Source Apportionment of Urban Background Particulate Matter in Birmingham, United Kingdom Using a Mass Closure Model

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ABSTRACT

Particulate matter (PM) collected during the summer period of 2011 at the urban background of Elms Road Observatory Site (EROS) in Birmingham, United Kingdom was studied and apportioned using the mass closure model. Particulate matter samples were analysed for Cu, Zn, Fe, Ni, Mn, Cl−, NO3−, SO42−, PO43−, C2O42−, Na+, NH4+, K+, Ca2+, OC and EC using the standard procedures. Results showed mean mass concentrations of 5.42 ± 1.7 µg m−3 for PM2.5 and 5.41 ± 0.27 µg m−3 for PM10−2.5. Organic carbon (OC, 26%) formed the major component of PM2.5 followed by sulphate (25%) and ammonium (12%). In the coarse PM fraction, ammonium, chloride and OC constituted 17, 15 and 14%, respectively of mass concentration. Metal concentrations in both PM fractions were less than 2% of the observed mass. The mass closure model applied to apportion PM2.5 and PM10−2.5 chemical species was able to identify four components namely: carbonaceous (45 and 19%, respectively), sea salt (7 and 25%), secondary aerosol (48 and 13%) and minerals (13 and 12%). The mass closure model was unable to explain all the chemical components in the coarse PM category leaving the unidentified mass as 31%. On the other hand, the model overestimated the mass of PM2.5 by 14%. The study showed secondary aerosol and carbonaceous species as the dominating sources of PM pollution in the study area.

Keywords: Particulate matter; Urban background; Mass closure model; Emission sources.

INTRODUCTION

The increase in the particulate matter emissions into the air via the anthropogenic and natural sources continues to degrade the air quality (Taiwo et al., 2014a, b; Lin et al., 2015; Sarigiannis et al., 2015; Wang et al., 2015). The influence of particulate matter on the visibility, atmospheric chemistry, human health, ecological systems, and global climate has been reported (IPCC, 2001; Chen et al., 2010; Taiwo et al., 2014a). Particulate matter varies in sizes, components, and composition depending on the primary emission sources, age, atmospheric processing and gaseous emissions (Vallius, 2005). The vehicular emissions, secondary aerosol, marine, resuspension of soil, industry, biomass burning, waste incineration and road dust constitute the major emission sources in the urban environment (Harrison et al., 2003a; Charron et al., 2005; Connell et al., 2006). The different chemical substances such as metals, water-soluble ions, elemental carbon, aromatic hydrocarbons, organic acids, alcohols, levoglucosans, sterols, polycyclic aromatic hydrocarbons (PAHs) and volatile organic compounds are considered as the particulate matter (PM) components (Harrison et al., 2003a, b; Harrison et al., 2004; Dall’Osto et al., 2008; Harrison and Yin, 2010; Yin et al., 2010; Taiwo et al., 2014b). The toxicities of most of these substances had been documented. For instance, PAHs are carcinogenic, cytogenic and mutagenic (Massolo et al., 2002; Rehwagen et al., 2005); metals including lead, cadmium, mercury are toxic to the human health as well as the environment (WHO, 2011). The proofs of the impacts of particulate matter on the intrauterine or postnatal death or congenital defects, prematurity, and foetal development had been established (Maisonet et al., 2001; Perera et al., 2003). In Toronto, USA, 1,700 annual premature deaths and 7,000 hospital visits have been associated with air pollution (Buset et al., 2006). A wide range of PM effects on the human health has led to the establishment of health-based air quality standards and objectives at the local and international levels to minimize its emissions. In 2008, the European Union (EU) air quality standard for PM2.5 was also introduced as an annual limit value of 25 µg m−3 to be achieved between 2010 and 2015 (EU, 2008). A daily average value of 50 µg m−3 (not more than 7 days year−1 exceedances), and an annual mean limit

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of 40 µg m⁻³ (not more than 35 exceedances per year) were set for PM₁₀ (WHO, 2006).

