Temporal Analysis of Non-Exhaust Emissions from Road Traffic

Marylebone Road, London and Neath Road, Swansea

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DECLARATION

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I declare that I have personally prepared this Journal Article and that it has not in whole or in part been submitted for any other degree or qualification. The work described here is my own, carried out personally unless otherwise stated and written in my own words. All sources of information, including quotations, are acknowledged by means of reference.

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Temporal Analysis of Non-Exhaust Emissions from Road Traffic on Marylebone Road and Neath Road (Swansea)

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S *Supporting Information*

ABSTRACT

Purpose: Particulate matter (PM) is classified as a Group 1 carcinogen and road traffic is a significant contributor of PM in London and Swansea. Sources of road traffic related particles are classified into exhaust and non-exhaust. Non-exhaust particles are highly toxic due to the presence of heavy metals. This study has investigated not only the heavy metals but also analysed the components of non-exhaust PM from road traffic on Marylebone Road (MB) and Neath Road in Swansea (SM) to provide key insights on non-exhaust trends.

Methods: Datasets of the key trace metals (Cu, Fe, Zn) of non-exhaust components from different campaigns were compared using Mann-Whitney test. Non-exhaust component concentrations from 2011 to 2018 were estimated by scaling the corresponding traffic incremental heavy metal values using the non-exhaust literature. The linear trends of non-exhaust PM concentrations at MB and SM were calculated using Theil-Sen method.

Significant new results: The nitric acid/hydrogen peroxide (HNO_3/H_2O_2) digestion had a significant 53% higher Cu extraction at 95% confidence interval than hydrofluoric acid (HF) digestion. The non-exhaust proportion of PM_{10} at MB reached a maximum of 82% in 2018 showing a good agreement with the 80-90% prediction by 2020 [1]. All the non-exhaust PM concentrations except the tyre wear component at MB were significantly higher than SM at 99.9% confidence interval.

Implications: Any two heavy metal datasets cannot be merged for higher time-resolution or compared ignoring their measurement methodologies, particularly the digestion method protocols, as the extraction or recovery efficiency could vary significantly. The non-exhaust proportion of PM_{10} is increasing at a statistically significant rate (5.34 % year^{-1} at 99.9% confidence interval), indicating an urgency of regulating non-exhaust emissions in the urban areas of United Kingdom.

Keywords: *Non-exhaust PM, Trace metals, Defra, Filter digestion, Trends, Brake wear, Resuspended dust etc.*

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1. INTRODUCTION

Globally air pollution was the fifth leading mortality risk factor in 2017 accounting for approximately 5 million premature deaths [2]. Air pollution affected the life expectancy worldwide and contributed to an average life expectancy loss of about 20 months [2]. In 2013, the International Agency for Research on Cancer (IARC) unanimously classified outdoor air pollution and particulate matter (PM) from outdoor air pollution as a Group 1 carcinogen [3]. PM sources in urban areas generally include road transport, industries, construction and demolition, non-road mobile machineries, domestic wood burning, sea salt, and forest fires. In London, road traffic is the primary source of PM ($PM_{2.5}$ and PM_{10}) and 50% of PM emissions comes from the road transport sector [4]. Road transport vehicles emit PM through both exhaust and non-exhaust pathways. Non-exhaust emissions (NEE) of PM are generated mainly by tyre wear, brake wear, road surface wear and resuspension of road dust [5]. The NEE contains toxic heavy metals like iron (Fe), copper (Cu), zinc (Zn), and antimony (Sb) [6]. Toxicological studies consistently link the exposures to these heavy metals with adverse health effects such as lung-inflammation and DNA damage [3, 6].

The NEE components exhibit significant influence on the roadside PM concentrations. NEE are generally more abundant in the coarse size fraction ($PM_{2.5-10}$) [7]. However, Iijima et al. (2007) reported that a significant part of brake wear lies within the fine size fraction [8]. Cu and barium (Ba) are key trace metals for brake wear; Zn is a key trace metal for tyre wear; aluminum (Al), silicon (Si) and Fe are key trace metals for resuspended road dust. There is currently no unique tracer available for road surface wear [9]. Vehicle weight influences all sources of NEE and heavier vehicles have been demonstrated to emit more PM when compared to their counterparts [6].

NEE contributed 4-5 µg m^{-3} to the roadside increment in PM, mostly in the form of $PM_{2.5-10}$, on Marylebone Road in London [10]. In London, the proportion of NEE to the total traffic emissions has increased because of effective exhaust emissions standards, PM control technologies and currently unregulated NEE [10]. The principal aim of this study is to investigate trace metals data and analyse the long-term changes in non-exhaust PM concentrations from road traffic on Marylebone Road in London and Neath Road in Swansea.

2. MATERIALS AND METHODS

2.1 Study area

Trace metals and PM datasets used in this study were accessed from the urban traffic and urban background monitoring stations of the Heavy metals network of the Department for Environment, Food & Rural Affairs (Defra), Clean air for London (ClearfLo) project and Automatic Urban and Rural Network (AURN) as listed in **Table S1** (please refer SI). The AURN site located adjacent to Marylebone Road (MB) opposite Madame Tussauds in London is an urban traffic site characterised by a street canyon configuration. In 2018, the traffic flow on Marylebone Road (Baker St to Park Crescent) was recorded as 72,156 vehicles per day making it a heavily trafficked six lane road in central London [11]. Depending upon the analyses, data of AURN urban background sites at North Kensington (NK) and London Westminster (WM) were used. NK site is in a residential area whereas WM site is surrounded by a mixed commercial and residential area.

