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COMPOSITION AND SOURCES OF ORGANIC TRACERS IN AEROSOL PARTICLES OF INDUSTRIAL CENTRAL INDIA

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Abstract

Organic aerosols are important atmospheric components, and their formation and sources represent important aspects of urban air quality and health effects. Asia, including India, is the largest global source of aerosol particles due to regional natural advection (e.g. desert and soil dust) and anthropogenic activities (e.g. emissions from traffic, industry and

burning of coal, biomass and agricultural waste) that generate vast amounts of particulate matter (PM) significantly contributing to climate change. This article reports on the distributions, concentrations, and sources of organic compounds (i.e., alkanes, carboxylic acids, carbonyl compounds, alcohols, plasticizers, PAHs, biomarkers) of PM in the ambient atmosphere of an extensively industrialized area of central India (Raipur, Chhattisgarh, a coal mega-burning region). The dominant components are emissions from fossil fuel utilization, burning of biomass and plastics, and fugitive sources. Speciation and variations of potential new tracer compounds identified are also described.

Keywords: PM₁₀, lipids, PAH, hydrocarbons, terpenoids, fugitive emissions, GC-MS, Raipur

1. Introduction

Organic carbon comprises a large and highly variable fraction of the fine ($\approx 12\%$) and coarse ($\approx 8\%$) ambient aerosol particle mass in India (e.g. Satsangi et al., 2012; Ram and Sarin, 2010; Rangarajan et al., 2007). Organic compounds are important components of atmospheric particulate matter, and their identities, sources and fate have been utilized as multi-tracers for air quality assessments (Simoneit, 1984, 1989; Rogge et al., 1996; Schauer et al., 1996). They also play an important role in photochemical reactions leading to ozone formation (Bowman et al., 1995). Atmospheric organic matter changes chemical, optical and hygroscopic properties of inorganic aerosols and is associated with indirect climate forcing (IPCC, 1995; Saxena et al., 1995). Furthermore, trace organic constituents of aerosols have adverse health effects due to their carcinogenic and/or mutagenic properties (Brown et al., 1996; Hannigan et al., 1998; Kawanaka et al., 2004). Organic matter of aerosol particles is known to contain numerous

organic species, including alkanes, alkanols, carboxylic acids, carbonyl compounds, and aromatic compounds, that are used as source, transport, and receptor tracers in conjunction with volatile and inorganic species (Simoneit, 1984, 1989; Rogge et al., 1996; Schauer et al., 1996; Omar et al., 2006, and references therein). The compositions of organic aerosols are highly variable and need to be defined for each new study area. Many detailed investigations of organic compounds of aerosols in various parts of the world have been reported, but uncertainties remain, especially those concerning the composition of the more polar, water-soluble, and bio-organic fractions (e.g. Simoneit et al., 1988; 1991a, b; 2004a; Schauer et al., 1996; Didyk et al., 2000; Graham et al., 2002; Li et al., 2006; Schnelle-Kreis et al., 2007; Bi et al., 2008; Jia et al., 2010; Fu et al., 2009, 2012).

Asia is the largest source of aerosol particulate matter (PM) in the world because this region has natural dust advection and sizable anthropogenic activities (e.g. emissions from traffic, industry, and the burning of coal, biomass, agricultural waste, etc.). This PM contributes significantly to climate change (e.g. Satheesh and Ramanathan, 2000; Ramanathan et al., 2007; Gustafsson et al., 2009). Recently, Fu et al. (2009, 2010) reported the detailed organic molecular composition of aerosol PM in the Madras region on the southeastern coast of India. In their study they identified fossil fuel combustion as the most significant source of organic compounds. A study of dicarboxylic acids (potential oxidation products of organic compounds) has been presented for aerosols collected in the winter in New Delhi (Miyazaki et al., 2009). The central region of India is a major industrial area with limited published data on pollution (Pandey et al., 1999). We present an initial study on the concentrations of 14 compound classes containing 148 organic species, including aliphatic hydrocarbons, PAHs, polar lipids, tracers of biomass burning, synthetic organic compounds, and unresolved complex mixture (UCM) in

urban/industrial aerosols of central India. Six possible major emission source categories of organic tracers in aerosol particles are reported. Based on this selected set of samples, an initial insight is provided into the organic composition of aerosol PM in an extensively industrialized area of central India.

2. Experimental Methods

2.1. Study area

Three of the most industrialized cities of Chhattisgarh state were selected for this study. They are Raipur, Bhilai, and Korba, all > 250 m above sea level (Fig. 1). Raipur is the capital of the state of Chhattisgarh with a population of 2 million, and it is becoming an important regional commercial and industrial locale for coal, power, steel, and aluminum industries. Raipur is India's largest iron market and there are > 1000 steel rolling mills, sponge iron plants, steel foundries, metal-alloy plants, agro-industries, and plastic industries in and around the city. Bhilai, the second-largest city in Chhattisgarh with population of 0.8 million, is located 20 km away in west of Raipur. The city is renowned as the location of one of the largest steel plants in the world (capacity: 3.15 MT yr^{-1}). Korba, another city in Chhattisgarh with a population of 0.5 million, is known for power generation and aluminum production. Most of the electricity of the state is supplied by the coal-burning thermal power plant ($> 3600 \text{ MW}$) in Korba.

The climate is mainly tropical and sub-humid. The highest average temperature (≈ 34 °C) during 2006 occurred in June, and January and February were the coldest months of the year. The highest humidity ($\approx 85 \%$) was observed during June-August and the wind speed reached a maximum 9 km hr^{-1} during the months of August–September of that year.

A major forest fire in December 2006 impacted the Raipur region with heavy smoke haze. Smoke PM (Sample 17F) was sampled to compare its composition with the ambient aerosol PM during normal conditions.

2.2. Collection of particulate matter

A Partisol Model 2300 sequential speciation air sampler (Thermo Fisher Scientific, USA, 10 L min^{-1}) and a high volume air sampler (Netel, NPM-HVS/R, flow rate of $1.06 \text{ m}^3 \text{ min}^{-1}$) were used for the collection of PM on quartz fiber filters in molded filter cassettes. The PM_{10} and $\text{PM}_{2.5}$ speciation was effected by the inlet impactor of the air sampler. The samplers were installed on the roof of a building, $\approx 10 \text{ m}$ above ground level. The site description and measurement of PM are summarized in Table 1. Prior to their use, the filters were heated to $600 \text{ }^\circ\text{C}$ to lower their background levels and then placed in cleaned polyethylene dishes. Weighed filters were put in the sampler and PM was collected. A total of 17 samples (SPM, PM_{10} , and $\text{PM}_{2.5}$) were taken from January to December, 2006 at four sampling locations. Ten of the 17 samples were analyzed for organic tracers (Table 2). A sample blank was also taken for each location. The loaded filters were dismantled, wrapped with aluminum foil, placed in a polyethylene dish, and brought to the laboratory. The filters were transferred into desiccators and weighed to record the total suspended particulate matter (SPM) content and then stored at $-20 \text{ }^\circ\text{C}$ prior to analysis.