The pragmatic mass closure model was developed by Harrison et al. (2003a) for reconstruction of the measured PM chemical species into major source components that could be used as aerosol tracers. This model had been applied to identify and apportion particulate matter collected from urban background, roadside and industrial sites (Harrison et al., 2003a, Terzi et al., 2010; Yin et al., 2010; Zhang et al., 2010). For instance, Zhang et al. (2010) employed the mass closure model to PM data collected from the industrial sites in Ordos region, Inner Mongolia, China. The model revealed contributions to PM as organic matter (23–37% for PM₁₀, 28–39% for PM₂₅), crustal material (15–19% for PM₁₀, 14–21% for PM₂₅), trace ions (13–14% for PM₁₀, 14–16% for PM₂₅) and trace elements (4% for PM₁₀, 5% for PM₂₅). The present study aims at identifying and apportioning the emission sources of PM₂₅ and PM₁₀₋₂₅ sampled from an urban background site in Birmingham, UK using the mass closure model.

METHODOLOGY

Brief Description of the Study Area

The background station is the Elms Road Observatory Site (EROS, 1.93°W; 52.45°N) located in an open field within the University of Birmingham campus (Fig. 1). The site is about 3.5 km southwest of the centre of Birmingham, which has a population of over one million and part of a conurbation of 2.5 million population (Yin et al., 2010). The possible anthropogenic sources of emission at the site include a nearby railway, some moderately trafficked B roads and other surrounding activities from the University and local residents (Yin et al., 2010).

PM Sampling and Analysis

PM sampling was carried out using a Partisol sequential air sampler (Rupprecht and Patashnick Dichotomous Partisol-Plus Model 2025) during the summer period of 2011 (June 2–18). Two Partisol samplers were set-up and run simultaneously for 24 hours (12:00 noon–12:00 noon) for a 16-day sampling period. The average wind speed and temperature during the sampling were 4.5 ± 1.7 m s⁻¹ and 12.5 ± 4.3°C, respectively (data calculated from the Birmingham Tyburn Roadside’s Automatic Urban Rural Network (AURN) Site at uk-air.defra.gov.uk/networks/aurn-site-info). Partisol 1 was fitted with quartz fibre filters, for the analysis of OC/EC and water-soluble ions while Partisol 2 was fitted with Teflon filters for determination of PM mass concentration and metal components.

Determination of PM Mass Concentrations

PM mass concentration (PM₂₅ and PM₁₀₋₂₅) was determined gravimetrically by weighing the Teflon filters before and after sampling with a Sartorius microbalance (model MC5). Before weighing, all filters were equilibrated for 24 hours in the weighing at a relative humidity of 38–45% and temperature of 20–22°C. An ionizing blower was used to eliminate the effects of static electricity during the weighing process (Harrison et al., 2003b).

Determination of Water-Soluble Ions

After the removal of 1 cm² punch from the exposed quartz filter samples (for OC/EC determination); the remaining portion was extracted for water-soluble ions with 15 mL distilled de-ionized water (DDW, 18 Ωm) and sonicated in an Ultra-sonication bath for 30 minutes. The extracts were filtered and analyzed for major ions (phosphate, chloride, sulphate, oxalate and nitrate, calcium, ammonium, sodium

Fig. 1. The Google map showing the study area.
and potassium) using the Ion Chromatography System (ICS). The anions (PO$_4^{3-}$, SO$_4^{2-}$, NO$_3^-$, C$_2$O$_4^{2-}$ and Cl$^-$) were analysed using Dionex ICS-2000 equipped with an analytical column, AS 11 HC (2 × 250 mm) and a guard column, AG 11 HC (2 × 50 mm). About 3 mL of the digested sample was introduced into the autosampler of the Dionex ICS-2000 instrument. The eluant used for the determination of anions was potassium hydroxide. The cations (Ca$^{2+}$, NH$_4^+$, Na$^+$, K$^+$) were measured with Dionex DX500 equipped with an analytical column CS 12A (4 × 250 mm) and a guard column CG12A (4 × 50 mm). About 3 mL of the digested sample was introduced into the autosampler of the Dionex ICS-2000 instrument. The eluant solution used was methane sulphonic acid. Calibration curve for determination of water-soluble ions was obtained with series of measured standards prepared in the concentration range of 0–20 ppm.