Swansea is a city located on the south coast of Wales and the Defra urban traffic site located on Wychtree Street adjacent to Neath Road is surrounded mainly by residential area. The traffic flow on Neath Road (A48 to M4 jn45) was recorded as 37, 552 vehicles per day in 2018 making it a busy dual carriage way in Swansea [11]. For main analysis, data of the Swansea Morriston (SM) site and the urban background site at Coedgwilym (SC) were used. The SC site is inside Coedgwilym cemetery and surrounded by a residential area. Wind speed and wind direction data were obtained from Heathrow Airport and Cardiff Airport for MB and SM respectively. *The SM site was particularly chosen for the contrasting surrounding area compared to the street canyon setting of MB where the air pollution studies are extensively carried out [9].*

2.2 Study period and data quality

The study analysis can be broadly divided into two segments. The first segment involves an intercomparing of ClearfLo project trace metals data and Defra trace metals data at the MB site. The corresponding study period for the first segment was from 2011 to 2012. The second segment concerns the estimation of incremental non-exhaust PM concentrations based on the trace metals data of Defra followed by temporal analysis of incremental non-exhaust PM concentrations at the MB and SM sites from 2011 to 2018. The time period of meteorological datasets used in the second segment was from 2011 to 2018.

In the Defra network, trace metals are measured on a weekly basis in PM_{10} fraction of ambient air using Partisol 2025 (Thermo Scientific, USA) samplers. These filters were digested using nitric acid/hydrogen peroxide HNO_3/H_2O_2 digestion following European Standard EN14902:2005 and then analysed with the Inductively coupled Plasma - Mass Spectrometry (ICP-MS) [12]. For ClearfLo project, filters were digested using hydrofluoric acid (HF) and then metals were analysed similarly with ICP-MS [13]. Defra network has rigorous Quality Assurance/Quality Control (QA/QC) right from valid sampling hours to ratification procedure [14]. The long-term Defra network data was imported from Defra's data selector webpage [15] and higher time resolved ClearfLo trace metals data of PM_{10} size fraction were sourced from project supervisors.

Data capture rates of AURN PM_{10} at all the sites except SC met the 90% data capture target of Air Quality Directive (2008/50/EC) throughout study period [16]. PM data was collected from AURN and King's College London air pollution networks using the importAURN and importKCL functions of R package 'openair' [17, 18]. Meteorological data was imported from NOAA Integrated Surface Database using R package 'worldmet' [18, 19]. Cu, Fe and Zn metals of PM_{10} size fraction were used in this study as key tracers of brake wear, resuspended road dust and tyre wear respectively. Time averaging of ratified Defra network data was monthly, ClearfLo project was daily, ratified AURN PM data was hourly, traffic data was hourly or annual and meteorological data was hourly. Based on the statistical analysis (e.g. time-series plots, boxplots) it was ensured that there were no extreme outliers in air pollution (trace metals and PM), traffic and meteorological datasets.

2.3 Methods

2.3.1 Representativity of ClearfLo data

As the ClearfLo project data overlapped with the ratified Defra data from 2011 to 2012 at the MB site, an intercomparison study was conducted to decide whether the ClearfLo project data could be further used in the analysis. Trace metals data of MB & WM sites from Defra network and MB & NK sites from ClearfLo project were used for the analysis. Trace metals data of MB from ClearfLo project had a higher time resolution than Defra network. So, the concentrations of ClearfLo were averaged by month to allow the comparison with Defra monthly data. The traffic increment of trace metal concentrations at MB was measured using the twin-site approach as explained in the Eq. (1) below [20].

$$C_{x,\ \text{local traffic}} = C_{x,\ \text{urban traffic}} - C_{x,\ \text{urban background}} \qquad \textbf{(1)}$$

It was ensured that both urban traffic and urban background datasets were from the same project or network to avoid confounding by the measurement methodology and instrumentation. So, NK was chosen as the urban background site for ClearfLo project whereas WM was used as the urban background site for Defra data. Then the traffic increments of trace metal concentrations of ClearfLo and Defra were summarised using stats, boxplots, timePlots and compared with non-parametric Mann-Whitney test. Deming regression plots were developed with identity line using R package 'mcr'[18, 21] as this approach is used in the literature to compare two measurement methods by means of regression analysis [22].

2.3.2 Estimation of Non-Exhaust PM concentration

The tyre wear component, brake wear component and resuspended dust component were assumed to be the predominant contributors to the non-exhaust PM concentration. The road surface wear component was ignored in further analysis as there is no unique tracer available for this source [9]. Traffic increment concentrations of the three non-exhaust components were estimated using the traffic incremental trace metal concentrations and corresponding scaling factors. Scaling factors were developed based on the previous source apportionment studies [9, 23, 24]. Based on the assumption that 50% of the measured Zn in the PM_{10} size fraction arises from tyre wear and a Zn content of 1% in tyre rubber [24], a scaling factor of 50 was used to estimate the tyre wear component. The scaling factor of 27.37 was estimated for brake wear component based on the results from a brake dust study at MB that Cu represented about 3.65% of the brake dust mass [23]. The main component of resuspended dust was considered as soil & other crustal matter whose percentage by weight of Fe is 5% [26]. Corresponding scaling factor of 4 was estimated based on the assumption that only 20% of the measured Fe arises from resuspended dust [9, 25]. Therefore, the traffic incremental non-exhaust PM concentration was calculated using Eq.(1) & Eq. (2).