2.3. Extraction

Filters were solvent-extracted with dichloromethane (DCM) followed by methanol using an accelerated solvent extraction (ASE) 300 apparatus at $100 \text{ }^\circ\text{C}$ and 1500 psi pressure (Dionex, California). Polycyclic aromatic hydrocarbons (PAHs), 1,3,5-

triphenylbenzene, and pesticides were analyzed in the DCM extracts. For total extract analyses, aliquots of the DCM and methanol extracts were combined (200 to 1000 μL total). Aliquots (typically 25 μL) of these total extracts were converted to trimethylsilyl derivatives prior to gas chromatography-mass spectrometry (GC-MS) analysis. Further details are given in the Supporting Information (SI) section.

2.4. Instrumental analysis

GC-MS was used to analyze PAHs, pesticides, and the total extract of each sample. PAHs and pesticides were quantified using internal standards, and surrogates were used to calculate loss during the analysis. All concentrations reported here are corrected for surrogate recovery and blank concentration. The total extract of each sample was also analyzed by GC-MS both as native and as derivatized aliquots. Compound identification was performed by comparing the chromatographic retention characteristics and mass spectra of our samples with authentic standards, reported mass spectra, and the mass spectral library of the GC-MS system. The mass spectra of unknown compounds were interpreted based on their fragmentation patterns. Compounds were quantified using the total ion current (TIC) peak area and converted to compound mass using peak areas of external standards. Procedural blanks were analyzed and showed no significant background interferences. Details of the extraction parameters and instrumental analysis are given in the SI (see extraction and instrumental analysis section).

3. Results and Discussion

The mass distribution of the aerosol particulate matter in the Raipur area is presented in

Table 2. The annual (January-December, 2006) mean mass concentrations of SPM, PM₁₀, and PM_{2.5} (n =13) in the ambient air of Raipur city were 551±139, 246±68 and 115±36 µg m⁻³, respectively. Mass concentrations for PM₁₀ during July 2009 to June 2010 in the Raipur region were reported to vary from 110-456 µg m⁻³ (mean 271 µg m⁻³; Deshmukh et al., 2012). The lowest concentration of PM₁₀ and PM_{2.5} was observed in the rainy season (August-September, 2006). The annual mean concentration ratios of [PM₁₀]/[SPM] and [PM_{2.5}]/[PM₁₀] in the air were 0.44±0.06 and 0.46±0.03, respectively. The SPM, PM₁₀, and PM_{2.5} concentrations were fairly negatively correlated with the temperature (T; r = 0.32-0.35), and relative humidity (RH; r = 0.47-0.58). The annual mean concentrations of coarse organic carbon (OC₁₀), coarse elemental carbon (EC₁₀), fine organic carbon (OC_{2.5}), and fine elemental carbon (EC_{2.5}) in the PM of Raipur city were 6.3±0.9, 16.9±4.5, 7.1±1.7, and 13.1±3.6 %, respectively.

The concentrations of the organic compounds identified in the aerosol PM from the Raipur region are given in Table 3. The major compound groups for the urban samples were polar compounds (such as *n*-alkanoic acids, anhydrosaccharides, and plasticizers) with minor neutral species (such as the unresolved complex mixture (UCM) of branched and cyclic hydrocarbons, *n*-alkanes, *n*-alkanols, and PAHs). These compound groups are described in detail below.

3.1. Aliphatic Hydrocarbons

Both *n*-alkanes and the UCM, typical of petroleum derived lubricants (Simoneit, 1984, 1985), were found at trace levels during summer and at low concentrations during winter (e.g. Fig. 2a and b; Table 3). The *n*-alkanes had carbon preference indices (CPI) ranging from 0.8-2.5 (mean 1.3) and comprised from 0.8 to 6.2 % of the total extractable organic

matter (EOM). The CPI values are used as a diagnostic proxy to identify sources of *n*-alkanes (Simoneit and Mazurek, 1982; Rogge et al., 1993) and were calculated for C₂₀ to C₃₃. A CPI value of ~1 indicates the petroleum influence. The distributions of *n*-alkanes with low CPI values in the Raipur region samples indicate the significant anthropogenic influence (incomplete combustion of fossil fuels), which is similar to other urban aerosol *n*-alkanes, e.g. Santiago (Chile), Guangzhou (China), Beijing (China), Madras (India). The UCM and *n*-alkane concentrations varied from 8 to 970 ng m⁻³ (mean 303) and 0.5 to 712 ng m⁻³ (mean 151), respectively. These concentration values are considerably lower than those for other large cities, such as Santiago (Chile), Los Angeles (CA), Guangzhou (China), Beijing (China), and Ibadan (Nigeria) (Rogge et al., 1993; Simoneit et al., 1988; Didyk et al., 2000; Bi et al., 2008; Zhou et al., 2008, 2009), but similar to Madras (India) (Fu et al., 2009, 2010) (cf. Table 4). The *n*-alkanes have a dual source from petroleum product utilization and natural vegetation waxes. The latter source consisted of the longer chain plant lipids mainly as *n*-alkanes, *n*-alkanoic acids and *n*-alkanols; all are compounds > C₂₀ (Simoneit and Mazurek, 1982). The contribution of epicuticular wax to the total *n*-alkanes was calculated by subtraction of the smooth alkane envelope from the total alkanes (Simoneit et al., 1991a). The concentrations of the wax alkanes ranged from not detectable to 159 ng m⁻³, with the highest concentrations during winter (Table 3). This maximum winter concentration of wax alkanes was also reported for Guangzhou (Bi et al., 2008). The biomarkers (hopanes and steranes) characteristic for the petroleum component (Simoneit, 1984, 1985) were not detectable in our samples.

There was a minor UCM and intermediate level of *n*-alkanes in the Raipur forest fire sample (17F) (supporting information - Fig. SI 1a and c; Table 3). The plant wax alkanes

were also low in this sample, indicating that the fire burned hot and the fuel had a low wax content.

3.2. Polycyclic Aromatic Hydrocarbons (PAHs)

PAHs are ubiquitous atmospheric pollutants and some of them are well known human carcinogens (IARC, 1991). PAHs are produced from incomplete combustion of any organic material. Natural sources of PAH emissions include forest fires (Simoneit, 2002; Vila-Escalé et al., 2007), and major anthropogenic sources include foundry industries, emissions from vehicles and burning of fossil and biomass fuels (e.g., Rogge et al., 1993; Yang et al., 2002; Simoneit et al., 2007).

