Linking urban air field measurements to their chemical analysis and their effects on health: Part I

David Healy1*, V. Silvani2, E. Peri-Trepaz1, J. Lopez1, A. Whittaker1, J. Weng1, J. Heffernan1 and J. Sodeau1
1 Department of Chemistry and Environmental Research Institute, University College Cork, Ireland
2 Department of Biochemistry, University College Cork, Ireland
*Email: healydaj@yahoo.com

Introduction

Internationally collected data demonstrates that adverse health effects correlate with fine particulate matter (PM) both geographically and seasonally. However, major questions concerning the mechanisms by which they act remain unanswered. The aim of this study was to characterise meteorologically and spatially different PM2.5 (particulate matter collected with 50% efficiency for particles with an aerodynamic diameter of 2.5 μm) on its physicochemical and biological properties. PM2.5 was collected at three sites representative of southern Irish atmosphere (located throughout Cork, Ireland): a central urban site (City), an urban background site (UBS) and a rural site (RS), over the four seasons. A portion of the biological component (e.g. fragments of pollen and spores) were identified by scanning electron microscopy exclusively in the spring and summer samples at all three sites. At the city site more than 50% of particulates were closer to the accumulation range/ transient nuclei or Aitken nuclei size range (1 - 0.01 μm particle mean aerodynamic diameter) irrespective of season and were comprised predominantly of chain like soot aggregates. Elemental composition demonstrated spatial and seasonal variation; all samples contained varying levels of total carbon but levels were highest at the city site during the winter season. Higher transition metal concentrations were evident at the city and UBS sites, whereas higher concentrations of SO4²⁻ were observed in the rural samples. A good agreement was noted between total sulfur and SO4²⁻ at both the UBS and rural site (r² = 0.895 and 0.898 respectively), whereas the city site correlation (0.668) suggested that sulfur exists in other forms as well as SO4²⁻ (e.g. metal sulfates).

PM2.5 Toxicity

- Local effects: Respiratory System
- Systemic effects: Cardiovascular System
- Induction of inflammatory responses in the lungs
- Induction of systemic inflammatory responses and changes in neural control of heart function

Objectives:

- To physicochemically characterize the geographically and meteorologically different PM2.5 samples, along with determining a biological component (endotoxin) that have been categorised according to site and season.
- To determine any geographical/seasonal differences in both the toxicity profile and chemical composition for the PM2.5 sampled in the urban area of Cork City.
- To use the physicochemical database to determine the toxicity profile of PM2.5, and determine any links that different samples may have with their chemical composition.

Sampling Methodology

PM2.5 was collected onto polyurethane foam filter (PUF) using a three stage high volume cascade impactor (flow rate of 900 l/min) during a 2 year sampling campaign, collecting for 7 day periods, at three sampling sites (City, Urban background, and Rural sites). All particulates recovered from the same site during the same season were pooled together to give a homogenous batch of particles representative of that site during a particular season and to avoid any day-to-day variations in composition that could be attributed to anthropogenic and meteorological activities.

Gravimetric analysis

FIGURE 1 Average ambient mass concentrations (μg/m³) at the three sites during each season.

Physical Characterisation

FIGURE 2 SEM image of the filter substrate after collection (A), and the same filter after the particle recovery method (B).

Chemical Characterisation

FIGURE 3. SEM images (×10,000) of the PM2.5 samples collected from ambient air in Cork during the winter season, used both for the physicochemical analysis and biological investigations. (A) City winter, (B) Rural winter, and (C) UBS winter.

PM2.5 concentrations were identified as Fe, Mn, Ti and Cu were found to be more evident in the city site samples (compared to the UBS and rural site samples) whereas Zn, Pb, V, and Ni were noticeably higher at the city site. Transition metals such as Fe, Mn, Ti and Cu were found to be more evident in the city site samples (compared to the UBS and rural site samples) whereas Zn, Pb, V, and Ni were noticeably higher at the city site. Antioxidants such as SO4²⁻, NO3⁻ and Cl⁻; and cations such as Na⁺ and NH4⁺ were found to be major components in all samples.