$$\text{incNonexhaustPM} = \text{incBrakeWear} + \text{incTyreWear} + \text{incResuspendedDust} \qquad \textbf{(2)}$$

$$\Rightarrow \quad \text{incNonexhaustPM} = 27.37^*(C_{Cu,traffic}) + 50^*(C_{Zn,traffic}) + 4^*(C_{Fe,traffic})$$

As these scaling factors were empirical figures and determined based on the studies in United Kingdom, they were applied to both urban traffic sites. Linear trends of monthly values of incremental concentrations of brake wear, tyre wear, resuspended dust and non-exhaust PM were estimated using Theil-Sen function of the R package 'openair' from 2011 to 2018 [17, 18]. Theil-Sen method is based on the median of the dataset and resistant to outliers. The p-value estimates were calculated based on bootstrap sampling [27, 28]. Finally, non-exhaust component concentrations and non-exhaust PM concentrations of MB in London were compared with Neath Road in Swansea using non-parametric Mann-Whitney test and estimates of trend analysis.

3. RESULTS AND DISCUSSION

3.1 Representativity of ClearfLo data

The traffic incremental trace metals concentrations of ClearfLo and Defra from 2011 to 2012 were analysed and summary statistics of incremental trace metals (Cu, Fe, Zn) are listed in **Table 1**. The traffic incremental values are differing between the two campaigns for all tracers. From **Figure 2** it can be understood that median values of Cu and Zn are higher for Defra whereas median value of Fe is higher for ClearfLo. A comparison of Fe time-series plots revealed a clear deviation between campaigns (please refer **Figure S1** in SI). However, a non-parametric Mann-Whitney test between the traffic incremental trace metal values of two campaigns showed that the difference was significant at 95% confidence level for Cu ($W = 84$, $p = 0.037$) only.

Table 1

Descriptive statistics and Mann-Whitney test results of ClearfLo and Defra datasets at the Marylebone Road monitoring station (2011-2012)

		Traffic incremental trace metal (ng m^{-3})			Mann-Whitney test results		
		Mean	**Median**	**SD**	**W-statistic**	**p-value**	**N**
ClearfLo	Cu	43.56	39.95	14.53	**84**[a]	**0.037**	17
Defra	Cu	57.57	61.22	21.75			17
ClearfLo	Fe	1575	1386	604.7	133	0.708	17
Defra	Fe	1190	1225	412.1			17
ClearfLo	Zn	15.89	15.50	3.20	192	0.106	17
Defra	Zn	16.90	17.19	8.23			17

[a] Values highlighted are statistically significant

The urban background stations were chosen from same campaign (NK, WM) and a Mann-Whitney test confirmed that their measurements were similar at a 99.9% confidence interval indicating that the differences were not due to different background stations. So, the statistically significant differences in Cu could be due to different acid digestion methods of the PM_{10} size fraction filter. The acid digestion methods might also have influenced the recovery of Fe and Zn in ClearfLo and Defra campaigns. HF and HNO_3/H_2O_2 were the acids used for filter digestion in ClearfLo and Defra campaigns respectively.

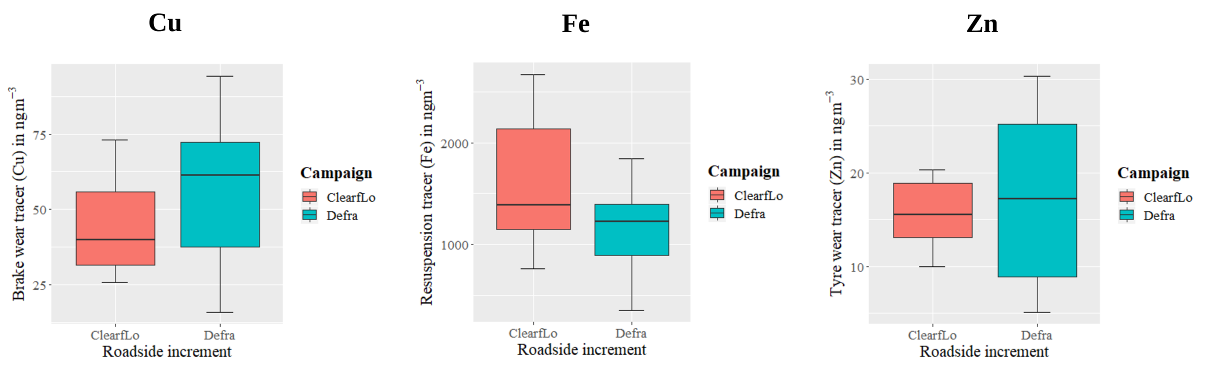

Figure 1. Boxplots comparing the traffic incremental trace metal concentrations (ng m^{-3}) of ClearfLo and Defra datasets at the Marylebone Road monitoring station (2011-12)

A recent study on evaluation of different acid digestion protocols for metal quantification has found that HF had higher recovery of Fe whereas HNO_3/H_2O_2 had higher extraction of Cu and recovery of Zn [29]. Comparably from our analysis, ClearfLo (HF) had higher Fe (13%) levels and Defra (HNO_3/ H_2O_2) had higher Cu (53%) and Zn (10%) levels.

ClearfLo data (y-axis) was tested against Defra data (x-axis) using Deming regression plots for method comparison. The regression procedure considers the measurement errors in both test and reference methods. Best fit line above the identity line (1:1) implies over reading of metals by ClearfLo and best fit line below the identity line (1:1) implies over reading of metals by Defra, reason being the differences in acid digestion. So, the Deming regression plots in **Figure 2** confirmed with the above-mentioned findings as the best fit line of Cu (R^2 = 0.32) was below the identity line and the best fit line of Fe (R^2 = 0.23) was partly above the identity line, whereas the (x, y) pairs of Zn (R^2 = 0.03) were not following any specific trend with identity line.