The list and concentrations of PAHs measured in this study is presented in Table 3. Benzo[ghi]perylene (BgP) was not detected in the forest fire sample (17F), and anthracene was not detected in sample 8R. Retene (Re), a molecular marker of conifer wood combustion in ambient air (Ramdahl, 1983), was absent in samples 5R, 6R, 14B, and 16K. The concentrations of individual PAHs ranged from 0.01 (Phe) to 338 (Fl) ng m^{-3} , and the total PAH concentrations (Σ PAHs) ranged from 0.69 (sample 8R) to 1188 ng m^{-3} (sample 17F).

The aerosol particles (in urban air) generally have higher Σ PAHs in winter than in summer and rainy months (Table 3). Winter samples (sample 13R) from Raipur had higher Σ PAHs than in the summer (samples 6R and 7R) and the rainy season (sample 8R). The lower concentration in the summer and rainy months may be due to lower fuel consumption, higher wind speeds, higher inversion heights, and higher temperatures, along with enhanced photodecomposition of PAHs, which lead to increased dispersion and decrease in the Σ PAHs. In the rainy season, PAHs are also removed by precipitation. Σ PAHs in Bhilai (samples 14B and 15B) and Korba (sample 16K) were comparable to Raipur. In Bhilai during the winter of 2006 (sample 15B), the Σ PAHs

was 435 ng m^{-3} , significantly higher than the annual means of 55 and 62 ng m^{-3} reported previously for 1995 in that area (Pandey et al., 1999). Σ PAHs for the Raipur forest fire (sample 17F, 1168 ng m^{-3}) was much higher than the other samples (Table 3). The Σ PAHs of Raipur were lower than that reported for the air of Delhi, the capital and one of the largest cities in India (Sharma et al., 2007). The Σ PAHs in Raipur were also lower compared to Delhi by about two orders of magnitude in the summer months, 3 orders of magnitude in the rainy months and by a factor of 3 in the winter months (Sharma et al., 2007). Furthermore, the Σ PAHs in Madras varied from $2\text{-}83 \text{ ng m}^{-3}$ (Fu et al., 2009, 2010), somewhat lower than our study.

The PAH profiles of all the samples are similar containing BgP, BbF, Py, BeP, BaP, and DbA as major components. These higher molecular weight PAHs have a greater contribution to the total PAH concentrations. Additionally most samples were dominated by 5 and 6 ring PAHs (Fig. 3). Higher molecular weight PAHs had a greater contribution to the total particle phase PAH concentrations because they are partitioned to the particle phase. This is in agreement with the fact that only particle bound PAHs were analyzed in this study. On the other hand, the PAH profile of the Raipur forest fire (sample 17F) showed a major contribution of Fl, Phe, BaA, Chry, BbF, and BaP. This sample was dominated by 4 ring PAH compounds (Fig. 3), typical of freshly emitted smoke (Oros and Simoneit, 2001a, b; Medeiros and Simoneit, 2008).

3.3. Polar Lipids

The total *n*-alkanoic acids were the significant components of the urban samples (1.5 to 51 % of EOM). The total concentrations of these acids ranged from 2.4 to 7716 ng m^{-3} (mean 1210 ng m^{-3}), with a concentration of 10430 ng m^{-3} for the smoke sample (Table 3). These values are similar as reported for other urban areas (e.g. Rogge et al., 1993; Abas and Simoneit, 1996; Didyk et al., 2000). A concentration range of 40 to 1448 ng m^{-3} has been reported for Madras,

India (Fu et al., 2009, 2010). The *n*-alkanoic acids of these samples ranged mainly from C₉ to C₁₈ (C_{max} at 16, Fig. 2c). Only a trace of acids > C₂₀ was found for urban sample 7R and the smoke sample 17F. The concentrations of the alkenoic acids were low and comprised C_{18:1} and C_{18:2} from 0.1 to 184 ng m⁻³ (Table 3). The low levels indicate rapid removal of the alkenoic acids by photo-oxidation and possibly the presence of aged aerosol particles.

The *n*-alkanols were also detected as trace components (0.6 to 9.5 % of EOM) with a bimodal distribution (Table 3). Hexadecanol and octadecanol occurred in all spring and summer samples and the homologs > C₂₀ were intermittent. The latter homologs are attributed to plant wax, and the C₁₆ and C₁₈ alcohols may have an industrial origin (e.g. emollients in cosmetics). However, alkanols from plant waxes were significant in the aerosols from Madras (11 to 155 ng m⁻³, Fu et al., 2009, 2010).

Other lipids detected intermittently are thermal degradation products from fats and oils used in cooking (Rogge et al., 1991; Schauer et al., 1999, 2002; Nolte et al., 1999), or from biomass burning (Simoneit et al., 2003). The former group consisted of acylglycerides, with 1-monoacylglycerides (I) as major (all chemical structures cited in the text are given in the SI as Appendix I) and 2-monoacylglycerides (II) as minor components (Table 3). The source of γ -palmitolactone (III) is unknown. The acylamides (IV), especially with high erucamide (Table 3), may also be from cooking rather than from burning of biomass (Schauer et al., 1999; Simoneit et al., 2003). Acylamides were not detected in the smoke sample (17F).

Steroids were intermittent trace components of some of the urban samples, and were significant in sample 17F (Table 3). Cholesterol, a tracer for cooking meat in urban areas, was found in samples 6R, 16K, and 17F with the various C₂₉ compounds. The stigmastadienes (24-

ethylcholestadienes), which are thermal dehydration products from sitosterol, were found in the smoke impacted sample 17F (Simoneit, 2002).

3.4. Biomass Burning Tracers

The major tracers for smoke particles from burning of biomass were the derivatives and breakdown products from the constituent biopolymers, such as cellulose and lignin; and compounds from the direct volatilization of natural products such as terpenoids and steroids (Simoneit, 2002). Anhydrosaccharides were the tracers from burning of cellulose and hemicelluloses, whereas the methoxyphenols were the tracers from burning of lignin (Simoneit et al., 1993, 1999).

3.4.1. Anhydrosaccharides

The anhydrosaccharides were comprised of levoglucosan (V), the dominant compound in all cases of burning cellulose (e.g. Fig. SI 1c), mannosan (VI), galactosan (VII), and anhydroglucofuranose (VIII). Their concentrations varied from 0.3 to 3998 ng m⁻³ for the urban samples and 42695 ng m⁻³ (38 % of EOM) for the smoke impacted sample (17F, Table 3). Levoglucosan was most abundant among all sugars detected ranging from 0.31 to 31000 ng m⁻³. The significant contribution of anhydrosaccharides to the total EOM indicates burning of biomass in the Raipur region. Although these compounds are water soluble they are preserved during long-range transport and over long time periods (Simoneit et al., 2004a,b). However, recent experimental and modeling studies have shown that levoglucosan undergoes significant oxidation in the presence of HO[•], NO₃, and SO₃ (Hennigan et al., 2010; Hoffmann et al., 2010). The modeling calculations have estimated that degradation fluxes of levoglucosan by OH radicals is higher in the summer than in the winter season (Hoffmann et al., 2010). This lower

degradation in winter or more extensive burning may explain the higher levoglucosan level in the winter than in the summer samples of this study. A biomass burning component was also evident in the aerosols from Madras, India, where the levoglucosan, with galactosan and mannosan, concentrations varied from 5 to 427 ng m⁻³ (Fu et al., 2009, 2010).