**Metal Analysis**

The exposed Teflon filters were digested using the reverse aqua regia procedures described in Harrison et al. (2003b). A 5 mL mixed acid extractant (65 mL concentrated nitric acid and 185 mL concentrated hydrochloric acid dissolved in 1 L DDW) was introduced into the exposed filter samples and heated at 100°C for 30 minutes in a water bath and then placed in the ultrasonic bath set at 50°C for further 30 minutes. This cycle was repeated and the resulting digested solution transferred to a graduated flask and diluted to 10 mL with distilled deionized water. The extracts of filter samples were analysed for metals (Mn, Cu, Zn, Fe and Ni) using Graphite Furnace Atomic Absorption Spectrophotometer (GFAAS, Perkin Elmer™ Instrument, USA). The instrument was calibrated with appropriate standards (0–100 µg L$^{-1}$) to obtain the calibration curves.

**Organic and Elemental Carbon Analysis**

Organic and Elemental Carbon (OC/EC) analyses were determined using the Sunset Laboratory Thermal-Optical Carbon Aerosol Analyzer. A 1 cm$^2$ portion of exposed quartz fibre filter punch was placed into the manganese dioxide (MnO$_2$) oven of the analyser for OC/EC measurement. Thermal-Optical Carbon Aerosol Analyzer uses a thermal desorption that was combined with an optical transmission of laser light through the sample to speciate carbon collected on a filter paper (Sunset Laboratory Inc., 2000). The instrument measures OC using the Flame Ionization Detector (FID) during an initial non-oxidizing temperature ramp from ambient to 870°C under helium atmosphere. EC is measured during the second temperature ramp from 550 to 850°C under helium/oxygen mixture. The full procedures for determination of OC/EC had been described elsewhere in Yin et al. (2010). The OC/EC instrument was calibrated with sucrose standards (1–5 µg L$^{-1}$).

**Data Analysis**

Data collected were analysed for simple descriptive statistics of mean and standard deviation using the Windows Microsoft Excel package. Data are also presented in tables and pie charts.

**Mass Closure Model**

The mass closure model uses eight components of the measured PM chemical species with their corresponding conversion factors to infer contribution to aerosol sources through mass reconstruction. The eight components are presented in Table 1. They include:
- Ammonium sulphate ([NH$_4$]$_2$SO$_4$) derived from reaction of sulphuric acid (formed as a result of oxidation of sulphur dioxide) and ammonia.
- Ammonium nitrate (fine mode, NH$_4$NO$_3$) derived from neutralization of nitric acid vapour (product of oxidation of nitrogen dioxide) by ammonia.
- Ammonium sulphate and ammonium nitrate are known as secondary aerosol.
- Sodium nitrate (coarse mode, NaNO$_3$) is formed from the reaction of marine aerosol or sea salt with nitric acid vapour (product of oxidation of nitrogen dioxide) by ammonia.
- Ammonium sulphate and ammonium nitrate are known as secondary aerosol.
- Sodium nitrate (coarse mode, NaNO$_3$) is formed from the reaction of marine aerosol or sea salt with nitric acid vapour.
- Sodium chloride (NaCl) is derived mainly from sea salt.
- Calcium is represented by gypsum (CaSO$_4$·2H$_2$O).

