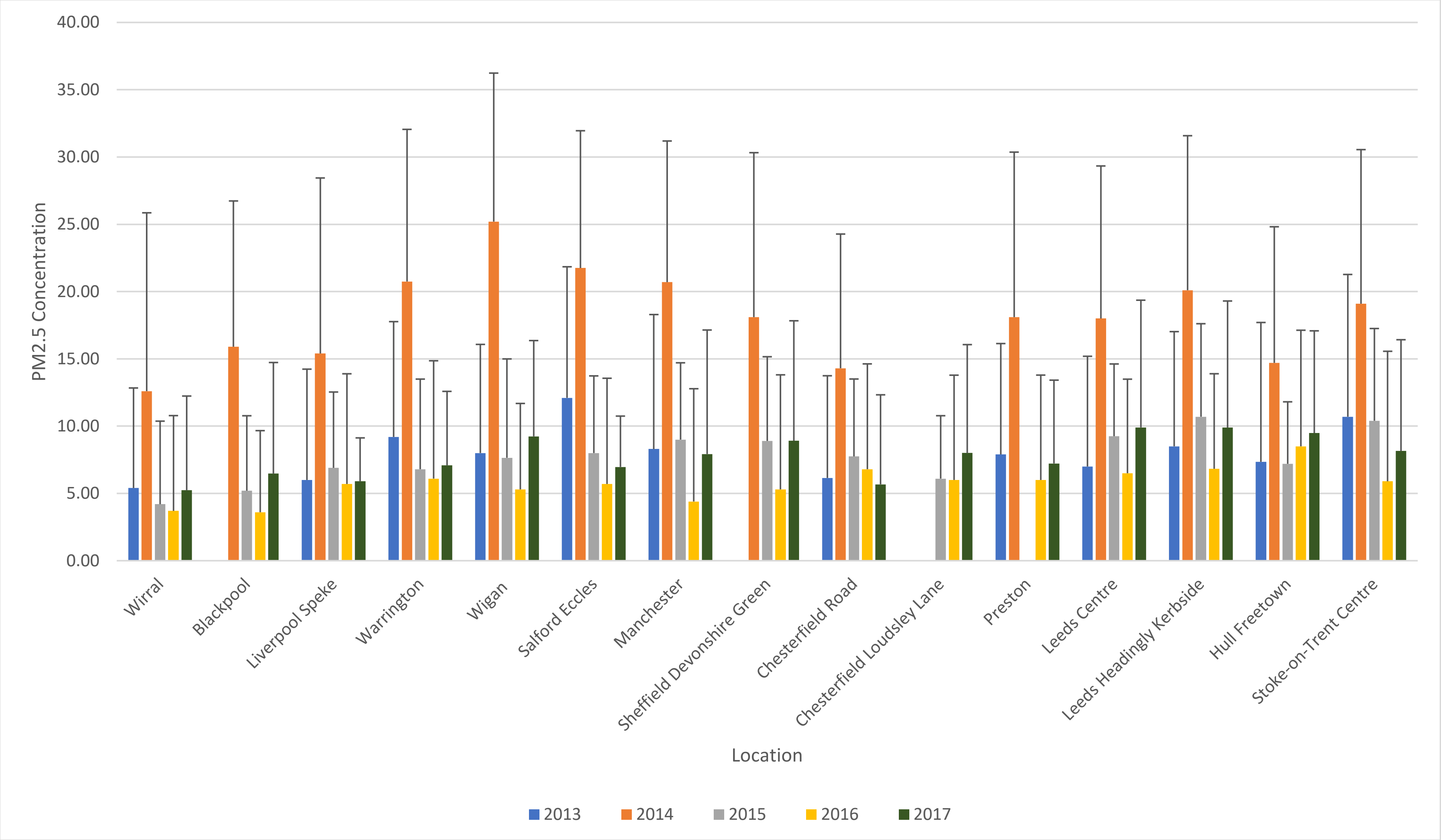

Figure 5.3: Graph showing $PM_{2.5}$ concentration for all locations across all study years for September.

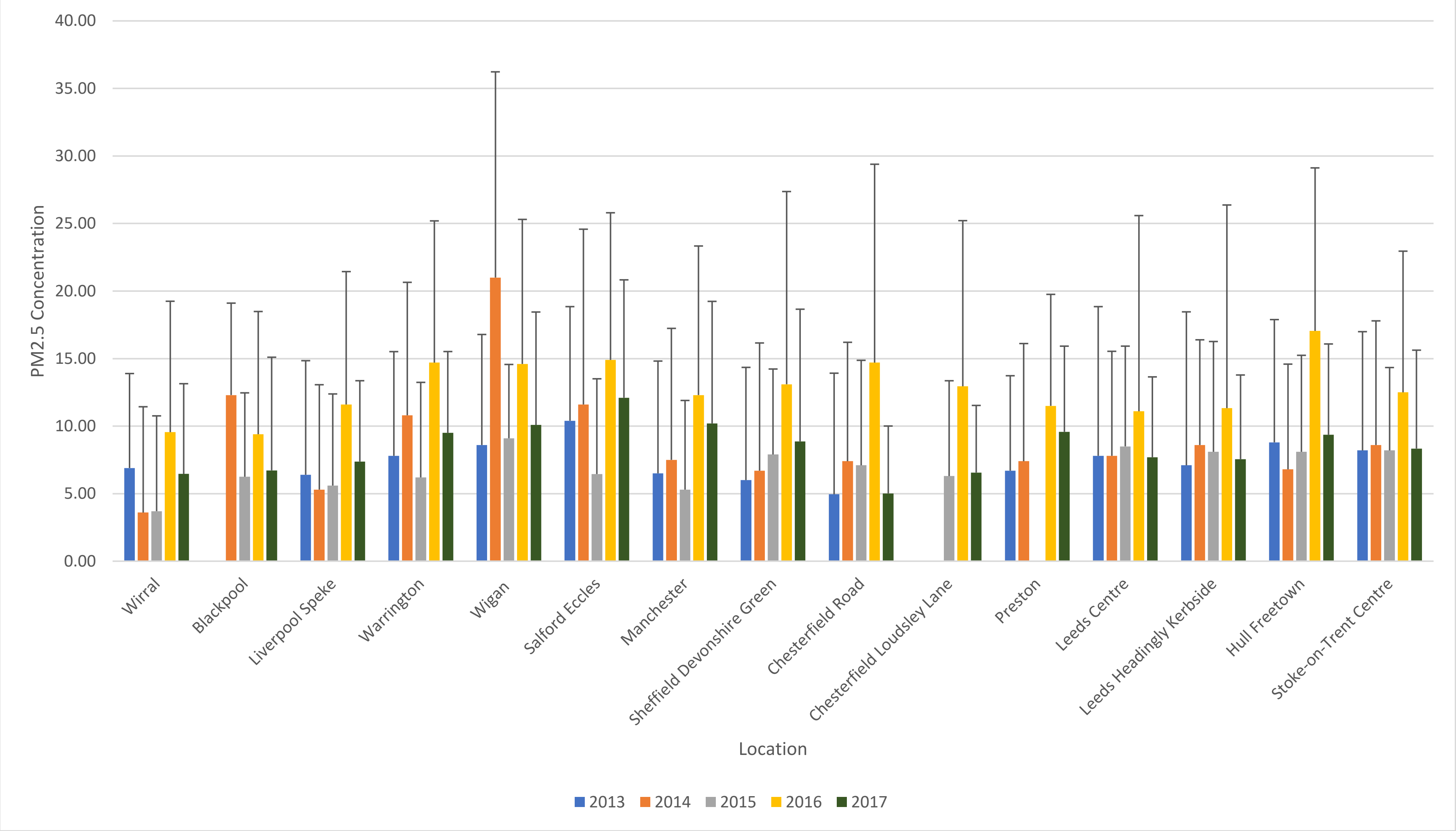

Figure 5.4: Graph showing $PM_{2.5}$ concentration for all locations across all study years for December.

Figure 5.5 shows that for March in Warrington, Scunthorpe, and Leeds Headingly Kerbside 2013 had the highest pollution levels. For Sheffield Devonshire Green, Chesterfield Roadside and Scunthrope 2014 had the highest levels. For Salford Eccles, Bury Whitefield Chesterfield Loudsley Lane and Hull Holderness 2015 had the highest levels. For Stoke-on-Trent A50 roadside 2017 had the highest pollution concentration. All locations across the whole study period had high standard deviation for instance Sheffield Devonshire Green had 25.80 in 2014 suggesting high levels of variation in pollution levels.

Figure 5.6 shows that for June 2016 tend to have the highest pollution concentration. Except for 2017 were Hull Holderness, Leeds Centre and in 2015 Bury Whitefield, Salford Eccles and in 2013 Warrington had the highest PM_{10} concentration. The standard deviation tended to be low expect for some anomalies across all locations all the years for instance in 2014 all standard deviations were under 6 expect for Scunthrope which was 11.50 suggesting a small level of variation in the pollution levels.

Figure 5.7 shows that for most locations for September 2014 had the highest pollution concentration expect for Bury Whitefield were 2015 had the highest and Chesterfield Loudsley Lane, Hull Holderness and Stoke-on-Trent A50 roadside where 2017 had the highest pollutant concentration. The standard deviation for 2016 was particularly high, for instance Sunthrope had a standard deviation of 13.69, suggesting a high level of variation in the pollution levels. For the other years studied the standard deviation was still fairly high suggesting variation in the pollution levels.

Figure 5.8 shows that for all locations studied in December 2016 had the highest pollution concentration. There were also high levels of standard deviation, for instance Leeds Headingly Kerbside had a standard deviation of 20.21, suggesting a lot of variation in the pollution levels. Across the locations there was similar pollution levels for each area.