3.4.2. Methoxyphenols

Lignin, a major biopolymer of higher plants, yields phenolic tracers upon burning in the smoke PM which are characteristic of the type of biomass fuel (Hawthorne et al., 1988; Simoneit et al., 1993). The major tracers for lignin burning in the atmosphere are 4-hydroxybenzoic acid (IX), indicative of grasses and other non-woody vegetation; vanillic acid (X) with analogs, indicative of mainly softwood; and syringic acid (XI) with analogs, indicative of hardwood (Simoneit et al., 1993). These methoxyphenols were found as trace components in samples 5R, 7R, 13R, and 15B, but were present in significant amounts in the smoke sample 17F (Table 3). Based on the methoxyphenol composition the fuel that burned to produce the smoke sample 17F was primarily hardwood (guaiacyl to syringyl moiety ratio = 0.47, Oros and Simoneit, 2001a). The data for the other ambient samples were too sparse to make a fuel type assessment, except sample 15B in Bhilai which reflected a mixture of all three biomass fuel types.

3.4.3. Diterpenoids

Dehydroabietic acid (XII) and retene (XIII) are secondary tracers from biomass burning emissions and indicate conifer (softwood) fuel (Oros and Simoneit, 2001b; Ramdahl, 1983). These compounds occurred intermittently in the urban samples as trace components, but were not present in the smoke impacted sample (Table 3). The natural product resin acids, i.e. pimaric and isopimaric acids, in sample 8R have an unknown conifer source.

3.4.4. Triterpenoids

Triterpenoids, both thermally altered and natural products, were found only in the sample impacted by smoke (Fig. SI 1c and d, Table 3). The composition of the triterpenoid skeletons is consistent with an origin from hardwood as already mentioned above.

3.5. Synthetic Organic Compounds

Synthetic organic compounds produced by the chemical industry are numerous and varied. They are used in vast quantities, and upon disposal can impact the environment, i.e. the atmosphere in this case. The atmospheric particles in urban areas contain plasticizers, silicones, and other synthetic organic compounds from fugitive sources.

3.5.1. Plasticizers

Plasticizers, including softeners, antioxidants, and initiators, are introduced to the atmosphere by direct out-gassing (e.g. vinyl chloride and other volatile compounds) and by burning of plastics (Simoneit et al., 2005). The dominant plasticizers in our samples were phthalates ranging in concentrations from 2 to 926 ng m⁻³ with highest levels during winter (Table 3). Additional plasticizers found in most of the samples were dioctyl adipate and triphenyl phosphate, which were also high in winter (Table 3). Silicones (e.g. decamethylcyclopentasiloxane, Table 3) were significant in summer and winter, and probably were derived from burning of silicone polymers. Plasticizers in aerosols from Madras, India varied from 175 to 857 ng m⁻³, with higher values during summer (Fu et al., 2009, 2010). The smoke impacted sample 17F contained only traces of these compounds, whereas the urban aerosols had 5 to 44 % of EOM attributable to synthetic compounds. The presence of 1,3,5-triphenylbenzene, a specific tracer from burning of plastics (Simoneit et al., 2005), in most samples (Table 3), confirmed that such materials were burned in

the Raipur region. The higher levels of these pollutants during winter may reflect a lower inversion height or more extensive burning. Nevertheless, the Raipur region obviously is polluted by significant emissions from burning of plastics and other wastes.

3.5.2. Fugitive Emission Sources

The significant organic compounds from fugitive emission sources in our samples were industrial chemicals such as fragrance (ethyl 4-ethoxybenzoate, XIV), feedstock (e.g. dodecyl acrylate, XV, and 2,2,4-trimethylpentane-1,3-diol diisobutyrate, XVI), pesticide (e.g. diphenyl sulfone, XVII), or drug (e.g. phenindione, XVIII) compounds (Table 3). Diphenyl sulfone has been reported in lake sediments receiving discharges from a land-fill (Wick and Gschwend, 1998) and in the volatile compounds trapped from ambient air over a land-fill in South China (Zou et al., 2001). These fugitive emissions were intermittent and in some cases quite significant in the samples from the Raipur region. More extensive sampling, additional locales and source tests may better constrain the emission sources of these and related compounds.

3.5.3. Pesticides

Among the 21 pesticides analyzed only HCB (0.1 ng m^{-3}), metribuzin (26 ng m^{-3}), chlorpyrifos (0.7 ng m^{-3}), and the endosulfans (3 ng m^{-3}) were detected in the smoke impacted PM sample 17F (Table 3). Recent studies have shown that pesticides revolatilize from soils and vegetation during biomass/wildfire burning (Primbs et al., 2008; Genualdi et al., 2009), and this may be the reason why they were present in this sample. Most of the pesticides analyzed are partitioned into the atmospheric gas phase and not in particulate matter. This partitioning might be the reason for the non-detection of pesticides in the other samples.

3.6. Soil Resuspension

Soil is resuspended as dust into the atmosphere by wind erosion, and during agricultural tilling and harvesting. The conservative tracers found in soils are the water-soluble saccharides trapped in particles (Simoneit et al., 2004a; Medeiros et al., 2006). They are comprised of α - and β -glucose (XIX) (the most common sugar in nature, Pigman and Horton, 1970), inositol (XX), sucrose (XXI), and mycose (also known as trehalose, XXII). Mycose is a dominant fungal disaccharide while sucrose is predominant in phloem of plants (Niederer et al., 1989; Bielecki, 1995). A direct contribution of bioaerosols (e.g. pollen, spores, fungal mycelia, etc) containing saccharides to aerosol PM may also occur (Elbert et al., 2007; Després et al., 2012; Fu et al., 2012).

Only aerosol sample 5R, taken during the spring, had detectable amounts of these saccharides (total 267 ng m⁻³ or 24 % of EOM, Table 3). Sucrose was the dominant compound (Fig. SI 1a), which is consistent with spring growth and agricultural tilling.