Conclusion

- The influence of primary sea salt (Na⁺ and Cl⁻) in the Irish atmosphere was noted at all of the three sampling sites.
- At the city site more than 50% of particulates were closer to the accumulation range/transient nuclei or Aitken nuclei size range (1 - 0.01 μm particle mean aerodynamic diameter) irrespective of seasons, when morphologically analysed.
- Relatively low concentrations (EUmg) of Endotoxin were found on all of the PM2.5 samples collected. (Data not shown)

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Introduction

Epidemiological studies linking particulate matter (PM) air pollution with adverse respiratory and cardiovascular effects have focused attention on the interaction of PM and lung cells both in vitro and in vivo. We treated human lung epithelial cells, A549, with 5.5, 11 and 22 µg/cm² of ambient air PM₂.₅ (PM ≤2.5 µm aerodynamic diameter), collected from three sites over four seasons from the Irish atmosphere in the region of Munster (Cork). Production of interleukin (IL)-6, IL-8, TNF-α and reactive oxygen species (ROS) was measured. All samples (in the absence of cytokotropin) determined the respiratory burst and lactate dehydrogenase (LDH) assay at three different concentrations (5.5, 11 and 22 µg/cm²) induced intracellular ROS and release of IL-6 and IL-8 except TNF-α, (which after 72hrs were close to that of the control). The city sites showed a consistent ability to increase the production of intracellular ROS irrespective of the season, measured by dichlorofluorescein acetate. PM₂.₅ samples collected during the summer season at the City, Rural and Urban Background sites were the most potent stimulators for IL-6 release, reaching an average maximum of 10.06, 8.52 and 4.21 fold increase of control, respectively. Univariate regression and multivariate analysis were used to test for correlation of viability, cytokine release and the induction of intracellular reactive oxygen species (ROS) with the concentrations of 24 elements, 10 ions and endotoxin content. Principle component analysis on the elemental/biological components and toxicological endpoints database identified 4 principle components that accounted a total variance of 78.62%. Results indicate that elemental components and physical shape of the particles could play an important role in explaining the seasonal and geographical variations in PM-induced health effects related to respiratory illnesses.

Objectives

- To investigate the effect of the chemical composition of PM₂.₅ on its ability to induce a toxic effect on the human lung epithelial cell line A549 and possibly identify correlations between compositional components and biological effects induced.
- To determine any geographical/seasonal differences in both the toxicity profile and chemical composition for the PM₂.₅ sampled in the urban area of Cork City.

Methodology

Univariate regression analysis

Results

Univariate regression analysis

Conclusions

PCA indicates that the toxic profile of PM₂.₅ is clearly linked with the elemental content. FOUR different components were identified: 1st PC correlates ROS and transition metals, allowing the separation of City/UBS (polluted) from the rural (unpolluted) samples; for the 2nd PC a correlation was noted for crustal/soil derived elements (Ca, Mn, Al, K) and the toxicological endpoints (IL-6, IL-8, LDH and endotoxin); the 3rd PC identifies a relationship between sea-spray/marine (Na⁺, Cl⁻, Mg, Ti) and IL-8, and between secondary inorganic aerosols species (SO₄³⁻, NH₄⁺, NO₃⁻) and ROS, IL-6 and LDH. The 4th PC shows a positive correlation between hydrocarbons (C, H, Ti, Al) and LDH, this is especially clear for the city site during winter and autumn e.g. heating systems.

• PCA indicates that the toxic profile of PM₂.₅ is linked with the elemental components of the samples collected at the three sampling sites over the four seasons.
• The production of intracellular ROS, the release of IL-6 and cytotoxicity are someway dependant on secondary inorganic aerosols species (SO₄²⁻, NH₄⁺, NO₃⁻) that in turn dictate the acidity of the particle.
• Results also propose new hypotheses e.g. endotoxin content, IL-8, IL-10 being dependent on crustal type elements within the composition of PM.
• Results agree with well recognised hypotheses e.g. generation of ROS by transition metals.
• Our results indicate that the ability of PM₂.₅ to induce a biological effect is largely dependent on elemental composition and therefore directly related to the geographical location and seasonality.

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