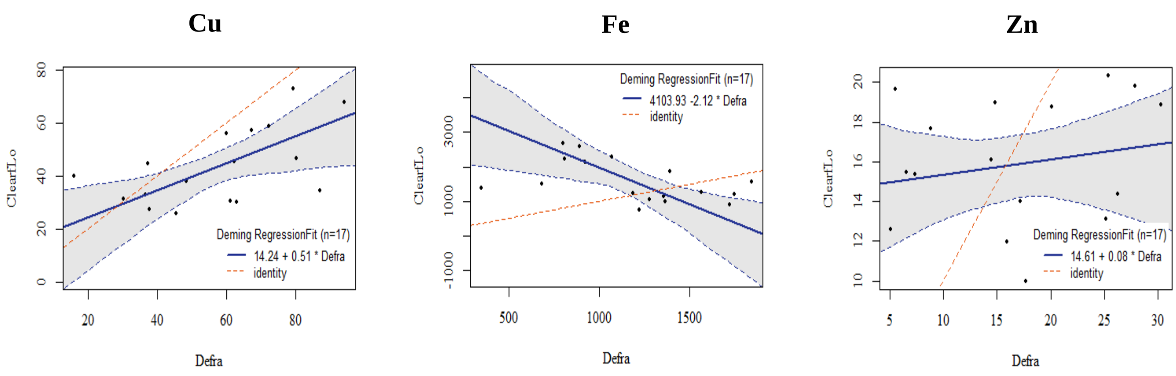

Figure 2. Deming regression plots along with identity lines for traffic incremental trace metal concentrations (ng m^{-3}) of ClearfLo and Defra datasets; test method was ClearfLo and the reference method was Defra

Because of the statistically significant differences in the trace metal (Cu) values due to acid digestion methods, the higher time resolved ClearfLo project data could not be combined with long-term Defra data in main analysis. There were other shorter campaigns that could have been included but were not because of similar representative differences in measurement methodologies. So, long-term Defra data at MB and SM were used for further analysis.

3.2 Analysis of Non-exhaust PM concentrations

As per the Section 2.3.2, traffic incremental concentrations of the non-exhaust components and combined Non-exhaust PM (NePM) were estimated using scaling factors for data from 2011 to 2018. Only PM_{10} concentrations were used in the analysis as trace metals were measured in PM_{10} size fraction, unavailability of $PM_{2.5}$ data and partly since the non-exhaust sources contribute to both $PM_{2.5-10}$ and $PM_{2.5}$. Theil-Sen method was used to estimate the linear trends of NePM and traffic incremental PM_{10} (incPM_{10}) at the MB site [27, 28]. **Figure 3** shows that the proportion of NePM in the incremental PM_{10} was increasing significantly at a rate of 5.34 % year^{-1} at 99.9% confidence interval and reached a maximum of 82% in 2018 at the MB site. These trends matched with the prediction made by Rexeis and Hausberger. (2009) that NePM of PM will increase to some 80-90% by 2020 [1]. They assumed that NePM will not change while making predictions which was also in a good agreement with a near zero slope estimate of 0.02 µg m^{-3} year^{-1}. The declining yet statistically significant trend of incPM_{10} at 99.9% confidence interval could be attributed to improving exhaust emission standards and PM control technologies. Similar analysis for SM couldn't be carried out due to unavailability of PM_{10} data at both SM and SC (refer in SI).

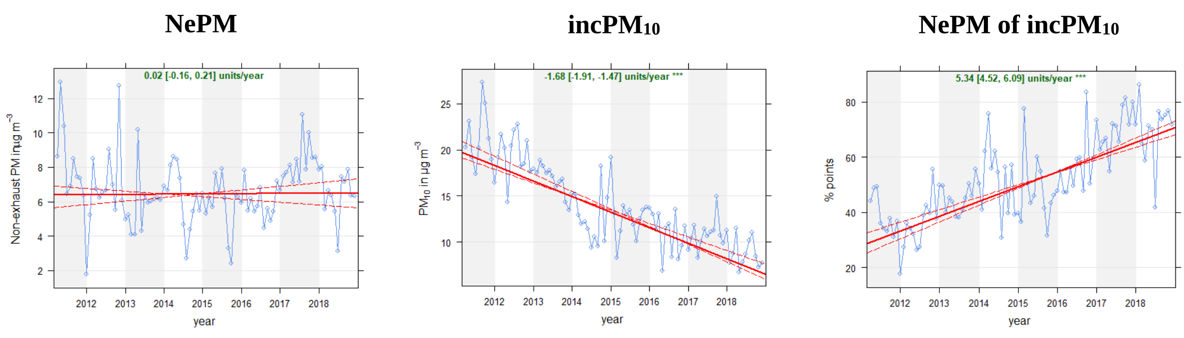

Figure 3. Linear trends of the traffic incremental non-exhaust PM concentration, PM_{10} concentration and NePM percentage of PM_{10} at the Marylebone Road site (2011-2018) using Theil-Sen method