3.7. Comparisons and Source Apportionments

The mean concentrations of the major organic compound groups in the PM of the Raipur area are compared with those of other large metropolitan regions in Table 4. The mean UCM value and the ratio of UCM/*n*-alkanes of 2 are considerably lower than the other examples, indicating lower emissions of lubricating oil from vehicular traffic in Raipur (Simoneit, 1985). This ratio is 65 for PM of Los Angeles, a city with primarily automobile traffic (Rogge et al., 1993). The ratio of *n*-alkanes to PAHs is 1.14, also lower than the other cities, and may indicate an enhancement of *n*-alkanes in emissions from coal burning (Oros and Simoneit, 2000). The *n*-alkanoic acids and *n*-alkanols in Raipur PM fall in a similar range as the other cities. The levoglucosan and

plasticizer levels are significant, probably indicating extensive burning of wood and plastics or additional direct volatilization of plasticizers.

The organic compound concentrations in the Raipur aerosol particulate matter have been summed for six major emission source categories. These data have been normalized and plotted as pie diagrams (Fig. 4), representative of the organic compounds but not total PM. The source categories are summed as follows:

(1) Petroleum product utilization, representing typical emissions from traffic and industrial engines, was comprised of the UCM and total alkanes less the plant wax alkanes. PAHs were not summed with this category because in source tests their emission factor was low (e.g. Schauer et al., 1996). The emissions from burning of coal (UCM, PAHs) could also not be separated from the petroleum product utilization due to the lack of existing source tests for this region (see category 3 below).

(2) Biomass burning overlaps with plastic and waste burning, but for this region a distinction can be made. The tracers summed for biomass smoke emissions were the anhydrosaccharides, methoxyphenols, half of the total PAHs, diterpenoids, and triterpenoids.

(3) Open burning of plastics and waste (municipal garbage) in land-fills emits plasticizers, fillers, and PAHs (other half of the total) (Didyk et al., 2000). It should also be noted that a significant amount of the high PAH concentrations probably derive from coal combustion. Adding such a category would require analysis of fractionated samples and determination of the hydroxy-PAHs to assess the emission factors and apportion that source strength (Simoneit et al., 2007; Zhou et al., 2009). The compounds derived from fugitive sources may be emitted directly or also by burning, and thus were added to this category.

(4) Food preparation by cooking in homes and commercial facilities (which can also include rendering and cremation) emits natural and altered product compounds in smoke PM (e.g. Schauer et al., 1996, 1999, 2002; Nolte et al., 1999). For this category, the other lipids (acylglycerides and acylamides) and the alkanolic acids, less their wax component, were summed.

(5) The natural background generally consists of higher plant wax composed of long chain ($> C_{20}$) *n*-alkanes, *n*-alkanols, *n*-alkanoic acids, and wax esters (Simoneit, 1989). Natural waxes are trace components comprised of the sum of the plant wax alkanes, the alkanols $> C_{20}$, and an equivalent amount of the alkanolic acids as the alkanols.

(6) Soil resuspension/erosion was only found in the spring sample 5R and the category is comprised of the saccharides (Simoneit et al., 2004a).

The pie diagrams for the source emission categories were quite diverse (Fig. 4), having major contributions from categories 1 (engine emissions) and 2 (biomass burning) for all samples, with the exception of sample 16K. These categories were dominant in the winter. Plastic and waste burning (category 3) and cooking (category 4) emissions heavily impacted samples 6R, 8R, 14B, and 16K in late spring and summer. The natural background (category 5) was low for all samples and soil advection (category 6) was only observed in spring. The obvious variability in source strengths is due to the limited sample set, but generally anthropogenic emissions dominate, and further work by monitoring agencies is warranted.

4. Conclusions

The organic tracers (i.e., *n*-alkanes, plant wax alkanes, PAHs, *n*-alkanoic acids, *n*-alkanols, lipids, steroids, anhydrosaccharides, methoxyphenols, diterpenoids, triterpenoids, plasticizers,

saccharides, and pesticides) in aerosol particulate matter (PM) were investigated for the three most polluted cities (i.e. Raipur, Bilai, and Korba) of Chhattisgarh state, India. All organic tracers, except methoxyphenols, diterpenoids, triterpenoids, saccharides, and pesticides, were present in all PM samples. Among these, the *n*-alkanol, lipid, and saccharide tracers were concentrated in the spring (sample 5R), mainly due to a soil origin. Whereas, the other *n*-alkane, PAH, *n*-alkanoic acid, and anhydrosaccharide tracers were found in the PM_{2.5} fraction, mainly due to primary emissions of fine aerosol particles. The wind speed and ambient temperature had a significant influence on the organic tracer concentrations in the PM. The highest concentrations of organic tracers were detected in the winter PM. The tracers from plastics were present in all PM due to their wide production, use and disposal in this urban/industrial region. Traces of pesticides were found only in the forest fire sample. The combustion of mainly fossil fuel products (i.e., coal), and to a lesser extent biomass/waste burning, were the dominant sources for the organic tracers in the aerosol PM of central India. The organic compounds from the natural background were low.

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References

Abas, M.R.B., Simoneit, B.R.T., 1996. Composition of extractable organic matter of air particles from Malaysia: Initial study. *Atmospheric Environment* 30, 2779-2793.

- Bi, X.H., Simoneit, B.R.T., Sheng, G.Y., Ma, S.X., Fu, J.M., 2008. Composition and major sources of organic compounds in urban aerosols. *Atmospheric Research* 88, 256-265.
- Bieleski, R.L., 1995. Onset of phloem export from senescent petals of daylily. *Plant Physiology* 109, 557-565.
- Bowman, F.M., Pilinis, C., Seinfeld, J.H., 1995. Ozone and aerosol productivity of reactive organics. *Atmospheric Environment* 29, 579-589.
- Brown, J.R., Field, R.A., Goldstone, M.E., Lester, J.N., Perry, R., 1996. Polycyclic aromatic hydrocarbons in central London air during 1991 and 1992. *Science of the Total Environment* 177, 73-84.
- Deshmukh, D.K., Tsai, Y.I., Deb, M.K., Mkoma, S.L., 2012. Characterization of dicarboxylates and inorganic ions in urban PM₁₀ aerosols in the Eastern Central India. *Aerosol and Air Quality Research* 12, 592-607.
- Després, V.R., Huffman, J.A., Burrows, S.M., Hoose, C., Safatu, A.S., Buryak, G., Fröhlich-Nowoisky, J., Elbert, W., Andreae, M.O., Pöschl, U., Jaenicke, R., 2012. Primary biological aerosol particles in the atmosphere: A review. *Tellus B* 64, 15598. Doi:10.3402/tellusb.v64:0.15598.
- Didyk, B.M., Simoneit, B.R.T., Pezoa, A.L., Riveros, L.M., Flores, A.A., 2000. Urban aerosol particles of Santiago, Chile: Organic content and molecular characterization. *Atmospheric Environment* 34, 1167-1179.
- Elbert, W., Taylor, P.E., Andreae, M.O., Pöschl, U., 2007. Contribution of fungi to primary biogenic aerosols in the atmosphere: wet and dry discharged spores, carbohydrates and inorganic ions. *Atmospheric Chemistry and Physics* 7, 4569-4588.