As with $PM_{2.5}$ the pollution levels where higher in the later part of the years, in the Autumn and winter months September and December. This is mainly as a result of strong wind speeds which discourage the dispersion of pollution and wet deposition (De Lange, Garland & Dyson, 2019) and Li, Ma, Wang, Liu & Hong, 2017).

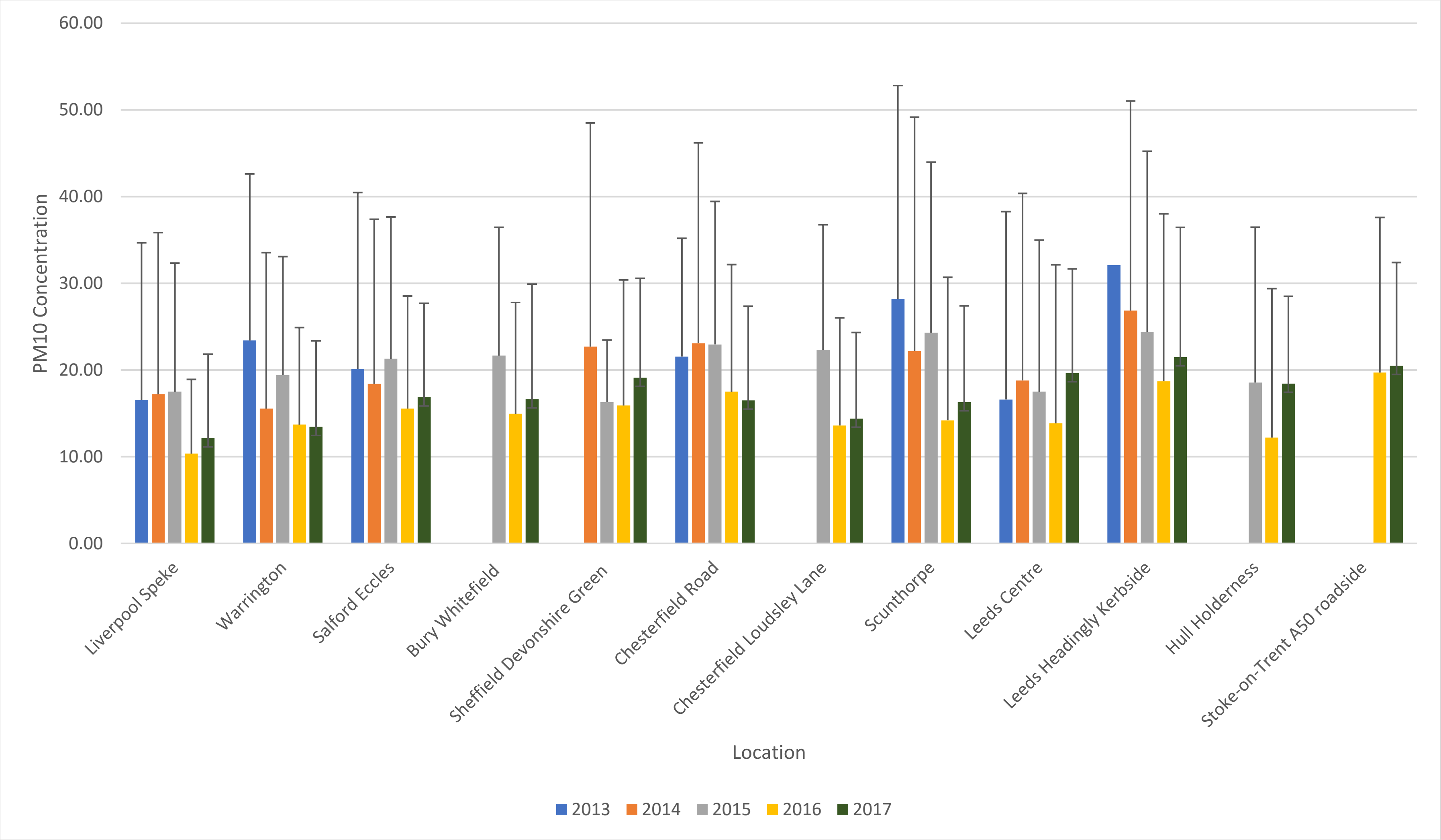

Figure 5.5: Graph showing PM_{10} concentration for all locations across all study years for March.

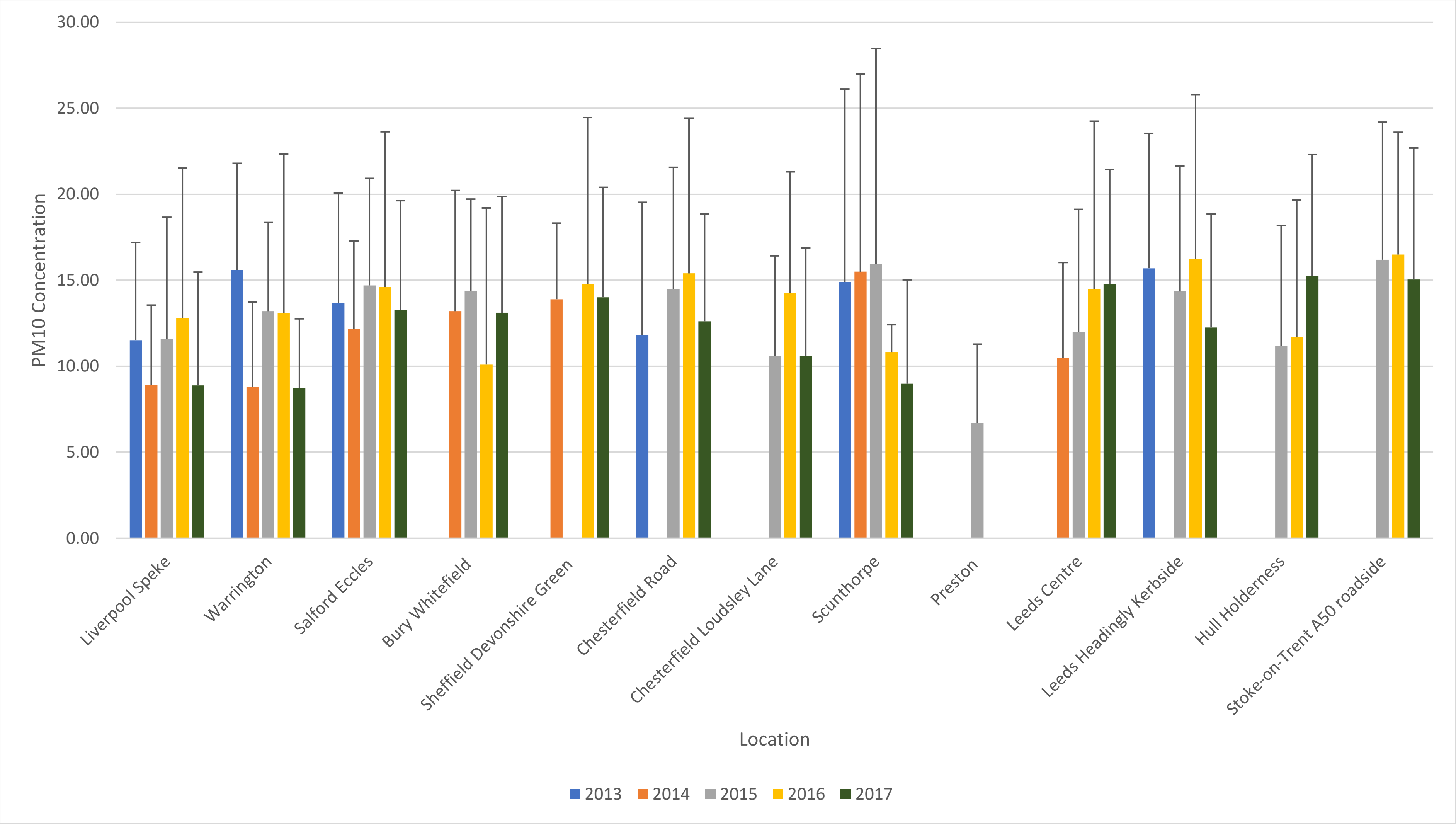

Figure 5.6: Graph showing PM_{10} concentration for all locations across all study years for June.