3.3 Marylebone Road and Swansea Morriston

The summary statistics of non-exhaust component concentrations and NePM at the MB and SM sites are given in **Table 2**. The findings of Air Quality Expert Group report that 4-5 µg m^{-3} of non-exhaust PM_{10} contributed to the total mass and 6.62 µg m^{-3} calculated from this study at the MB site are showing good agreement [10]. The resuspended dust (RD) component alone contributed more than 60% to NePM at both the sites (refer **Figure S2** in SI). According to a literature review on the non-exhaust traffic related PM emissions, RD contribution lies in between 28% and 59% which would mean that the two urban traffic sites in consideration were generating RD beyond the expected range [30]. Being a heavily trafficked site, the median concentrations of all the non-exhaust components were found to be higher at the MB site as shown in **Figure 4**. A non-parametric Mann-Whitney test was performed between the non-exhaust components of MB and SM sites and the results indicated that all the MB site components except tyre wear were significantly higher than the SM site components at 99.9% confidence interval. Corresponding W-statistics and p-values are highlighted in **Table 2**. The street canyon configured MB site had relatively lower wind speeds (-17%) than the coast-based SM site (See **Figure S3** in SI) and that could have contributed to significantly higher pollutant levels at the MB site, as it lacks better air pollution dispersion.

Table 2

Descriptive statistics and Mann-Whitney test results of the traffic incremental non-exhaust components of the Marylebone Road (MB) and the Swansea Morriston (SM) sites (2011-2018)

		Traffic incremental concentrations (μg m^{-3})			Mann-Whitney test results		
		Mean	**Median**	**SD**	**W-statistic**	**p-value**	**N**
Brake wear	MB	1.27	1.25	0.41	**7796[a]**	**<2.2e-16**	92
Brake wear	SM	0.54	0.50	0.20			88
Resuspension	MB	4.66	4.72	1.25	**7982[a]**	**<2.2e-16**	92
Resuspension	SM	1.73	1.66	0.54			88
Tyre wear	MB	0.76	0.72	0.57	4511	0.1857	92
Tyre wear	SM	0.68	0.58	0.37			88
NePM[b]	MB	6.69	6.62	2.01	**7747[a]**	**<2.2e-16**	92
NePM[b]	SM	2.96	2.89	0.84			88

[a] Values highlighted are statistically significant; [b]Non-exhaust particulate matter concentration

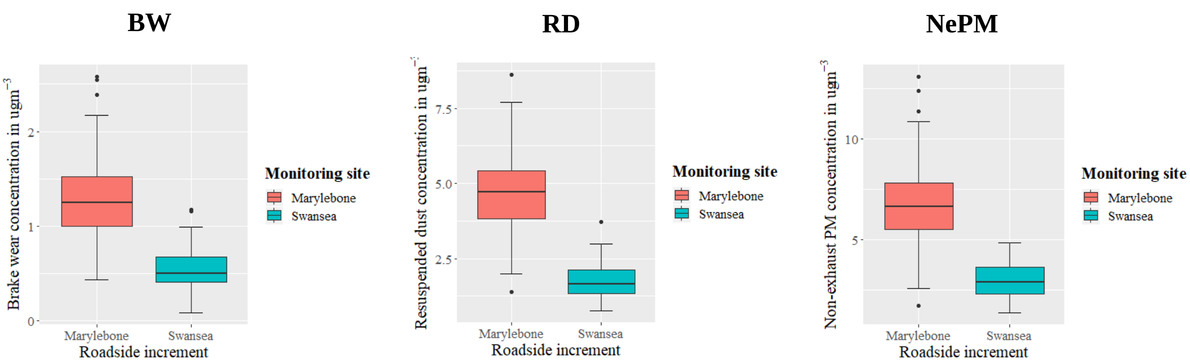

Figure 4. Boxplots comparing the traffic incremental non-exhaust component concentrations of Marylebone Road site and Swansea Morriston site (2011-2018); BW - Brake wear and RD – Resuspended dust

The linear trend comparison of non-exhaust components at the MB and SM sites using Theil-Sen method showed that the resuspended dust component at the SM site was increasing significantly at a rate of 0.09 $\mu g\ m^{-3}\ year^{-1}$ at 99.9 % confidence interval in the study period (please refer **Figure S4** in SI). Daily traffic flows were decreasing over the years at the SM site (See **Figure S5** in SI) and with lesser traffic the vehicles would cruise at faster speeds. High speeding of vehicles would generate more resuspension, and this might likely explain the resuspended dust results observed at the SM site [31]. Due to the unavailability of Automatic Number-Plate Recognition (ANPR) data at both MB and SM, the weight-based effect of traffic fleet composition on non-exhaust PM concentrations could not be assessed. The key recommendations from this study are as follows,

1. Based upon the analysis of the ClearfLo and Defra datasets, it has been concluded that future NEE measurement campaigns would benefit from a consistent methodological approach to measuring non-exhaust PM composition.
2. The trend analysis of the non-exhaust PM from road traffic on Marylebone Road in London and Neath Road in Swansea highlight the importance of considering NEE in the United Kingdom’s National Air Quality Policy.

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SUPPORTING INFORMATION

The literature review started in 2017 with measurement module material, review articles and scientific reports on non-exhaust emissions in United Kingdom. Key research articles and reports used in this study were identified from the Non-Exhaust Emissions textbook edited by Amato, F. (2018). Air Quality Expert Group (AQEG) reports on particulate matter and non-exhaust emissions helped me in understanding the local road traffic related emissions. Traffic datasets were searched on the Google Dataset Search and higher time resolved traffic data (2013 to 2018) was secured from Transport for London (TfL) using Freedom of Information (FoI) request in June 2019. Project supervisors shared ClearfLo project data and rest of the traffic data. Keywords such as tracers, non-exhaust components, road dust, road traffic, particulate matter, toxicity, XRF, ICP-MS, filter digestion and oxidative stress were employed while searching for relevant articles and chapters on Google Scholar, PubMed and Science Direct.