- Fu, P. Q., Kawamura, K., Pavuluri, C.M., Swaminathan, T., 2009. Molecular characterization of urban organic aerosol in tropical India: contributions of biomass/biofuel burning, plastic burning, and fossil fuel combustion. *Atmospheric Chemistry and Physics Discussions* 9, 21669-21716.
- Fu, P. Q., Kawamura, K., Pavuluri, C.M., Swaminathan, T., Chen, J., 2010. Molecular characterization of urban organic aerosol in tropical India: contributions of primary emissions and secondary photooxidation. *Atmospheric Chemistry and Physics* 10, 2663-2689.
- Fu, P.Q., Kawamura, K., Kobayashi, M., Simoneit, B.R.T., 2012. Seasonal variations of sugars in atmospheric particulate matter from Gosan, Jeju Island: Significant contributions of airborne pollen and Asian dust in spring. *Atmospheric Environment* 55, 234-239.
- Genualdi, S. A., Killin, R. K., Woods, J., Wilson, G., Schmedding, D., Simonich, S. L. M., 2009. Trans-Pacific and regional atmospheric transport of polycyclic aromatic hydrocarbons and pesticides in biomass burning emissions to Western North America. *Environmental Science and Technology* 43, 1061-1066.
- Graham, B., Mayol-Bracero, O.L., Guyon, P., Roberts, G.C., Decesari, S., Facchini, M.C., Artaxo, P., Maenhaut, W., Köll, P., Andreae, M.O., 2002. Water-soluble organic compounds in biomass burning aerosols over Amazonia 1. Characterization by NMR and GC-MS. *Journal of Geophysical Research* 107, 8047, doi:10.1029/2001JD000336.
- Gustafsson, Ö., Kruså, M., Zencak, Z., Sheesley, R.J., Granat, L., Engström, E., Praveen, P.S., Rao, P.S.P., Leck, C., Rodhe, H., 2009. Brown clouds over South Asia: Biomass or fossil fuel combustion? *Science* 323, 495-498.

- Hannigan, M.P., Cass, G.R., Penman, B.W., Crespi, C.L., Lafleur, A.L., Busby, W.F., Jr., Thilly, W.G., Simoneit, B.R.T., 1998. Bioassay-directed chemical analysis of Los Angeles airborne particulate matter using a human cell mutagenicity assay. *Environmental Science and Technology* 32, 3502-3514.
- Hawthorne, S.B., Miller, D.J., Barkley, R.M., Krieger, M.S., 1988. Identification of methoxylated phenols as candidate tracers for atmospheric wood smoke pollution. *Environmental Science and Technology* 22, 1191-1196.
- Hennigan, C. J., Sullivan, A. P., Collett, Jr. J. L., Robinson, A. L., 2010. Levoglucosan stability in biomass burning particles exposed to hydroxyl radicals. *Geophys. Research Letters* 37, L09806, doi:10.1029/2010GL043088.
- Hoffmann, D., Tilgner, A., Iinuma, Y., Herrmann, H., 2010. Atmospheric stability of levoglucosan: A detailed laboratory and modeling study. *Environmental Science and Technology* 44, 694-699.
- IARC, 1991. International Agency for Research on Cancer, 1987-1991. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Vols. 43-53. Lyon, France.
- IPCC (Intergovernmental Panel on Climate Change), 1995. Climate Change 1994, Cambridge University Press, New York.
- Jia, Y.-L., Bhat, S., Fraser, M.P., 2010. Characterization of saccharides and other organic compounds in fine particles and the use of saccharides to track primary biologically derived carbon sources. *Atmospheric Environment* 44, 724-732.

- Kawanaka, Y., Matsumoto, E., Sakamoto, K., Wang, N., Yun, S.J., 2004. Size distributions of mutagenic compounds and mutagenicity in atmospheric particulate matter collected with a low-pressure cascade impactor. *Atmospheric Environment* 38, 2125-2132.
- Li, M., McDow, S.R., Tollerud, D.J., Mazurek, M.A., 2006. Seasonal abundance of organic molecular markers in urban particulate matter from Philadelphia, PA. *Atmospheric Environment* 40, 2260-2273.
- Medeiros, P.M., Simoneit, B.R.T., 2008. Source profiles of organic compounds emitted upon combustion of green vegetation from temperate climate forests. *Environmental Science and Technology* 42, 8310-8316.
- Medeiros, P.M., Fernandes, M.F., Dick, R.P., Simoneit, B.R.T., 2006. Seasonal variations in sugar contents and microbial community behavior in a ryegrass soil. *Chemosphere* 65, 832-839.
- Miyazaki, Y., Aggrawal, S.G., Gupta, P.K., Kawamura, K., 2009. Dicarboxylic acids and water-soluble organic carbon in aerosols in New Delhi, India, in winter: Characteristics and formation processes. *J. Geophys. Res.* 114, D19206, doi: 10.1029/2009JD011790.
- Niederer, M., Pankow, W., Wiemken, A., 1989. Trehalose synthesis in mycorrhiza of Norway spruce: an indicator of vitality. *European Journal of Forest Pathology* 19, 14-20.
- Nolte, C.G., Schauer, J.J., Cass, G.R., Simoneit, B.R.T., 1999. Highly polar organic compounds in meat smoke. *Environmental Science and Technology* 33, 3313-3316.
- Omar, N.Y.M., Radzi bin Abas, M., Rahman, N.A., Simoneit, B.R.T., 2006. Heavy Molecular Weight Organics in the Atmosphere: Origins and Mass Spectra. University of Malaya Publisher Press, Pantai Valley, 50603 Kuala Lumpur, Malaysia, 193 pp.

- Oros, D.R., Simoneit, B.R.T., 2000. Identification and emission rates of molecular tracers in coal smoke particulate matter. *Fuel* 79, 515-536.
- Oros, D.R., Simoneit, B.R.T., 2001a. Identification and emission factors of molecular tracers in organic aerosols from biomass burning: Part 2. Deciduous trees. *Applied Geochemistry* 16, 1545-1565.
- Oros, D.R., Simoneit, B.R.T., 2001b. Identification and emission factors of molecular tracers in organic aerosols from biomass burning: Part 1. Temperate climate conifers. *Applied Geochemistry* 16, 1513-1544.
- Pandey, P.K., Patel, K.S., Lenicek, J., 1999. Polycyclic aromatic hydrocarbons: Need for assessment of health risks in India? Study of an urban-industrial location in India. *Environmental Monitoring and Assessment* 59, 287-319.
- Pigman, W., Horton, D., 1970. The Carbohydrates - Chemistry and Biochemistry, 2nd ed., Vol. 1A, Academic Press, New York, 642 pp.
- Primbs, T., Wilson, G., Schmedding, D., Higginbotham, C., Massey Simonich, S., 2008. Influence of Asian and western United States agricultural areas and fires on the atmospheric transport of pesticides in the western United States. *Environmental Science and Technology* 42, 6519-6525.
- Ram, K., Sarin, M.M., 2010. Statio-temporal variability in atmospheric abundances of EC, OC and WSOC over Northern India. *Journal of Aerosol Science* 41, 88-98.
- Ramanathan, V., Ramana, M.V., Roberts, G., Kim, D., Corrigan, C., Chung, C., Winker, D., 2007. Warming trends in Asia amplified by brown cloud solar absorption. *Nature* 448, 575-578.