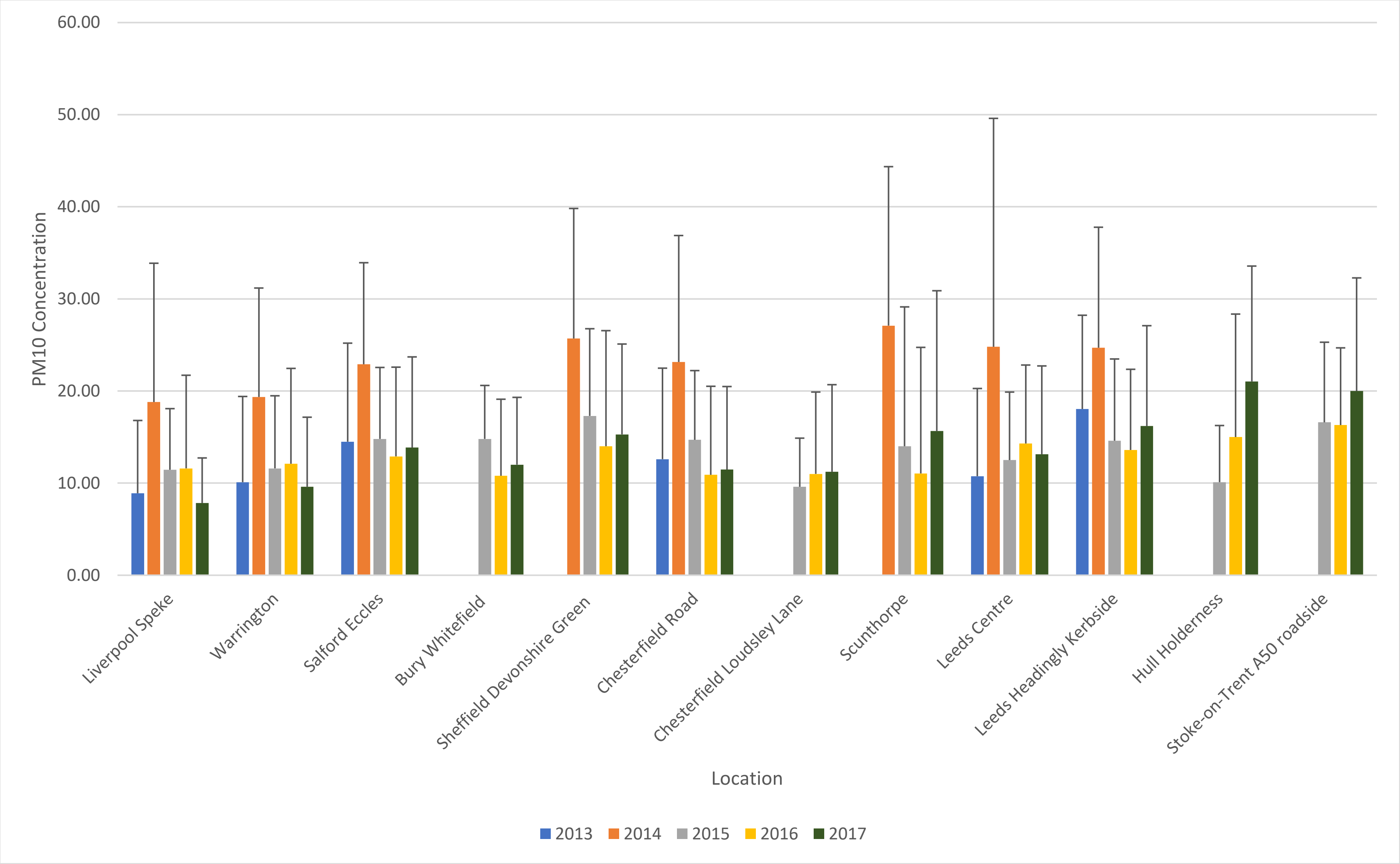

Figure 5.7: Graph showing PM_{10} concentration for all locations across all study years for September.

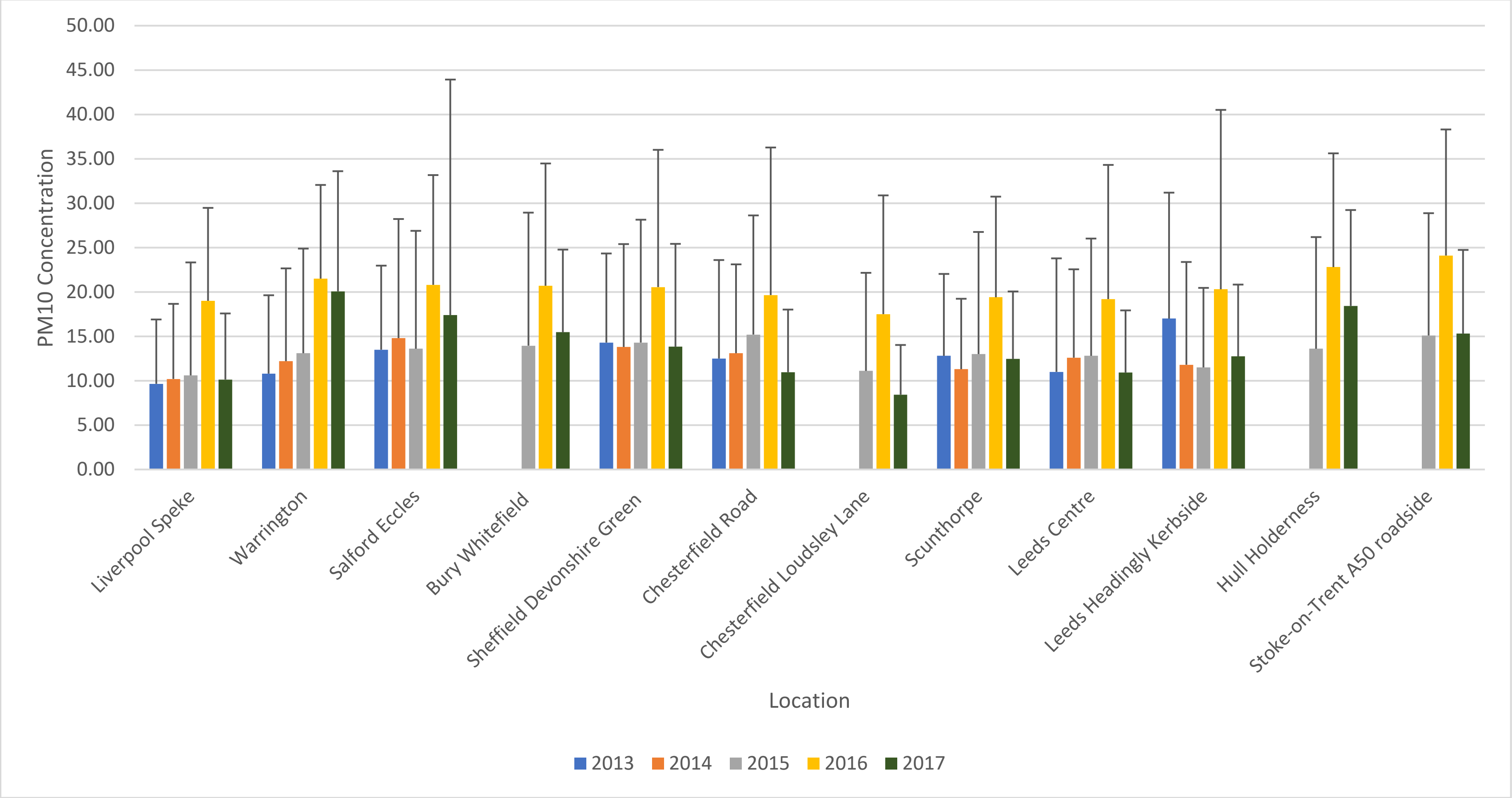

Figure 5.8: Graph showing PM_{10} concentration for all locations across all study years for December.

There were variations across the locations and months in which year the highest pollution concentration was found. In general, concentration decreased steadily from 2013 to 2017 however there where some locations were there was spikes in pollution levels in later years for instance Hull Holderness PM_{10} levels. This yearly decease is likely as a result in the change of electric generation for instance there was a decrease in production of electricity by coal by 6% from 2013 to 2014 (Department of Energy and Climate Change, 2014). There was an increase of 4.3% in the generation of electricity by renewables from 2013 to 2014 (Department of Energy and Climate Change, 2014). There was an 8% decrease in the amount of electricity produced from coal from 2014 to 2015 and generation by renewables increased by 5.5 (Department of Energy and Climate Change, 2015). Despite for some months having the highest pollution concentration in 2016 only 9% of electricity was generated by coal, with the main producer being gas at 42% (Department of Energy and Climate Change, 2016). In 2017 only 6.7% of electricity was produced by coal with gas producing the most with 40.4% and the amount generated by renewables increasing to 29.3% (Department of Energy and Climate Change, 2017). One of the possible reasons for an increase in pollution levels even with a decrease in the amount of coal being used is the fact that there has been an increase in the amount of wood used as fuel in both industries and homes which is a major contributor to particulate matter levels (DEFRA, 2018). PM_{10} concentration was higher than $PM_{2.5}$ concentration, which is since PM_{10} contains any fractions less than PM_{10}.

5.5.2 Correlation

Table 5.2 shows that there was no strong correlation between any IMD ranking and $PM_{2.5}$ concentration.

Table 5.2: Table showing correlation between $PM_{2.5}$ concentration and IMD rankings.

IMD	2013	2014	2015	2016	2017
Overall	-0.01	-0.02	-0.02	-0.03	-0.03
Barriers to housing	-0.05	-0.03	-0.09	-0.04	-0.04
Education and skills	-0.01	-0.02	-0.01	-0.03	-0.03
Employment	0.02	0.16	0.04	-0.02	0.004
Health	-0.03	-0.02	-0.01	-0.03	-0.02
Income	0.02	-0.001	0.03	-0.03	-0.002
Living Environment	0.02	0.19	-0.07	-0.01	-0.01

Table 5.3 shows that there was no correlation between IMD ranking and PM_{10} concentration.

Table 5.3: Table showing correlation between PM_{10} concentration and IMD rankings.

IMD	2013	2014	2015	2016	2017
Overall	0.15	0.14	0.06	-0.01	0.05
Barriers to housing	-0.01	-0.07	-0.01	-0.05	-0.02
Education and skills	0.12	0.12	0.04	-0.01	0.03
Employment	0.09	0.11	0.06	0.03	0.04
Health	0.12	0.15	0.05	-0.01	0.06
Income	0.09	0.11	0.09	0.03	0.05
Living Environment	0.03	-0.02	-0.03	-0.03	-0.03

5.6 Summary

There was generally a decrease in the pollution levels in later years however there was some instance where there was an increase. This could be due to the increase in wood being used as a fuel which contributes to particulate matter pollution. There was also an slight increase in winter months though not as great as found in previous studies.