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Conversion to</th>
<th>Numeric factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphate</td>
<td>(NH$_4$)$_2$SO$_4$</td>
<td>1.38</td>
</tr>
<tr>
<td></td>
<td>Hydrate</td>
<td>1.29</td>
</tr>
<tr>
<td>Nitrate (fine)</td>
<td>NH$_4$NO$_3$</td>
<td>1.29</td>
</tr>
<tr>
<td></td>
<td>Hydrate</td>
<td>1.29</td>
</tr>
<tr>
<td>Nitrate (coarse)</td>
<td>NaNO$_3$</td>
<td>1.37</td>
</tr>
<tr>
<td></td>
<td>Hydrate</td>
<td>1.29</td>
</tr>
<tr>
<td>Chloride</td>
<td>NaCl</td>
<td>1.65</td>
</tr>
<tr>
<td>Calcium</td>
<td>CaSO$_4$·2H$_2$O</td>
<td>4.30</td>
</tr>
<tr>
<td>Iron</td>
<td>Soil/road dust</td>
<td>5.50 (roadside)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9.00 (background)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.50 (roadside increment)</td>
</tr>
<tr>
<td>Elemental Carbon</td>
<td>Elemental Carbon</td>
<td>1.00</td>
</tr>
<tr>
<td>Organic carbon</td>
<td>Organic compounds</td>
<td>1.30 (roadside)</td>
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<tr>
<td></td>
<td></td>
<td>1.40 (background)</td>
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<tr>
<td></td>
<td></td>
<td>1.20 (roadside increment)</td>
</tr>
<tr>
<td>Water content</td>
<td>(Nitrate + Sulfate) × 0.29</td>
<td></td>
</tr>
</tbody>
</table>

Source: Harrison et al. (2003).
Iron, which is a tracer for road dust is generated from traffic. Mineral source is a sum of calcium and iron components.

- Elemental carbon (EC) is derived from incomplete combustion of fossil fuels.
- Organic carbon (OC) is produced from both primary and secondary sources.
- Carbonaceous species is the sum of EC and OC.
- Water content also formed a part in pragmatic mass closure model, although it is not measured in the chemical analysis. Water bound PM could form 20–35% of the PM mass concentration (Tsyro, 2005).

Further detailed procedures of mass closure model can be seen elsewhere in Harrison et al. (2003).

Quality Assurance
All the measuring and analytical instruments were properly calibrated during the period of sampling and laboratory analyses. Field blank filter samples (6) were analyzed for water-soluble ions, metals and OC/EC to correct the background concentration of elements present in the filters, and also to determine the detection limits (Taiwo et al., 2014a). Before sampling, the quartz filters (Whatman) were pre-treated by heating in an oven set at 500°C for 4 hours to remove any background OC present in the filters. All chemicals used for metal extraction were of ultra-pure grade. The procedure for metal analysis was evaluated by the analysis of NIST SRM 1684a in the earlier work (Allen et al., 2010), and more recent trials have shown high efficiency (> 85%) for all elements. The sample concentrations were calibrated with a series of mixed standards.

RESULTS AND DISCUSSION

Composition of Particulate Matter
The physical and chemical composition of fine and coarse particulate matter is presented in Table 2. The mean mass concentrations were 5.42 ± 1.7 µg m⁻³ for PM₂.⁵ and 5.41 ± 0.27 µg m⁻³ for PM₁₀₋₂.⁵. These mass concentrations were lower than the values previously reported at urban background sites in the UK (Harrison et al., 2004, Harrison and Yin, 2010, Gietl et al., 2010; Yin et al., 2010) and other European countries (Querol et al., 2004). In many European countries, the concentration of PM₂.⁵ measured in the urban background sites varied from 1.0 to 30 µg m⁻³ (Querol et al., 2004). For PM₁₀₋₂.⁵, the mass concentration obtained in this study was also lower than the value previously reported by Harrison et al. (2004) at the urban background locations in London and Birmingham, UK. The low mass concentrations of fine and coarse PM obtained in this study could be attributable to effectiveness of the air quality policies in the UK (AQEG, 2012). PM₁₀ concentrations in most cities in the UK including Birmingham had over the years, reduced tremendously (AQEG, 2005). For instance, the annual PM₁₀ mean value for Birmingham (data from the AURN Birmingham City Center and Tyburn Roadside sites) revealed a 45% decrease from 36.5 ± 20.7 µg m⁻³ in 1995 to 20.1 ± 9.4 µg m⁻³ in 2010 (Fig. S1 in the supplementary information). Previous studies have shown rare cases of PM₂.⁵ and PM₁₀ exceedances at the EROS site, and during the period of the present study (Harrison et al., 2003a, b, 2004, Harrison and Yin, 2008; Yin et al., 2010: Taiwo et al., 2014b).