In the manuscript it was mentioned that there was no PM_{10} data for Swansea Morriston (SM) monitoring site and Swansea Coedgwilym (SC) monitoring site. It's because these two sites are not part of AURN network. As a result, the traffic incremental PM_{10} concentrations at SM couldn't be estimated and the linear trends were not calculated for NePM of PM_{10} at the SM site using Theil-Sen method.

Data from the following tables and figures were referred in the manuscript. The numbering of tables and figures below reflect their order of appearance in the manuscript. The following **Table S1** was referred in **Section 2.1** of the manuscript while listing out the monitoring sites and Department for Transport (DfT) traffic data.

Table S1: Locations of AURN and Defra monitoring sites and nearby traffic counters of DfT

	ID	Latitude	Longitude	Environment type	Network
Marylebone Road (AURN)	MB	51.522530	-0.154611	Urban Traffic	Defra, ClearfLo
London Westminster (AURN)	WM	51.494670	-0.131931	Urban background	Defra, ClearfLo
North Kensington (AURN)	NK	51.521050	-0.213492	Urban background	Defra, ClearfLo
Traffic counter for MB	27236	51.522458	-0.156426	Urban Traffic	DfT
Swansea Morriston	SM	51.632696	-3.947374	Urban Traffic	Defra
Swansea Coedgwilym	SC	51.701679	-3.874010	Urban background	Defra
Traffic counter near SM	20636	51.675018	-3.916342	Urban Traffic	DfT

The Fe trends shown in **Figure S1** were referred in **Section 3.1** of the manuscript to highlight deviations. Information from the following pie-charts of **Figure S2** were referred in **Section 3.3** of the manuscript to explain the leading contributions of resuspended dust component to non-exhaust PM_{10} concentrations at both SM and MB sites.

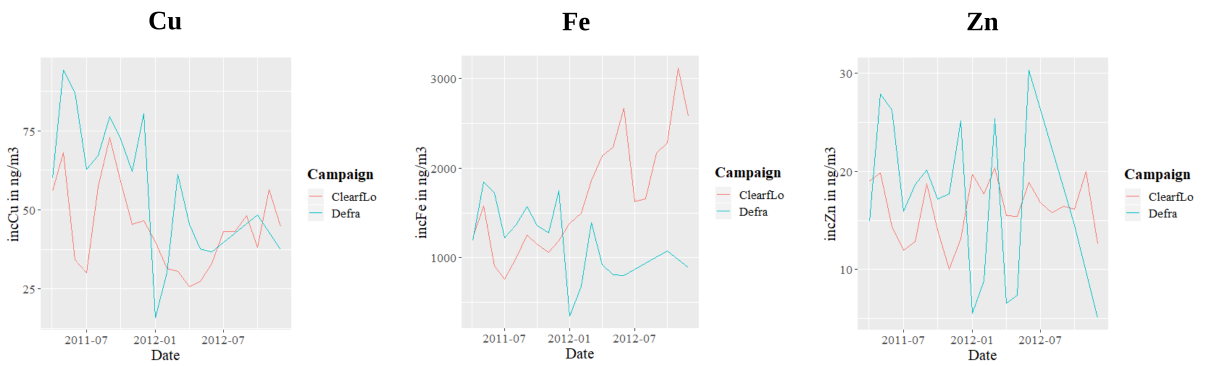


Figure S1. Time-series plots comparing trends of traffic incremental trace metal concentrations of ClearfLo project (red) and Defra (green) from 2011 to 2012

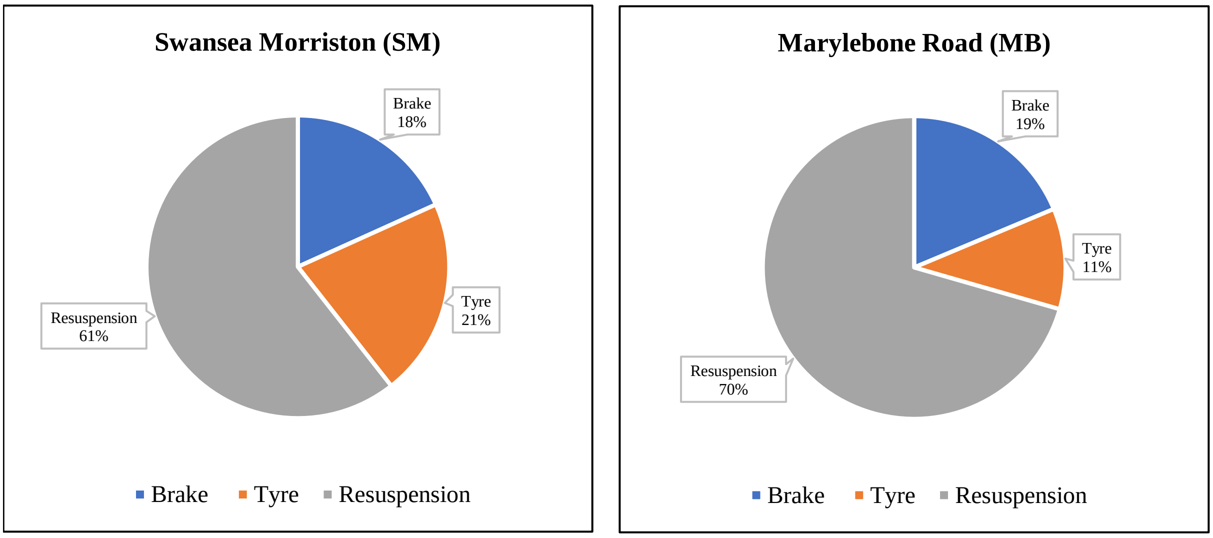


Figure S2. Pie-charts of the proportions of non-exhaust components in NePM at SM and MB (2011-2018)