There was no link found between socio-economic status and pollution concentration. This could be limited data due to some locations not monitoring particulate matter concentration or having missing data for varying levels of time. This could also be as a result of the data being collected at sampling points whereas the IMD is mapped at large spatial areas and there could be variations in the deprivation levels experienced by the population in these areas.

Chapter 6 Modelled Data

6.1 Introduction

Air pollution is recognised as a primary environmental issue with scientific evidence linking ambient air pollution with serious health effects. Therefore, it is important to generate accurate models of air pollution to quantify present and future health risks (Almissis, Philippopoulos, Tzanis & Deligiorgi., 2018).

Traditionally studies that have assessed impacted on air pollution health and other issues have had to rely on data collected by monitoring however this is often expensive it is often not possible on its own to capture the spatiotemporal variability (Brokamp, Brandt & Ryan, 2019). To deal with this problem method have been developed to predict pollution levels by modelling pollutant concentration based on features of the study area for example traffic density (Brokamp, Brandt & Ryan, 2019). Since it has become common to use modelled pollution concentration when conducting studies, it was deemed important to use modelled data as a part of this study.

When analysing pollution levels across a large area modelling is often used as it can provide information on a larger spatial scale cheaper and faster than primary data collection. With recent developments in GIS and other technologies it has enabled greater accuracy and faster development time which has greatly increased their use in research and the research surrounding the effectiveness and accuracy of different pollution models. Therefore, it was decided that it would be important to analyse the link between socio-economic status and air pollution levels generated by modelling since they have become a big part of the process of monitoring air pollution concentration.

To assess the differences in pollution concentration and spatial resolution modelled from Customer Data Research Centre (CDRC) was analysed for the Greater Manchester area.

6.2 Aims and Objectives

The aim was to assess the link between air pollution and socio-economic status using modelled data, to assess how road and socio-economic structure of a city effects pollution concentration.

The objectives were:

A. To source modelled data on PM pollution levels and data on the road and building structure in Greater Manchester.
B. To spatially analyse the modelled data.
C. To assess the road and building structure of Greater Manchester.

These objectives where selected to ensure the completion of the aim by assessing the link between socio-economic status and modelled air pollution and how the structure of Greater Manchester may affect the pollution concentration of an area.

6.3 Methodology

6.3.1 Study Area

The area selected to study was Greater Manchester as this will would allow analysis of spatial variation between the North West, spot sampling within Greater Manchester and then the modelled data of Greater Manchester. Having the same study area included in all stages of the research also allowed links to be made between the studies to assess if the link between socio-economic status and pollution concentration was found when using different techniques.

6.3.2 Data Used

The Consumer Data Research Centre (CDRC) was used to provide modelled PM pollution concentration and Ordnance Survey data was provided to information on the structure of the area to allow a more in-depth analysis to take place. The data used from the CDRC was from the Access to Healthy Assets and Hazards (AHAH). From this data set PM_{10} data was used which were annual mean averages of background pollution levels from DEFRA modelled data for 2015 (DEFRA, n.d). This would allow insights to be gained from the amount pollution sources contribute to levels at each study site. The AHAH overall index was also used as another measure of socio-economic status.

OS Open Map local data was used from the Ordnance Survey which contains information on the structure of a city. For this study the information on road types was used which provides maps of the roads which are broken down into 16 different categories to allow a more in-depth analysis as certain roads are going to have more traffic and therefore increase the concentration of pollution in that area. It also contains data on roundabouts which are analysed as areas where cars slow down or idle for a long period of time leads in an increase in pollution being released therefore increasing exposure to people traveling in the area. The road structure was analysed as previously discussed traffic is one of the main contributors to PM pollution.

For both data sets information for whole of Greater Manchester was downloaded to assess if the link between socio-economic status and air pollution is seen across the whole spatial area.

6.3.3 Data Analysis

Spatial analysis was used to assess the links between socio-economic status and PM levels as well as between road types and air pollution levels. Road types were also analysed with pollution concentration as it is known that they are a major source of PM pollution as well as studies showing an increase in morbidity and mortality for drivers, commuters and individuals living near major roadways (Zhang & Batterman, 2013). A pivot table was created to assess the different lengths of the various road types in each district within Greater Manchester as this is give an indication of the level of traffic in that area. Maps where also created showing the different road types, motorway junctions and roundabouts across Greater Manchester. This was then compared to the pollution levels in that area.

To assess the link between socio-economic status and pollution levels IMD ranking was used as well as AHAH index. By using another measurement of socio-economic status, it enables a comparison to be made to if the measurement of socio-economic status effects the results when analysing link between pollution concentration and socio-economic status.

ArcMap was used to create a visual representation of pollution levels across Greater Manchester. IMD was used to assess socio-economic status as well as well as the AHAH index to compare if there were any differences in deprivation levels of an area.

Maps where made showing the IMD and AHAH index, along with maps showing the pollution levels according to the AHAH data across Greater Manchester. This would enable comparison between socio-economic status and pollution concentration as well as comparison between the two measures of socio-economic status.

To conduct the spatial analysis a base map of Greater Manchester was first created by downloading a map of England in Lower Layer Super Output Areas (LSOA) and then using the geoprocessing tool clip with a map of Greater Manchester from the CDRC to create one that would show the LSOA of the study area. This enabled both the Index of Multiple Deprivation of AHAH data sets to be joined to the map as the data is in the same spatial disruption**.** This would then allow spatial analysis of pollution and deprivation levels across Greater Manchester. The OS Open Road local data was available to download by selecting national reference squares of which two where needed to have all the data for Greater Manchester. To isolate the relevant data the geoprocessing tool clip was used to create a layer of just the data needed for both data sets and then merge was used to create one layer. This then allowed for spatial analysis of the structure of the city.

To allow greater insight the distribution of deprivation across the study area, tables were made showing the number and percentage of LSOAs in each decile from the attribute table. This was done by selecting the IMD ranking in the attribute table and selecting ‘summarise’ and then ‘GM_LSOA.code’ which would create a table with the deciles and number of LSOAs in it. A new field was then be added to the table and field calculator used to calculate the percentage of LSOAs in each decile. A pivot table would also be created to show road length and PM_{10} concentration. This would then be used to perform a person correlation between the pollution levels and road length.

6.4 Results

6.4.1 Spatial Analysis

Figure 6.1 shows that the majority of Greater Manchester is in the most deprived deciles for the Health Deprivation and Disability Domain. A high amount of areas in decile 1 where situated in the centre of Manchester, a largely urban area. This is supported by table 6.1 which shows that 62.52% of LSOA’s where in the first three deciles.