In this study, the major contributor to fine PM was secondary aerosol, which constituted 48% of the measured PM₂.⁵ mass. Organic carbon made up 26% of the measured PM₂.⁵ mass (Fig. 2(a)). This is similar to the report of Harrison et al. (2004) at four different urban background sites in the UK where the carbonaceous species dominated the PM₂.⁵ mass. In the coarse PM portion, organic carbon formed 14% of the total measured mass (see Fig. 2(b)) while the values of EC was less than 1% of the mass concentration. The combined carbonaceous species constituted 35 and 14% of PM₂.⁵ and PM₁₀₋₂.⁵ respectively. The OC/EC ratio obtained

| Table 2. Physical and Chemical of Composition of PM₂.⁵ and PM₁₀₋₂.⁵ at EROS. |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| *(ng m⁻³)*                      | PM₂.⁵           |                 |                 | PM₁₀₋₂.⁵       |                 |
|                                 | Mean            | SD              | Min             | Max             | Mean            | SD              | Min             | Max             |
| PM mass                         | 5.42            | 1.7             | 2.31            | 8.84            | 5.41            | 0.27            | 2.20            | 12.20           |
| OC                              | 1411            | 434             | 692             | 2256            | 733             | 318             | 157             | 1295            |
| EC                              | 489             | 312             | 52.6            | 1049            | 16.7            | 109             | < 5.0           | 241             |
| Cl⁻                             | 232             | 160             | 64.1            | 598             | 810             | 670             | 75.3            | 1908            |
| NO₃⁻                            | 587             | 435             | 127             | 1449            | 304             | 319             | < 26            | 1099            |
| SO₄²⁻                            | 1334            | 955             | 561             | 3805            | 207             | 275             | < 150           | 856             |
| PO₄³⁻                            | 190             | 95.8            | 16.4            | 315             | 172             | 86.1            | 48.4            | 319             |
| C₂O₄²⁻                           | 104             | 29.6            | 68.9            | 165             | 59.8            | 8.80            | 46.3            | 76              |
| Na⁺                              | 238             | 406             | < 127           | 1345            | 310             | 270             | 11.7            | 1240            |
| Ca²⁺                             | 24.6            | 67.1            | < 207           | 201.9           | 102.8           | 124.4           | < 26            | 295.1           |
| NH₄⁺                             | 637             | 657             | < 33            | 1929            | 921             | 1227            | < 26            | 3128            |
| Cu                               | 8.33            | 23.3            | < 0.2           | 80.3            | 18.1            | 22.9            | < 0.05          | 63.3            |
| Mn                               | 38              | 23.9            | 4.13            | 71.3            | 40.7            | 27.4            | < 0.02          | 78.9            |
| Ni                               | 7.56            | 8.6             | < 0.1           | 23.8            | 17              | 19.6            | < 0.02          | 69.3            |
| Fe                               | 6.77            | 25.5            | < 2.0           | 66.6            | 4.62            | 18.7            | 4.62            | 56.8            |
| Zn                               | 13              | 8.7             | 2.92            | 29.2            | 1.5             | 9.6             | < 0.3           | 9.8             |

* PM mass in µg m⁻³, SD-standard deviation.
in this study was 2.9 for PM$_{2.5}$; this was slightly higher than the typical OC/EC ratio measured in the European cities (Querol et al., 2004). The OC/EC ratio value for PM$_{10-2.5}$ was 44. The OC/EC ratio of about 3.0 obtained for PM$_{2.5}$ occurred within the range 3–15 reported during the photochemical active period in New York, USA (Rattigan et al., 2010). According to Rattigan et al. (2010), the OC/EC ratio of 1.5 is a confirmation of traffic domination while OC/EC ratio value between 4 and 6 signifies impacts from regional forest fire plumes or long range urban plumes. The secondary OC formation might be responsible for the high PM$_{2.5}$ OC/EC ratio observed in the study area. EC is primary emitted from incomplete combustion of fossil fuel. A weak correlation was found between OC and EC in PM$_{2.5}$ ($R^2 = 0.02$) suggesting dissimilar emission sources. The high ratio of OC/EC observed for coarse PM in this study might suggest other emission sources of OC apart from anthropogenic origins. The coarse OC may arise from sources such as fossil fuel combustion, mechanical wear of tyres and from biological origins including plant debris, pollen and fungal spores (Pavuluri et al., 2011; Laongsri, 2012).