Mean wind speeds were estimated for SM and MB sites. Original PM_{10} data was plotted for the MB and WM sites using Polar plots in **Figure S3**. However, only differences of mean wind speeds data were referred in **Section 3.3** of manuscript. Statistically significant Theil-Sen estimates of resuspended dust component for the SM site shown in **Figure S4** were discussed in **Section 3.3** of the manuscript.

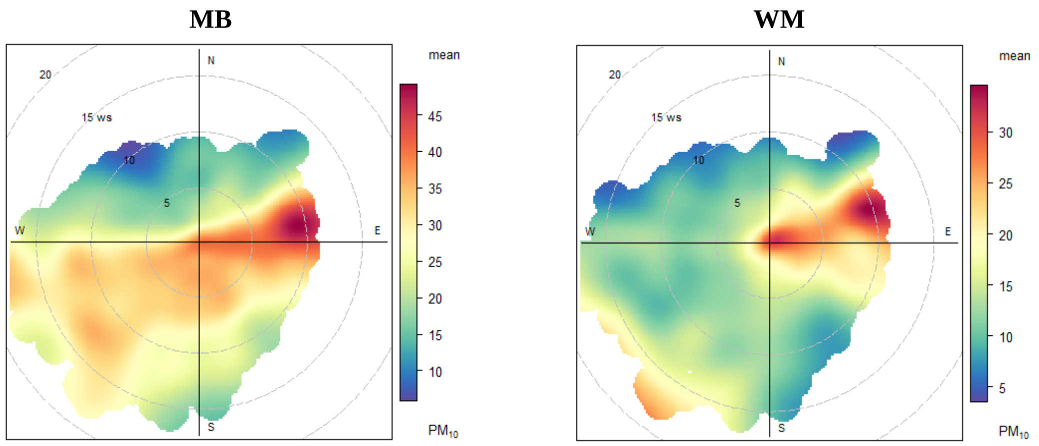


Figure S3. Polar plots using original PM_{10} data of Marylebone road (MB) and London Westminster (WM) monitoring sites. Heathrow Airport meteorological data was used for MB and WM (2011-2018)

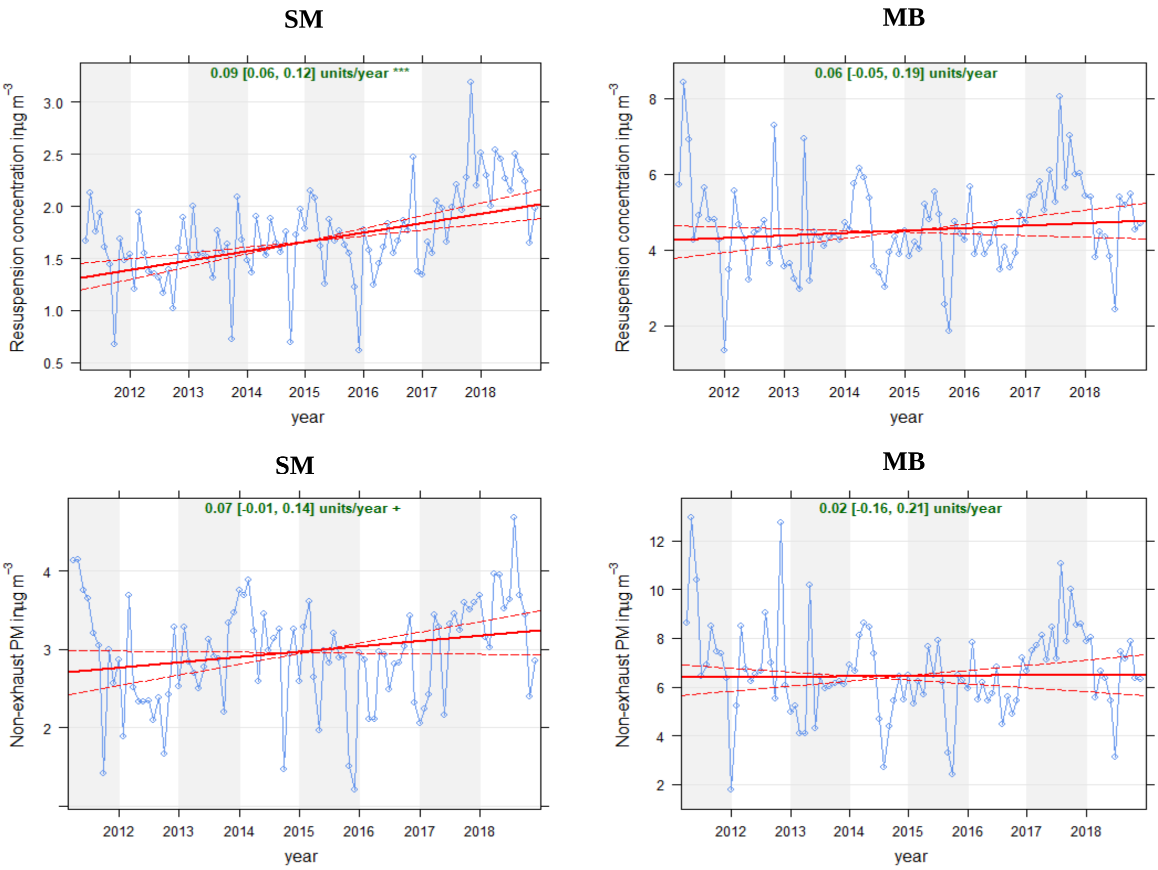
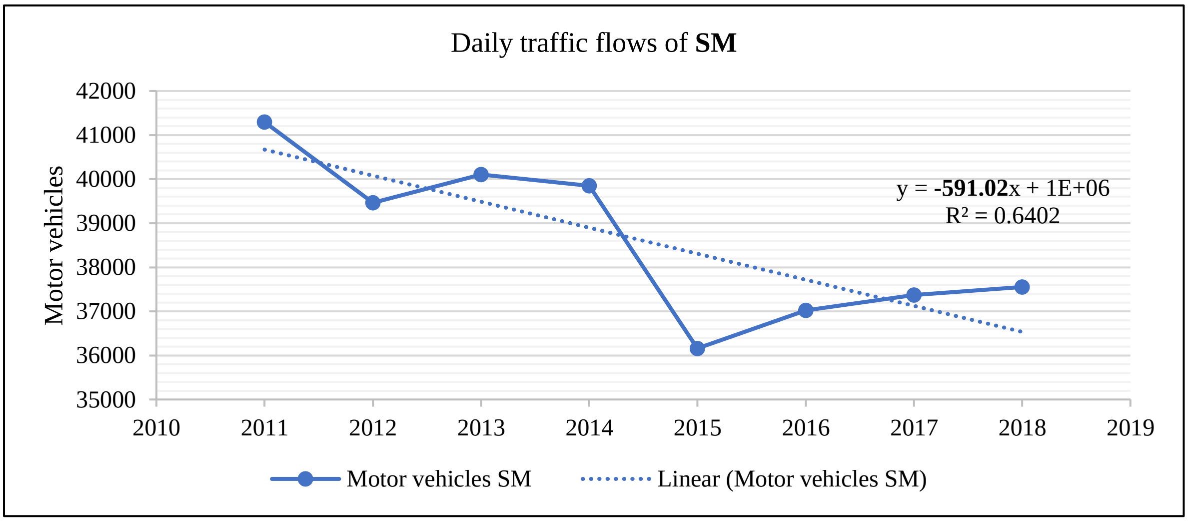