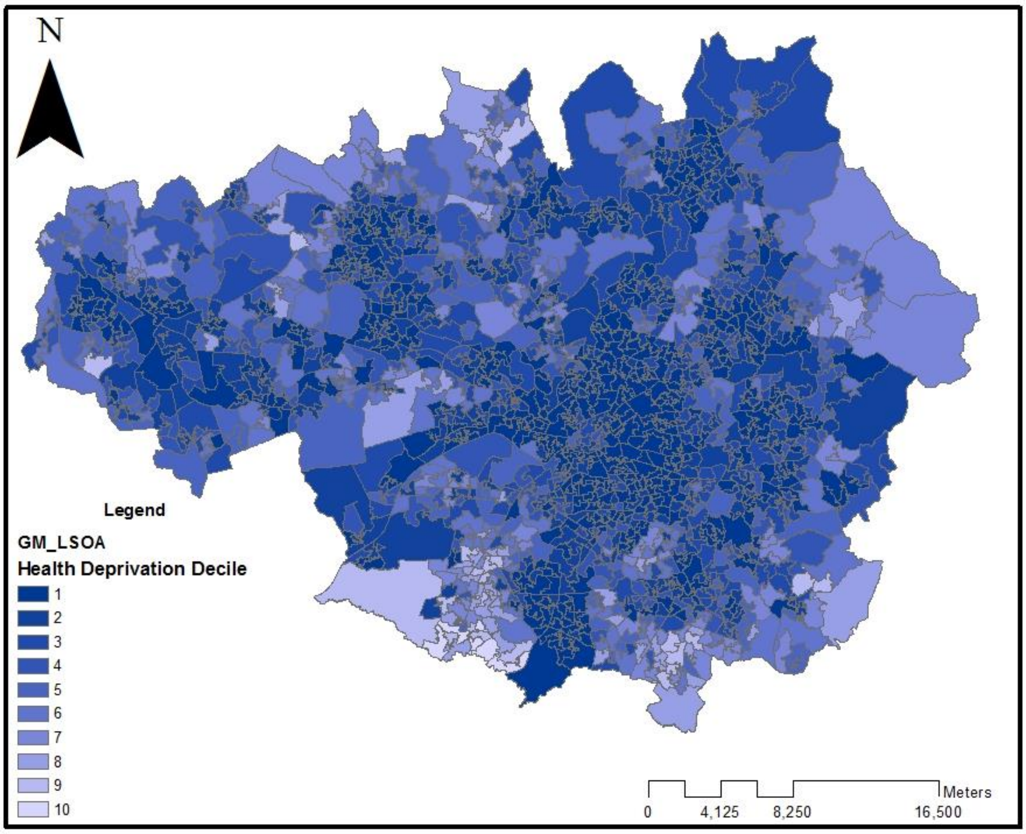

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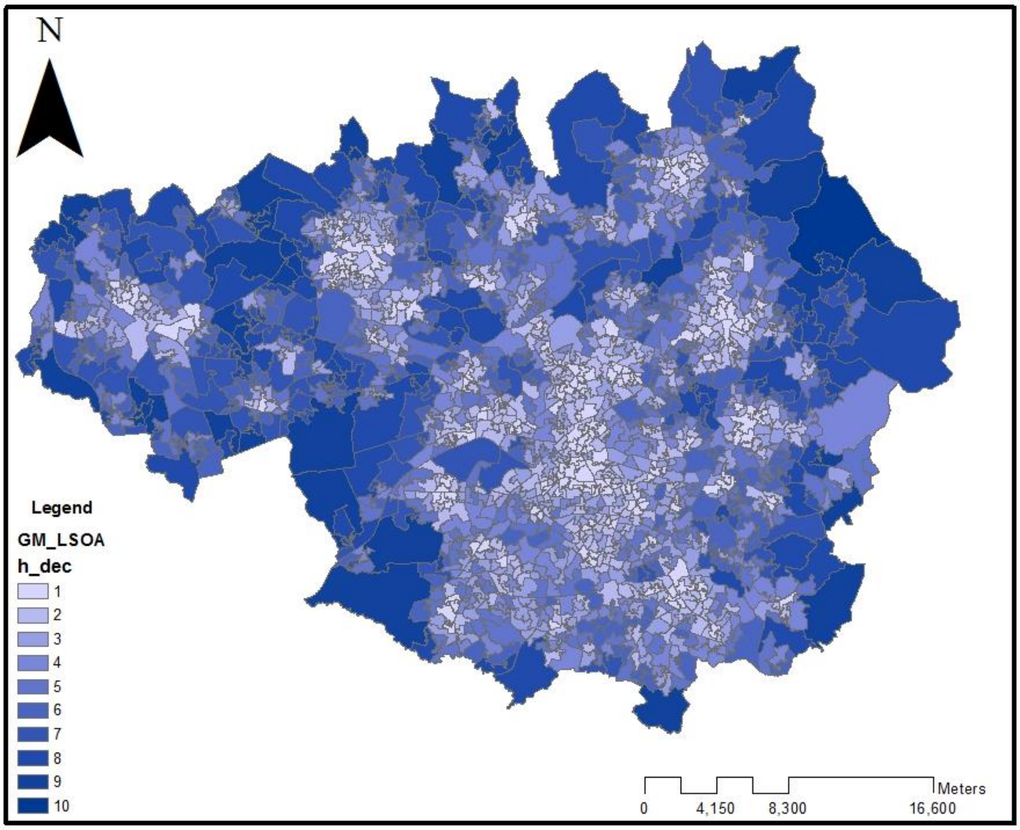
Figure 6.1: Map showing the Health Deprivation decile over Greater Manchester where 1 is the most deprived and 10 is the least.

Table 6.1: table showing the number and percentage of LSOA in each health and disability decile.

Health Deprivation Decile	Number of LSOA in Decile	Percentage of LSOA in Decile
1	523	31.26
2	316	18.89
3	207	12.37
4	177	10.58
5	151	9.03
6	123	7.35
7	98	5.86
8	49	2.93
9	23	1.37
10	6	0.36

The AHAH data for health indicates a different situation for health in Manchester as Figure 6.2 shows that the majority of Greater Manchester is in the best performing deciles for the health domain. Table 6.2 show that the majority of Greater Manchester was in the least deprived Health deciles as 61.39% of LSOAs where in the first 4 deciles. There was also a difference in where the most deprived areas where as they were on the edge of Greater Manchester rather than in the middle like in figure 6.1.



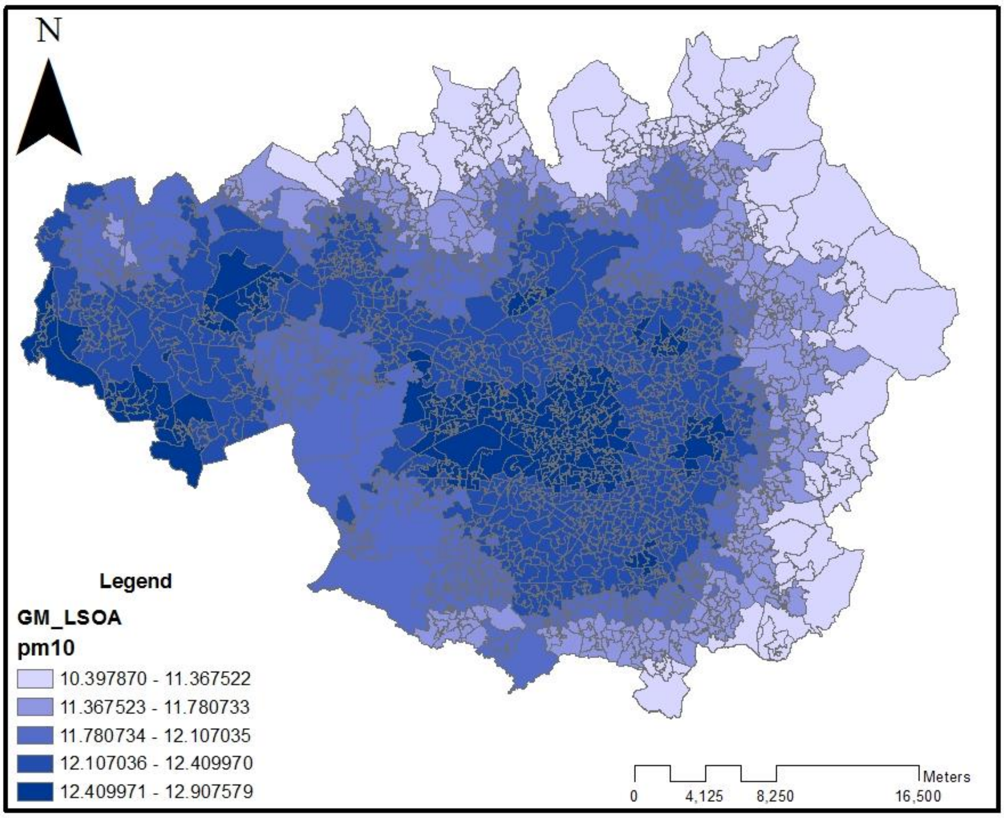
The data for this research have been provided by the Consumer Data Research Centre, an ESRC Data Investment.

Figure 6.2: Map showing the health decile from the AHAH data across Greater Manchester where 1 is the least deprived and 10 is the most deprived.

Table: 6.2 showing the number and percentage of LSOAs in each AHAH Health Decile in Greater Manchester.

Health Decile	Number of LSOA in Decile	Percentage of LSOA in Decile
1	196	11.72
2	300	17.93
3	293	17.51
4	238	14.23
5	195	11.66
6	183	10.94
7	132	7.89
8	96	5.74
9	39	2.33
10	1	0.06

Figure 6.3 shows that the highest pollution concentration was in the centre of Greater Manchester with the pollution concentration generally decreasing from there.



The data for this research have been provided by the Consumer Data Research Centre, an ESRC Data Investment.

Figure 6.3: Map showing the PM_{10} yearly averages from the AHAH data across Greater Manchester.

Figure 6.4 show that a lot of deprived deciles where in the centre of Greater Manchester however there was not a strong pattern in how the deciles where spread out across the study area. Table 6.3 shows there was similar numbers of LSOAs in each decile expect for decile 10 which only contained 3.17% of deciles.