Sulphate formed the highest percentage of anionic species (25%) measured in the fine PM fraction and chloride (15%) in PM$_{10-2.5}$ components. Cationic species was dominated by NH$_4^+$ in PM$_{10-2.5}$ (17%) and also in PM$_{2.5}$ (12%). The marine aerosol (NaCl) constituted one-fifth of PM$_{10-2.5}$ (Harrison and Yin, 2000). The OM/SO$_4^{2-}$ ratio was calculated to infer sources to PM pollution in this study. The high OM/SO$_4^{2-}$ (6.4) suggests biogenic influence and less photochemical aging (Ziemba et al., 2007). Smaller OM/SO$_4^{2-}$ (0.4–0.6) indicates anthropogenic activities and photochemical aging. The OM/SO$_4^{2-}$ ratio in this study was calculated as 1.48 and 4.96 for PM$_{2.5}$ and PM$_{10-2.5}$, respectively indicating anthropogenic and biogenic influences. Oxalate mean concentration was higher in the fine PM (104 ± 29.6 ng m$^{-3}$) than in the coarse PM mode (59.8 ± 8.8 ng m$^{-3}$) contrary to the findings of Yao et al. (2003) where oxalate dominated the coarse PM sampled in Beijing, China. High oxalate concentration in the fine mode is usually related to heterogeneous formation (Yao et al., 2003). The PM metal

![Fig. 2. Percent components of Particulate Matter (a-fine PM, b-coarse PM).](image-url)
values were generally low constituting less than 2% of the total mass (Figs. 2(a) and 2(b)). This is consistent with the study of Harrison and Yin (2010) at the EROS sampling sites. Manganese was the highest observed metal (37.99 ± 23.85 ng m⁻³ for PM₂.₅ and 40.69 ± 27.40 ng m⁻³ for PM₁₀₋₂.₅) followed by Zn in the fine mode and Cu in the coarse PM. The mean values of Mn and Ni in this study were higher than the values reported in PM₂.₅ by Harrison and Yin (2010) at the EROS background. However, Cu, Fe and Zn concentrations were less than the values reported by Harrison and Yin (2008). The high Mn and Fe in the coarse PM may be linked to re-suspended dust from the nearby railway.

**Mass Closure Model of Particulate Matter (PM)**

The result of mass closure model of EROS background particulate matter (PM) was presented in Fig. 3. The reconstructed mass for fine PM accounted for 114% of the measured PM mass, while only 69% was accounted for in the coarse particle mode. The model was better fit for PM₂.₅ in this study (R² = 0.67) than PM₁₀₋₂.₅ (R² = 0.34). The mass closure model underestimated the reconstructed mass for PM₁₀₋₂.₅ and overestimated the calculated mass for PM₂.₅. Reason for this underestimation of mass might be attributed to non-inclusion of strongly water-bound component and also the adopted conversion factors for estimating organic matter and crustal material (Harrison et al., 2003; Terzi et al., 2010). Water bound component in particulate matter has been estimated to account for 20–35% of total PM mass (Tsyro, 2005). Inclusion of strongly water-bound has been reported by Yin et al. (2010) as a major reason for overestimation of mass closure model, which was contrary to the finding of this study. The problem of the model overestimation may be directly link to positive sampling artefacts. According to Turpin et al. (2000), overestimation of particulate OC may result from adsorption of organic vapour onto quartz-fibre filter material.