- Ramdahl, T., 1983. Retene - a molecular marker of wood combustion in ambient air. *Nature* 306, 580-582.
- Rengarajan, R., Sarin, M.M., Sudheer, A.K., 2007. Carbonaceous and inorganic species in atmospheric aerosols during wintertime over urban and high-altitude sites in North India. *Journal of Geophysical Research* 112. D21307. Doi:10.1029/2006JD008150.
- Rogge, W.F., Hildemann, L.M., Mazurek, M.A., Cass, G.R., Simoneit, B.R.T., 1991. Sources of fine organic aerosol: 1. - Charbroilers and meat cooking operations. *Environmental Science and Technology* 25, 1112-1125.
- Rogge, W.F., Hildemann, L.M., Mazurek, M.A., Cass, G.R., Simoneit, B.R.T., 1993a. Sources of fine organic aerosol: 2. Noncatalyst and catalyst-equipped automobiles and heavy-duty diesel trucks. *Environmental Science and Technology* 27, 636-651.
- Rogge, W.F., Hildemann, L.M., Mazurek, M.A., Cass, G.R., Simoneit, B.R.T., 1993b. Quantification of urban organic aerosols on a molecular level: Identification, abundance and seasonal variation. *Atmospheric Environment* 27A, 1309-1330.
- Rogge, W.F., Hildemann, L.M., Mazurek, M.A., Cass, G.R., Simoneit, B.R.T., 1996. Mathematical modeling of atmospheric fine particle-associated primary organic compound concentrations. *Journal of Geophysical Research* 101, 19541-19549.
- Satheesh, S.K., Ramanathan, V., 2000. Large differences in tropical aerosol forcing at the top of the atmosphere and Earth's surface. *Nature* 405, 60-63.
- Satsangi, A., Pachauri, T., Singla, V., Lakhani, A., Kumari, K.M., 2012. Organic and elemental carbon aerosols at a suburban site. *Atmospheric Research* 113, 13-21.

- Saxena, P., Hildemann, L.M., McMurray, P.H., Seinfeld, J.H., 1995. Organics alter hygroscopic behavior of atmospheric particles. *Journal of Geophysical Research* 100, 18755-18770.
- Schauer, J.J., Rogge, W.F., Hildemann, L.M., Mazurek, M.A., Cass, G.R., Simoneit, B.R.T., 1996. Source apportionment of airborne particulate matter using organic compounds as tracers. *Atmospheric Environment* 30, 3837-3855.
- Schauer, J.J., Kleeman, M.J., Cass, G.R., Simoneit, B.R.T., 1999. Measurement of emissions from air pollution sources. 1. C₁ through C₂₉ organic compounds from meat charbroiling. *Environmental Science and Technology* 33, 1566-1577.
- Schauer, J.J., Kleeman, M.J., Cass, G.R., Simoneit, B.R.T., 2002. Measurement of emissions from air pollution sources. 4. C₁ through C₂₇ organic compounds from cooking with seed oils. *Environmental Science and Technology* 36, 567-575.
- Schnelle-Kreis, J., Sklorz, M., Orasche, J., Stölzel, M., Peters, A., Zimmermann, R., 2007. Semi volatile organic compounds in ambient PM_{2.5}. Seasonal trends and daily resolved source contributions. *Environmental Science and Technology* 41, 3821-3828.
- Sharma, H., Jain, V.K., Khan, Z.H., 2007. Characterization and source identification of polycyclic aromatic hydrocarbons (PAHs) in the urban environment of Delhi. *Chemosphere* 66, 302-310.
- Simoneit, B.R.T., 1984. Organic matter of the troposphere - III. Characterization and sources of petroleum and pyrogenic residues in aerosols over the western United States. *Atmospheric Environment* 18, 51-67.

- Simoneit, B.R.T., 1985. Application of molecular marker analysis to vehicular exhaust for source reconciliations. *International Journal of Environmental Analytical Chemistry* 22, 203-233.
- Simoneit, B.R.T., 1989. Organic matter of the troposphere - V: Application of molecular marker analysis to biogenic emissions into the troposphere for source reconciliations. *Journal of Atmospheric Chemistry* 8, 251-275.
- Simoneit, B.R.T., 2002. Biomass burning – a review of organic tracers for smoke from incomplete combustion. *Applied Geochemistry* 17, 129-162.
- Simoneit, B.R.T., Mazurek, M.A., 1982. Organic matter of the troposphere - II. Natural background of biogenic lipid matter in aerosols over the rural western United States. *Atmospheric Environment* 16, 2139-2159.
- Simoneit, B.R.T., Cox, R.E., Standley, L.J., 1988. Organic matter of the troposphere-IV: Lipids in Harmattan aerosols of Nigeria. *Atmospheric Environment* 22, 983-1004.
- Simoneit, B.R.T., Crisp, P.T., Mazurek, M.A., Standley, L.J., 1991a. Composition of extractable organic matter of aerosols from the Blue Mountains and southeast coast of Australia. *Environment International* 17, 405-419.
- Simoneit, B.R.T., Sheng, G., Chen, X., Fu, J., Zhang, J., Xu, Y., 1991b. Molecular marker study of extractable organic matter in aerosols from urban areas of China. *Atmospheric Environment* 25A, 2111-2129.
- Simoneit, B.R.T., Rogge, W.F., Mazurek, M.A., Standley, L.J., Hildemann, L.M., Cass, G.R., 1993. Lignin pyrolysis products, lignans and resin acids as specific tracers of plant