Figure S4. Linear trends of resuspended dust components and non-exhaust PM concentrations at the SM and MB sites (2011-2018) using Theil-Sen method

Daily traffic flows at the SM and MB sites were decreasing over the years as slopes are negative for the linear trend lines in **Figure S5**. This information was referred in **Section 3.3** of the manuscript.



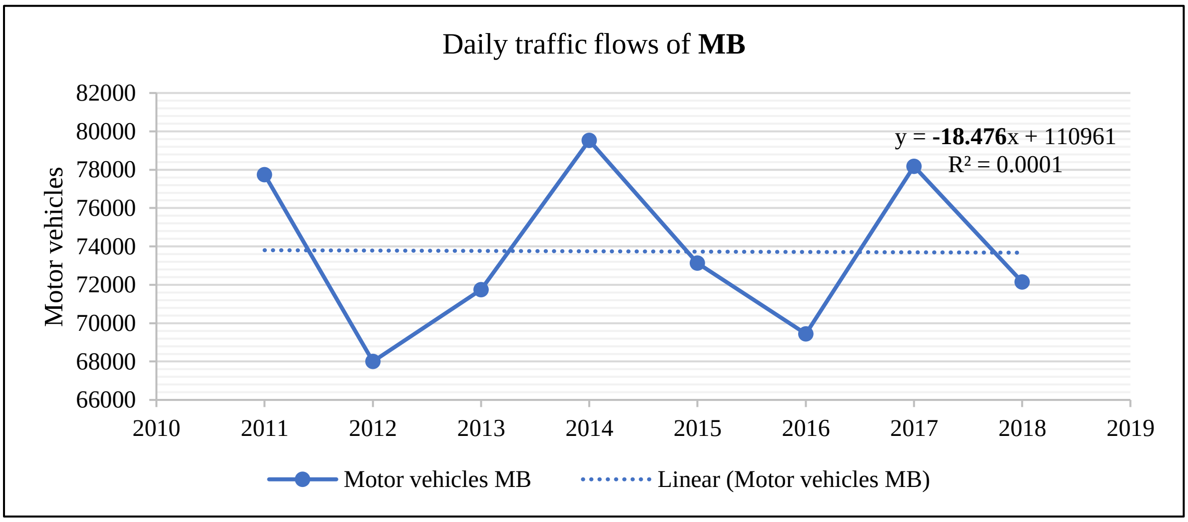


Figure S5. Daily traffic flow analysis of Neath Road (SM) and Marylebone Road (MB) from 2011 to 2018

OTHER INFORMATION

- R software was used to perform the complete statistical analysis of this project. The code is made available in a GitHub repository titled "Dissertation-code-R" at **https://github.com/Andhra-1771553**
- Word count was within the 6000-word limit, 10 pitch was used for main text in a single column layout. Total number of tables and figures in the main manuscript was six – 2 tables and 4 figures.
- As per the instructions given in the dissertation module handbook, the numbered style referencing of the School of Bioscience Education, King's College London was used for writing references.