The pragmatic mass closure model revealed four major sources, which were secondary aerosol (ammonium sulphate + ammonium nitrate), minerals (calcium sulphate + iron rich dust), sea salt (sodium chloride) and carbonaceous aerosol (OC and EC). The fine PM was dominated by secondary aerosol and carbonaceous species representing 48 and 45%, respectively while PM₁₀₋₂.₅ was predominantly sea salt (25%), carbonaceous aerosol (19%) and secondary aerosol (13%). In the previous study at EROS (Yin et al., 2010) where only PM₂.₅ was determined; the source contribution by mass closure model attributed 53 and 34% to secondary aerosol in the summer and winter seasons, respectively. The high contribution by secondary aerosol at the EROS site is a reflection of the east to west gradient in secondary nitrate and secondary sulphate being observed all over the United Kingdom (AQEG, 2012; Taiwo et al., 2014b). The high photochemical activities during the summer period could also contribute to the high values of secondary aerosol observed in agreement with the study of Yin et al. (2010).

Emission of carbonaceous species in this site might originate from many diverse sources including the local traffic, secondary formation, combustion processes and biological plants. Yin et al. (2010) employed chemical mass balance (CMB) and pragmatic mass closure models to identify emission sources of fine particles in EROS site identified a smoking engine signature. This was traced to the use of mowers for cutting grasses at the site and also an old generating set occasionally used near the site. Moreover, this site is around 3.5 km to the Birmingham City Center where high vehicular emissions and combustion processes are expected to be high (Taiwo et al., 2014b). The study of Wang et al. (2005) had assigned a high contribution to carbonaceous species (70%) in PM₁₀ sampled during the wintertime in Christchurch, Australia. In other sampling locations around the world, contributions by carbonaceous species in PM were 40% in London, UK (winter and summer,
Harrison et al., 2004); 36% in New Zealand (winter and summer, Ho et al., 2006); 31% in Mira Loma, California, USA (winter, Na et al., 2004); 28% in Moitinhos, Portugal (summer, Pio et al., 2008). According to Zhang et al. (2007), carbonaceous aerosol sometimes constitutes approximately 50% of urban fine PM.

Although, sea salt formed the major constituent of coarse particulate matter (25%); the mass closure model also assigned about 7% of PM2.5 to sea salt source. Sea salt in the PM coarse fraction may arise from the passage of clean continental marine air through the receptor site (Taiwo et al., 2014c). Neutralization of hydrochloric acid vapour (from incinerator and power plants) by ammonia might also be responsible for chloride formation in the fine PM mode (Harrison and Yin, 2000).

Minerals formed 12% of the coarse particles, lower than the mineral component (48%) reported by Harrison et al. (2004). Sources of mineral dusts in this site might include: possible construction activities around the site, re-suspension of road dust, soil and fugitive emissions. EROS site is very close to the railway line that passes through the University of Birmingham campus to the Birmingham City center. This might also, contributed to the mineral contents of coarse PM. A study by Sillanpää et al. (2006) reported minerals (60%) as the largest portion of PM10-2.5 measured in Athens, Spain. The study of Jung et al. (2010) revealed the high fraction of iron-containing dust (29–87%) in PM sampled from the underground subway stations in Seoul, Korea.

**CONCLUSION**

This present study revealed low mass concentrations of fine and coarse PM and their measured chemical components compared to the past studies at the site. Organic carbon (OC), sulphate and nitrate dominated the PM2.5 fraction while PM10-2.5 was dominated by ammonium and chloride. The mass closure model revealed four major components including secondary aerosol, which formed the highest percentage of PM2.5 and marine aerosol, which constituted the major portion of PM10-2.5. Other sources of PM in the study area were carbonaceous species and minerals. The mass closure could only account for 69% of the coarse PM mass, probably due to errors from the adopted conversion ratios and the water bound PM while the PM2.5 mass was over-estimated (114%), probably due to laboratory artefacts. The PM pollution measured in this site might therefore be influenced by the local emission sources including vehicular, combustion of fossil fuels, re-suspension of road and rail dust, construction activities, continental marine aerosol, incinerators and secondary formation. The coarse PM was predominantly controlled by natural origin while fine PM was majorly impacted by anthropogenic sources.

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**SUPPLEMENTARY MATERIAL**

Supplementary data associated with this article can be found in the online version at http://www.aaqr.org.

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