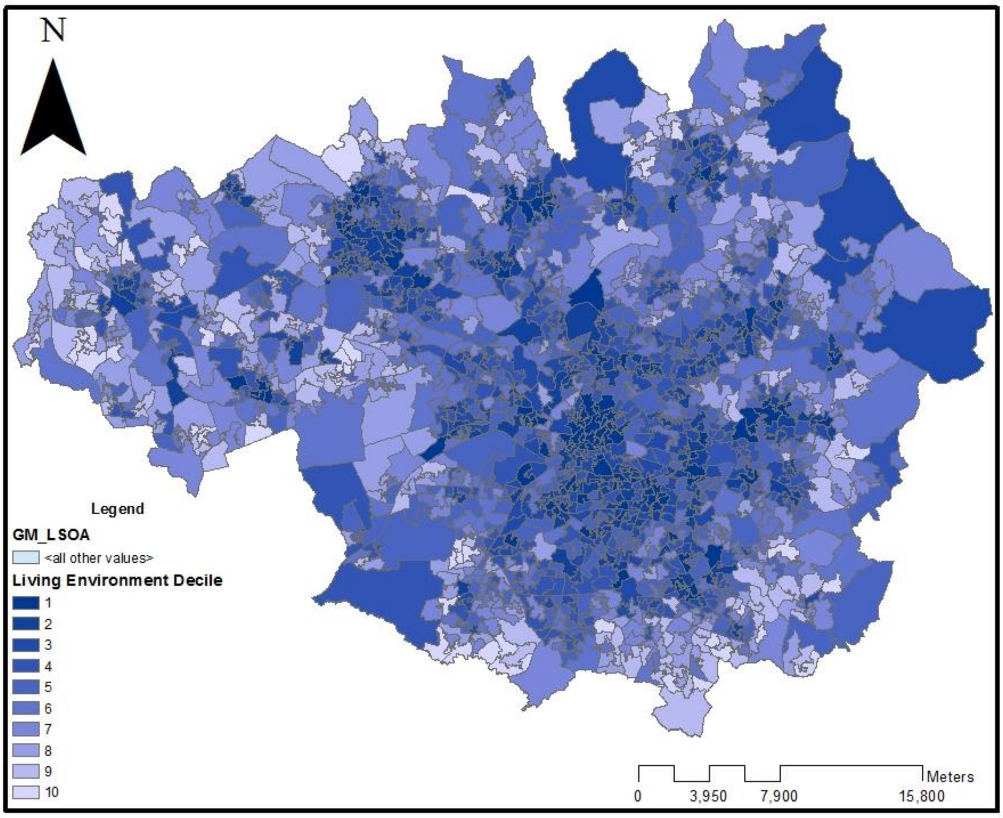


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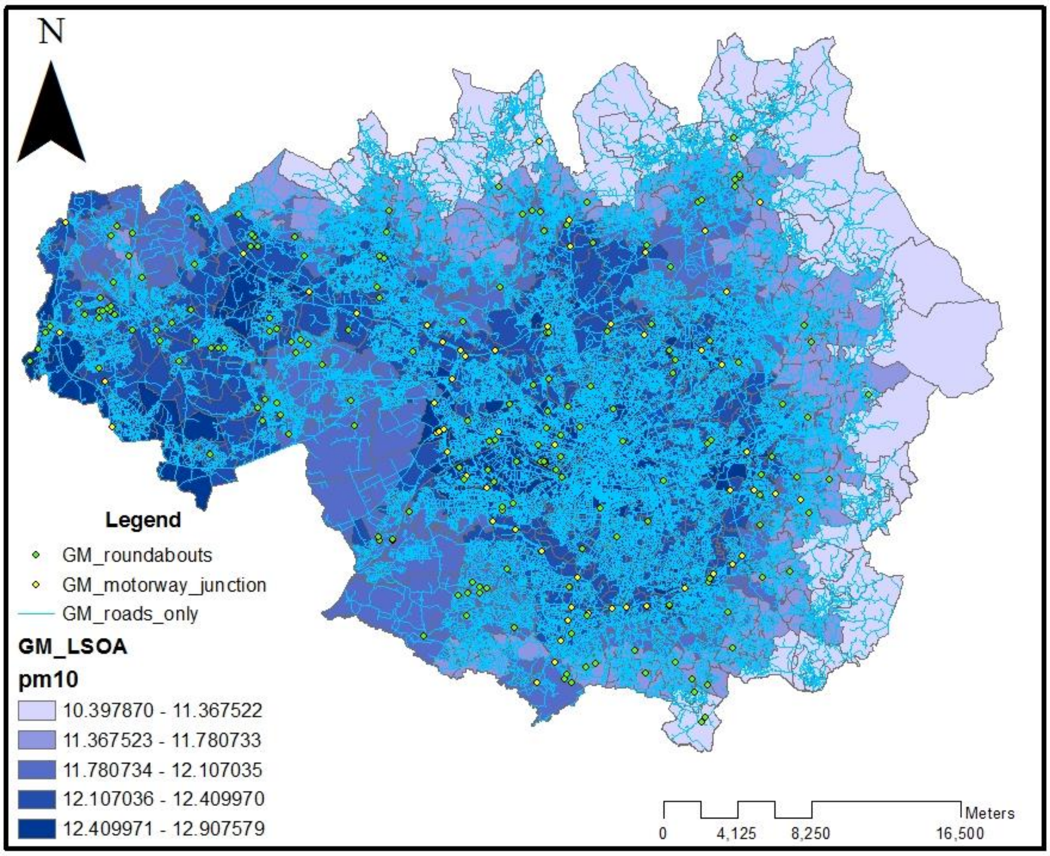
Figure 6.4: Map showing the Living Environment Decile for Greater Manchester.

Table 6.3: Table showing the number and percentage of LSOAs in each living environment decile.

Living Environment Decile	LSOAs in Decile	Percentage in Decile
1	121	7.23
2	148	8.85
3	203	12.13
4	237	14.17
5	238	14.23
6	199	11.89
7	185	11.06
8	162	9.68
9	127	7.59
10	53	3.17

Figure 6.5 shows that there was a high number of roads in the centre and south of Greater Manchester however all LSOAs had a moderate number of roads in them. Table 6.4 shows that there the most common type of road within the study area was local road. Table 6.5 shows that while the worst performing decile (6) contains the least length of road. This is supported by Table 6.6 which shows that there a weak negative correlation between road length and PM_{10} concentration. This suggests that road pollution might not be the main source of PM_{10} pollution across Greater Manchester.



The data for this research have been provided by the Consumer Data Research Centre, an ESRC Data Investment.
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Figure 6.5: Map showing the PM_{10} yearly averages and roads, motorway junctions and roundabouts across Greater Manchester.

Table 6.4: Statistics for different road types across Greater Manchester.

Road Category	Length	Minimum Length	Maximum Length	Average Length	Sum Length	Standard Deviation Length
A Road	8779	0.003	2123.98	61.54	540298.98	86.27
B Road	5934	0.003	919.68	65.71	389928.01	77.87
Guided Busway Carriageway	54	0.356	973.56	255.59	13801.97	241.83
Local Road	109470	0.002	2203.10	72.96	7987033.87	76.00
Minor Road	14587	0.002	1600.00	73.52	1072465.80	91.39
Motorway	1609	0.003	1766.62	176.82	284504.70	200.29
Primary Road	6245	0.002	1523.80	62.23	388628.13	86.36
Shared Use Carriageway	101	1.853	290.74	66.10	6676.45	47.67

Table 6.5: Length of road types in each PM_{10} decile.

Decile	A Road	B Road	Guided Busway Carriageway	Local Road	Minor Road	Motorway	Primary Road	Shared Use Carriageway	Grand Total
3	109839.4	69261.29		1221711	214451.9	18397.29	40316.71	218.2879	1674196
4	213458.6	174349.5	13473.81	3528088	448576.2	74073.3	149457.3	2037	4603514
5	191632.2	139756.1	328.1637	3113375	402499.9	186182.5	188817.9	2739.932	4225332
6	25368.8	6561.198		123858.7	6937.673	5851.584	10036.27	1681.229	180295.5
Grand Total	540299	389928	13801.97	7987034	1072466	284504.7	388628.1	6676.449	10683338

Table 6.6: Pearson Correlation between road length and average PM_{10} concentration.

Road Type	Pearson Correlation
Total Road Length	-0.15
A Road	-0.17
B Road	-0.11
Local Road	-0.18

6.5 Conclusion

There was shown to be differences in the deprivation levels awarded to areas from the IMD and AHAHA index. This is likely due to the fact that they use different measures to calculate deprivation this is an issue for studies as there is no standardised way to assess deprivation therefore this can affect the results of studies. The results also suggest that there was not a strong link between road lengths and PM_{10} concentration. This could be due to the fact that areas with smaller road length might have more traffic however as discussed in chapter 2 section 2.2 there are multiple sources for particulate matter pollution and often traffic is not the main source.

Chapter 7: Discussion

7.1 Introduction

This chapter will discuss the results found from each study and whether the findings support the same conclusions and how this relates to findings in previous studies. It will also assess the results in the context of the aims and the objectives of the study and the extent to which these have been addressed.

7.2 Socio-economic Status and Pollution Concentration

As discussed in the introduction section 1.2 one of the aims was to assess variations in air quality in areas of different socio-economic status and to determine the relationship between air quality and socio-economic status. This was determined after previous studies have found links between pollution concentration and socio-economic status as discussed in chapter 2 section 2.4.

To do this for the AURN and primary data study a person correlation was performed against the pollution levels. There was not found to be a significant link between socio-economic status and pollution levels between IMD ranking and all pollution levels through AURN and primary data studies. This is shown by table 4.25 were there was no significant Pearson correlation between IMD ranking and pollution concentration for any of the IMD domains. There was also found to be no significant correlation between pollution levels and IMD domains rank for all years in the AURN data study. This is shown by tables 5.2 and 5.3 which suggests that deprivation level may not influence exposure to pollution levels in these study areas and other factors are having a more substantial impact on pollution concentration. This is different to previous studies that have found a link between socio-economic status and pollution levels such as Fecht et al. (2015), which found a weak Pearson correlation between PM_{10} levels and social and deprivation characteristics in the six cities studied in England. However, even though the correlation was weak they did also find that at a national level the highest mean pollution concentration was experienced by the most deprived neighbourhoods. It was found neighbourhoods in the most deprived quintile experiences on average 2.6 $\mu g/m^3$ higher levels of PM_{10} than those in the least deprived quintile.

In the primary data study, the strongest link was found between Living Environment Decile and pollution levels with a correlation of 0.09 (TSP), 0.02 (PM_{10}), 0.11 ($PM_{2.5}$), 0.08 (PM_1) as shown by Table 4.25. This was the same for the AURN data study with a correlation of 0.02 (2013), 0.19 (2014), -0.07 (2015), -0.12 (2016), and -0.01 (2017) between Living Environment ranking and $PM_{2.5}$ concentration as shown by Table 5.2. It also shown Table 5.3 with a correlation of 0.03 (2013), -0.02 (2014), -0.03 (2015), -0.03 (2016), -0.03 (2017), between PM_{10} and Living Environment Rank. These results therefore suggest that there is not a strong correlation between the Living Environment Domain, or any other domain studied and particulate matter concentration. This contradicts other studies that have taken place in the UK such as Mitchell and Dorling (2003) who found that the 10% most deprived wards in Britain had a mean NO_2 concentration 17% above the national mean.

When analysing the number of LSOA in each decile for the health and disability domain in the AHAH data around 61% of all LSOA's were in the first three deciles as shown by Table 6.2. This suggests that Greater Manchester has a high level of deprivation of in terms of health which could suggest that the population may be susceptible to health effects of pollution levels as this has been found in previous studies such as Jans, Johnsson and Nilsson (2018) who found that low-income children were more affected and positive differences in baseline health were a key mitigating factor behind the effect of pollution on the SES health gap. Neidell (2004) also found people of a lower SES experience more severe health effects than those of a higher SES at the same pollution levels.

7.3 Road Traffic and Pollution Concentration

One of the aims of the modelled data study was to assess the road structure of Greater Manchester as well as assess traffic levels in the area. This was decided as traffic sources contribute to particulate matter pollution as discussed in chapter 2 section 2.2. Traffic is one of the largest contributors to particulate matter pollution (Bari & Kindzierski, 2017) and in 2016 traffic sources were the second biggest contributor to PM_{10} and $PM_{2.5}$ levels. Other studies such as analysed the effect of traffic sources on pollution concentration mostly using modelling techniques to calculate traffic flows and pollution levels. Rose, Cowie, Gillett and Marks (2009) used traffic counts, distance to main road and proposed weighted road density and tested the association between NO_2 levels. They found that weighted road density variable and traffic count density had similar results for predicating pollution levels.

As a result of this traffic counts were taken during the Primary Data study as traffic has been shown to produce Particulate Matter pollution (DERFA, 2018). Traffic counts where taken during the whole period of monitoring. The traffic counts will be discussed here along with Department for Transport traffic (DfT) counts as these counts will be from 24-hour averages to get a more information on the traffic levels in the areas all year around. This is discussed in more detail in Chapter 4 section 4.5.4.

Tables 7.1 to 7.3 show that there were similar levels of vehicle traffic in Areas 1 and 2 whereas Area 3 had significantly lower levels of traffic.

Table 7.1: Table showing the average number of vehicles for Area 1.

Vehicle Type	Average Number
Car	70
Van	16

Table 7.2: Table showing the average number of vehicles for Area 2.

Vehicle Type	Average Number
Car	87
Van	20
HGV	1

Table 7.3: Table showing the average number of vehicles for Area 3.

Vehicle Type	Average Number
Car	23
Van	6
HGV	1
Bus	3

Table 7.6 shows that there were higher traffic levels in Area 3 and table 7.4 shows the lowest traffic levels in Area 1 from Department of Transport traffic counts. This is the opposite of traffic counts taken during monitoring.

Table 7.4: Table showing Department of Transport traffic counts for Area 1.

Year	Motorcycle	Car/taxi	Bus/coach	Light Goods	HGV	Total
2013	32	10086	142	1495	182	11937
2014	61	9796	138	1185	124	11277
2015	54	9963	148	1242	191	11527
2016	53	10118	137	1357	121	11787
2017	53	10044	128	1428	121	11775

Table 7.5: Table showing Department of Transport traffic counts for Area 2.

Year	Motorcycle	Car/taxi	Bus/coach	Light Goods	HGV	Total
2013	196	25560	49	2835	887	29527
2014	201	24649	48	3037	783	28728
2015	205	24197	57	3194	777	28430
2016	200	24574	53	3489	789	29106
2017	202	24393	50	3673	794	29112

Table 7.6: Table showing Department of Transport traffic counts for Area 3.

Year	Motorcycle	Car/taxi	Bus/coach	Light Goods	HGV	Total
2013	78	4253	151	497	41	5020
2014	75	4368	145	532	42	5162
2015	66	4455	156	557	42	5276
2016	65	4524	145	609	43	5385
2017	65	4491	135	641	43	5376

There was found to be similar levels of traffic in the Primary Data Study for Area 1 and 2 as shown by tables 7.1 and 7.2 with Area 3 having significantly less vehicle traffic as shown by table 7.3. The Department of Transport data showed that Area 2 had the highest level of traffic unlike the primary data there was a significantly lower amount of traffic at Area 1 and Area 3 had the lowest levels and shown by tables 7.6 and 7.4. However, this could be because the count points for the Department of Transport were along main roads that where busier whereas the primary data traffic counts included smaller back roads which would have lower levels of traffic. When comparing the pollution concentration of the areas Area 1 had the highest TSP and PM_{10} and Area 3 had the highest $PM_{2.5}$ and PM_1 levels as shown by tables 4.21 to 4.23. The modelled data study found the worst performing PM_{10} decile had the least length of road. This is shown by table 6.5 were decile 6, the most deprived decile, in Manchester had 180295.5 miles of road whereas decile 4 had the most road 4603514 miles.

This indicates that vehicle traffic might not a major contribution to particulate matter pollution in these areas. Table 6.6 also shows when analysing the yearly average PM_{10} data from the AHAH data and road length from the OS Open road data there was no correlation found. This supported by the Department of Environment, Food and Rural Affairs (2019) which states that 38% of $PM_{2.5}$ pollution is generated from domestic wood and coal burning and only 12% from road transport. Since the study areas for the primary data collection were in residential areas this might be more likely to influence pollution concentration than road traffic.

7.4 Pollutant Concentration and Guidelines

Table 2.1 shows the air quality guidelines set by the European Union (EU) and World Health Organisation (WHO). While at present the UK must meet air quality guidelines set by the EU it does not have do so for ones suggested by WHO.

While the data from these studies is not in the form that is needed to assess if these guidelines have been met a comparison is being made to see how close the pollution concentration are to levels considered to present an acceptable risk to human health. Area 1 had an average PM_{10} concentration of 14.01 $\mu g/m^3$ and $PM_{2.5}$ concentration of 6.15 $\mu g/m^3$ as shown by table 4.29. Area 2 had an average concentration of 18.45 $\mu g/m^3$ and $PM_{2.5}$

concentration of 7.22 µg/m^3 as shown by table 4.21. Area 3 had an average concentration of 13.31 µg/m^3 and $PM_{2.5}$ concentration of 5.23 µg/m^3 as shown by table 4.23. All the averages for both pollutants meet both hourly for annual targets which suggests that pollutants in the area are being kept within guidelines and therefore keeping health effects to a minimum. However, when looking at the maximum pollution levels in each area they were extremely high as shown by table 4.21 to 4.23 with Area 1 having an extremely high maximum TSP concentration of 614.80 µg/m^3. It has been shown that short term health effects can be caused by short term exposure to high pollutant concentrations (DEFRA, 2019). However, the higher concentrations may not be consistent in these areas as only limited spot sampling had taken place therefore, they could be anomalies. Also, since the sampling only took place in three months, June, July and August it is possible that seasonal variations would have also affected the average pollution levels in the study areas. Hou, Zhu, Kumar and Lu found that there were fluctuations in $PM_{2.5}$ emissions throughout seasons were influenced by meteorological conditions. They found that generally $PM_{2.5}$ levels were higher in the autumn and winter months. Feng and Wang (2012) found that the weather events dust, precipitation and cold fronts have greater impacts on the concentration of coarse particles then fine particles. They also found the greatest impact of pollution levels were at the start of the weather events and after that they vary slowly. This could suggest that while weather can affect the pollution levels after the incident it will level out to normal levels.

7.5 Comparison of IMD and AHAH rankings

One of the aims of this study was to compare pollution levels in areas of different socio-economic status. To do this Index of Multiple Deprivation was used to asses deprivation level to the study areas in the primary data study and in the modelled data study.

The Index of Multiple Deprivation (IMD) ranks each ward in the UK with 1 being the most deprived whereas the Access to Healthy Assets and Hazards (AHAH) assesses the amounts of risk for health in each area. The aim of comparing the deciles of wards is to assess if the deprivation levels is similar to the risk level that has been assigned to the same area. When comparing the deciles is it important to note for the IMD 1 is the most deprived and 10 the least deprived whereas for the AHAH 10 is the most at risk and 1 is the least at risk.

When comparing overall levels assigned to the study areas from the IMD and AHAH there is a difference in the deciles each area is in. According to the IMD study Area 1 was in the 1st decile therefore one of the most deprived area in England and was in the 8th decile for the AHAH index. Area 2 was in the 5th decile in the IMD whereas in the 10th decile in AHAH index, this is a significant difference as in one it is a slightly deprived area and in the other it is one of the highest risk areas in England. Area 3 was in the 7th decile for the IMD and for the AHAH index it was in the 10th decile. As shown, there was often difference in risk and deprivation levels assigned to the study areas, this suggests that while an area might have a high level of risk it does not always equal to deprivation.

When looking at the Health Domain for the IMD and AHAH Area 1 from the Primary Data study was in decile 1 for IMD and 2 for AHAH. This suggests that it is an area of high deprivation but of low risk. Area 2 was in decile 2 for both and Area 3 was in decile 5 for the IMD and 2 for AHAH.

7.5 Conclusions

The main conclusion was that there was no statistically significant link found between socio-economic status and pollution concentration. This is different from previous studies such as Hajat, Hsia and O'Neill (2015) and Li at al. (2018) which have found a strong link between socio-economic status and pollution levels.

The three different studies looked at pollution levels on different spatial scales to assess if this had any effect on the results found between socio-economic status and pollution levels. It was found that there was no significant link between socio-economic status and pollution levels throughout the studies suggesting that study scale didn't affect the link between socio-economic status might not be affected by spatial scale used in a study.

There was not found to be higher levels of traffic in areas of higher pollutant levels which suggests that this was not a main pollutant source in these study areas. As discussed in chapter 2 section 2.2 there are multiple sources of particulate matter and these results suggest that road traffic is not a major contributor in the study areas in the Primary Data study.

Chapter 8: Conclusions

8.1 Key Findings

There was no significant link found between socio-economic status and pollutant concentration throughout all studies which is different than previous research undertaken in this area. This could be partially due to the fact that all domains of the Index of Multiple Deprivation (IMD) were assessed against pollution levels when they might not all be linked to pollution concentration. It could also suggest that the link between socio-economic status might be more complex than previously thought.

Another aim was to find if the link between socio-economic status and pollution concentration was affected by the different spatial scales throughout the different studies. Since there was no significant link found in all studies this suggests that the spatial scale will not affect any results suggesting it may not be an issue when selecting study areas for future studies.

There was not found to be higher levels of road traffic in areas of higher pollution levels for both the primary data traffic counts and the Department for Transport traffic counts. This suggests that for these studies areas it was not the primary contributor to pollution concentration. As discussed in Chapter 2 section 2.2 there are many sources of particulate matter pollution and this can cause difficulty in pinpointing the sources and reducing pollution levels. As discussed in section 2.3 there has been a reduction in the amount transport sources have contributed to particulate matter pollution from 1990 were 40.6 KT of PM_{10} emissions were produced by transport sources compared to 2016 were only 19.2 KT of PM_{10} were produced by transport sources (DEFRA, 2018).

The Primary Data Collection study showed that the average pollution concentration was not high; however, the maximum levels of pollutants were often very high. This is shown by Area 1 maximum $PM_{2.5}$ concentration of 86.49 $\mu g/m^3$, Area 2 having a maximum $PM_{2.5}$ concentration of 112.67 $\mu g/m^3$ and Area 3 having a maximum $PM_{2.5}$ concentration of 111.89 $\mu g/m^3$ as shown by Tables 4.21 to 4.23. This could suggest that people are exposed to high pollutant concentrations for short periods of times which could still cause negative health effects (DEFRA, 2019). For the AURN Data Study there was often found to similar pollution levels expect for on occasion for certain years there was jump in pollution levels for example figure 5.3 shows that September 2014 had a lot higher $PM_{2.5}$ levels then the other years studied. There was also not a large amount of variation in the different pollution concentration throughout the months suggesting particulate matter is not greatly affected by the change in meteorological conditions. This could mean future studies may not need a whole years' worth of pollution concentration data to get an accurate representation of pollution levels in an area.

Another aim was to evaluate if the different temporal scales of pollution data collection would affect the particulate matter levels found in these areas. As already stated, there was often not a great difference in the concentration found in both the primary and AURN data study. This suggests that even pollution data gathered over a shorter period of time can still average to longer term pollution levels. The most common background pollution PM_{10} was lower than both the primary and AURN data which is expected and shows that there is noticeable difference found in lowest average and highest pollution concentration experienced by the population. This suggests work needs to be done to lower population levels in this area to ensure that more often they are closer to the lower average levels and therefore limit the chance that the general public will experience negative health effects.

The hypothesis of there being a link between socio-economic status and pollution concentration was found to be not accurate. This is different to multiple different studies which have a found a statistically significant links between deprivation and pollution levels. This could suggest that previous research results might have not been solely influenced the differences in pollution concentration.

8.2 Limitations

As discussed previously in Chapter 5, not all sites for the AURN Data Study had pollution level data for the whole time period selected for the study. This could have affected the average pollution levels found therefore some conclusions might not be accurate. However, to reduce the risk of anomalies disproportionately affecting the overall results data was used for five years from 2013-2017. Also not ever monitoring station within the study area monitored the necessary pollutants therefore this also limited the amount of data available in different socio-economic status. However, there was still 19 stations were the necessary data was available therefore enough data was available to conduct analysis.

For the Primary Data Study, more monitoring events and potentially longer sampling times would have created a more accurate representation of the pollution levels in the study area. However as previously discussed in Chapter 4 section 4.6 this was not possible due to problems with the monitoring equipment not being able to record for long periods of time. It would also have been useful to have an area from each IMD decile rather than from three to assess if there was much difference in deciles that are closer together.

8.3 Recommendations for Future Research

It was found that there was no link between deprivation and pollution levels. This could suggest that previous research that found a link might have not included other reasons for the differences in pollution levels between different areas. This could also be of a result of spatial differences in the studies and future research should try to determine the effect of spatial area on the link between socio-economic status and pollution concentration.

As shown by the AURN data study there was often one permeant monitoring station in a city which will not give details about the whole city's particulate matter pollution level and has been shown in chapter 2 section 2.4 particulate matter has been shown to have negative health effects. Therefore, it would be useful for the government to invest in pollution monitoring equipment to allow for more knowledge to be developed on pollution concentration.

There was also evidence to suggest that traffic sources were not a major particulate matter pollution and therefore future studies should focus on other pollutant sources to be able to accurately detail the creators of pollutants. This is important as knowing the sources will allow for better decisions to be made by policy makers to reduce pollution levels.

There is no standard for determining socio-economic status for studies and this could lead to differences in results. While many studies that take place in the United Kingdom use the Index of Multiple Deprivation some do not, and it would be better for comparison between studies if areas where assign the same levels of deprivation.

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Appendix

Appendices A

Table showing statistics for TSP concentration for both machines.

	Minimum	Maximum	Mean	Std. Deviation
Machine 1 TSP	32.50	220.50	69.2649	39.36292
Machine 2 TSP	41.90	230.20	74.7487	36.21520

Appendices B

Table showing statistics for $PM_{2.5}$ concentration for both machines.

	Minimum	Maximum	Mean	Std. Deviation
Machine 1 $PM_{2.5}$	19.85	35.86	24.9865	2.94987
Machine 2 $PM_{2.5}$	23.00	39.96	28.5146	3.35521

Appendices C

Table showing statistics for PM_{10} concentration for both machines.

	Minimum	Maximum	Mean	Std. Deviation
Machine 1 PM_{10}	25.30	107.80	42.3432	15.98273
Machine 2 PM_{10}	30.00	113.40	46.4205	15.37051

Appendices D

Table showing statistics for PM_1 concentration for both machines.

	Minimum	Maximum	Mean	Std. Deviation
Machine 1 PM_1	13.66	18.86	16.0273	1.21640
Machine 2 PM_1	14.67	21.39	17.6144	1.47873

Appendices E

Table showing regression for TSP concentration between both machines.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.006[a]	.000	-.029	37.29168
a. Predictors: (Constant), machine1tbs				

Appendices F

Table showing regression for PM$_{10}$ concentration between both machines.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.061[a]	.004	-.025	16.17950
a. Predictors: (Constant), machine2pm10				

Appendices G

Table showing regression for $PM_{2.5}$ concentration between both machines.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.221[a]	.049	.022	2.91757
a. Predictors: (Constant), machine2pm2.5				

Appendices H

Table showing regression for PM_1 concentration between both machines.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.289[a]	.083	.057	1.18110
a. Predictors: (Constant), machine2pm1				

Appendices I

Tests of Between-Subjects Effects for TSP and overall IMD ranking.

Source	Sum of Squares	df	Mean Square	F	Sig.
Scale	45826.428	2	22913.214	29.928	.000
a. R Squared = .029 (Adjusted R Squared = .028)					

Appendices J

Pairwise comparison for TSP concentration and IMD ranking.

(I) scale	(J) scale	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
Deprived	slightly deprived	-9.967*	1.492	.000	-13.533	-6.402
	not deprived	.540	1.502	.978	-3.049	4.130
slightly deprived	deprived	9.967*	1.492	.000	6.402	13.533
	not deprived	10.508*	1.551	.000	6.802	14.213
not deprived	deprived	-.540	1.502	.978	-4.130	3.049
	slightly deprived	-10.508*	1.551	.000	-14.213	-6.802

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Sidak.

Appendices K

Tests of Between-Subjects Effects for PM_1 and IMD ranking.

Source	Sum of Squares	df	Mean Square	F	Sig.
Scale	116.624	2	58.312	2.324	.098
a. R Squared = .002 (Adjusted R Squared = .001)					

Appendices L

Pairwise comparison for PM_1 concentration and IMD ranking.

(I) scale	(J) scale	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Deprived	slightly deprived	-.525	.270	.148	-1.170	.121
	not deprived	-.020	.272	1.000	-.670	.630
slightly deprived	deprived	.525	.270	.148	-.121	1.170
	not deprived	.505	.281	.202	-.166	1.176
not deprived	deprived	.020	.272	1.000	-.630	.670
	slightly deprived	-.505	.281	.202	-1.176	.166

Based on estimated marginal means

a. Adjustment for multiple comparisons: Sidak.

Appendices M

Tests of Between-Subjects Effects for $PM_{2.5}$ and IMD ranking.

Source	Sum of Squares	df	Mean Square	F	Sig.
Scale	1266.238	2	633.119	16.830	.000
a. R Squared = .016 (Adjusted R Squared = .016)					

Appendices N

Pairwise comparison for $PM_{2.5}$ concentration and IMD ranking.

(I) scale	(J) scale	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
Deprived	slightly deprived	-1.069*	.331	.004	-1.859	-.278
	not deprived	.923*	.333	.017	.127	1.718
slightly deprived	deprived	1.069*	.331	.004	.278	1.859
	not deprived	1.991*	.344	.000	1.170	2.813
not deprived	deprived	-.923*	.333	.017	-1.718	-.127
	slightly deprived	-1.991*	.344	.000	-2.813	-1.170
Based on estimated marginal means						
*. The mean difference is significant at the .05 level.						
b. Adjustment for multiple comparisons: Sidak.						

Appendices O

Tests of Between-Subjects Effects for PM_{10} and IMD ranking.

Source	Sum of Squares	df	Mean Square	F	Sig.
Scale	10113.062	2	5056.531	20.740	.000
a. R Squared = .020 (Adjusted R Squared = .019)					

Appendices P

Pairwise comparison for PM_{10} concentration and IMD ranking.

(I) scale	(J) scale	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
Deprived	slightly deprived	-4.439*	.842	.000	-6.451	-2.427
	not deprived	.706	.848	.790	-1.320	2.731
slightly deprived	deprived	4.439*	.842	.000	2.427	6.451
	not deprived	5.145*	.875	.000	3.054	7.236
not deprived	deprived	-.706	.848	.790	-2.731	1.320
	slightly deprived	-5.145*	.875	.000	-7.236	-3.054

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Sidak.