- classes in emissions from biomass combustion. *Environmental Science and Technology* 27, 2533-2541.
- Simoneit, B.R.T., Schauer, J.J., Nolte, C.G., Oros, D.R., Elias, V.O., Fraser, M.P., Rogge, W.F., Cass, G.R., 1999. Levoglucosan, a tracer for cellulose in biomass burning and atmospheric particles. *Atmospheric Environment* 33, 173-182.
- Simoneit, B.R.T., Rushdi, A.I., bin Abas, R.M., Didyk, B.M., 2003. Alkyl amides and alkyl nitriles as novel tracers for biomass burning. *Environmental Science and Technology* 37, 16-21.
- Simoneit, B.R.T., Elias, V.O., Kobayashi, M., Kawamura, K., Rushdi, A.I., Medeiros, P.M., Rogge, W.F., Didyk, B.M., 2004a. Sugars – dominant water-soluble organic compounds in soils and characterization as tracers in atmospheric particulate matter. *Environmental Science and Technology* 38, 5939-5949.
- Simoneit, B.R.T., Kobayashi, M., Mochida, M., Kawamura, K., Lee, M.H., Lim, H.J., Turpin, B.J., Komazaki, Y., 2004b. Composition and major sources of organic compounds of aerosol particulate matter sampled during the ACE-Asia campaign. *Journal of Geophysical Research - Atmospheres* 109, doi:10.1029/2004JD004598,D19S10/1-22.
- Simoneit, B.R.T., Medeiros, P.M., Didyk, B.M., 2005. Combustion products of plastics as indicators for refuse burning in the atmosphere. *Environmental Science and Technology* 39, 6961-6970.
- Simoneit, B.R.T., Bi, X.H., Oros, D.R., Medeiros, P.M., Sheng, G.Y., Fu, J.M., 2007. Phenols and hydroxy-PAHs (arylphenols) as tracers for coal smoke particulate matter—source

- tests and ambient aerosol assessments. *Environmental Science and Technology* 41, 7294-7302.
- Vila-Escalé, M., Vegas-Vilarrúbia, T., Prat, N., 2007. Release of polycyclic aromatic compounds into a Mediterranean creek (Catalonia, NE Spain) after a forest fire. *Water Resources* 41, 2171-2179.
- Wick, L.Y., Gschwend, P.M., 1998. Source and chemodynamic behavior of diphenyl sulfone and ortho- and para-hydroxybiphenyl in a small lake receiving discharges from an adjacent superfund site. *Environmental Science and Technology* 32, 1319-1328.
- Yang, H.H., Lai, S.O., Hsieh, L.T., Hsueh, H.J., Chi, T.W., 2002. Profiles of PAH emissions from steel and iron industries. *Chemosphere* 48, 1061-1074.
- Zhou, J.B., Wang, T.G., Zhang, Y.P., Mao, T., Huang, Y.B., Zhong, N.N., Simoneit, B.R.T., 2008. Sources and seasonal changes in the distributions of aliphatic and polycyclic aromatic hydrocarbons in size fractions of atmospheric particles of Beijing, China. *Environmental Engineering Science* 25, 207-220.
- Zhou, J., Wang, T., Zhang, Y., Zhong, N., Medeiros, P.M., Simoneit, B.R.T., 2009. Composition and sources of organic matter in atmospheric PM₁₀ over a two year period in Beijing, China. *Atmospheric Research* 93, 849-861.
- Zou, S.C., Zheng, S.J., Zhang, Z.X., Wang, X.M., Sheng, G.Y., 2001. Composition and distribution of trace volatile organic compounds in the air of the landfill field of Guangzhou. *Zhongguo Huanjing Kexue* 20, 77-81.

Figure Legends

Figure 1. Location map showing the sampling area.

Figure 2. Example of GC-MS data for a total extract from a typical urban aerosol PM sample (5R, Daganía, Raipur): (a) Total ion current (TIC) trace, (b) m/z 85, key ion trace for *n*-alkanes, (c) m/z 60 key ion trace for *n*-alkanoic acids, and (d) m/z 178, 202, 228, 252, 276 and 306, normalized to show the PAH distribution. 4iP and 4nP = di-iso- and di-*n*-butyl phthalate, DEHP = diethylhexyl phthalate, FA= alkanolic acid, • = *n*-alkane, numbers refer to carbon chain length, PAH abbreviations as in Table 3.

Figure 3. PAH profile overviews. 3-ring PAHs: Ph and A; 4-ring PAHs: Fl, Py, Re, BaA, and Chry; 5-ring PAHs: BbF, BkF, BeP, and BaP; 6-ring PAHs: IdP, BgP, and DbA.

Figure 4. Source apportionment of the organic compounds in the aerosol PM: 1 = petroleum utilization emissions, 2 = biomass burning smoke, 3 = plastics burning, 4 = cooking emissions, 5 = natural background, and 6 = soil resuspension.

Table Legends

Table 1. Sampling site descriptions.

Table 2. Mass concentrations of PM in ambient air of the Raipur region, India ($\mu\text{g m}^{-3}$).

Table 3. Concentrations of organic compounds in PM of the Raipur region (ng m^{-3})^a.

Table 4. Comparison of concentrations of organic compound groups in PM of the Raipur region with other urban areas.

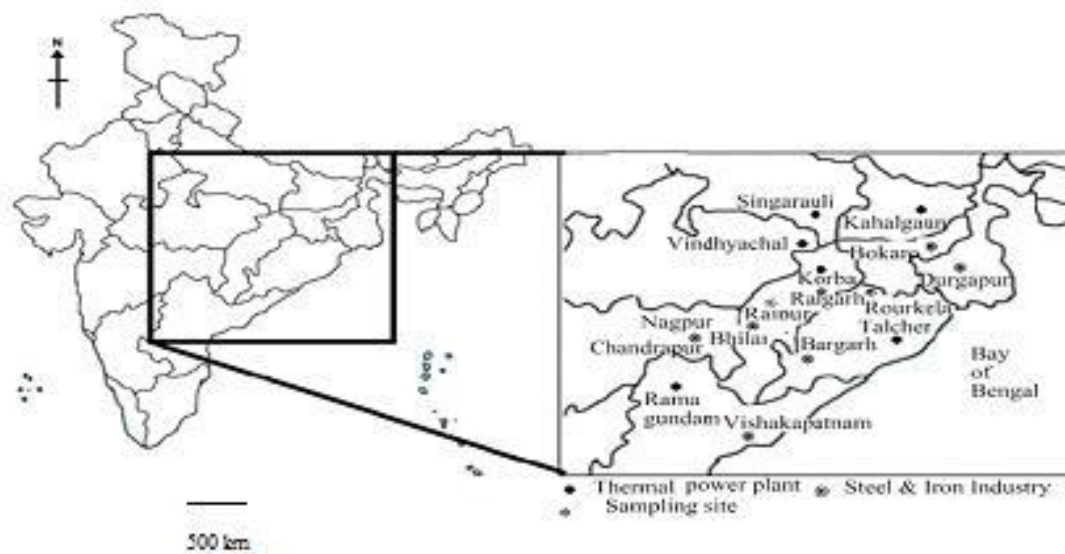


Fig 1

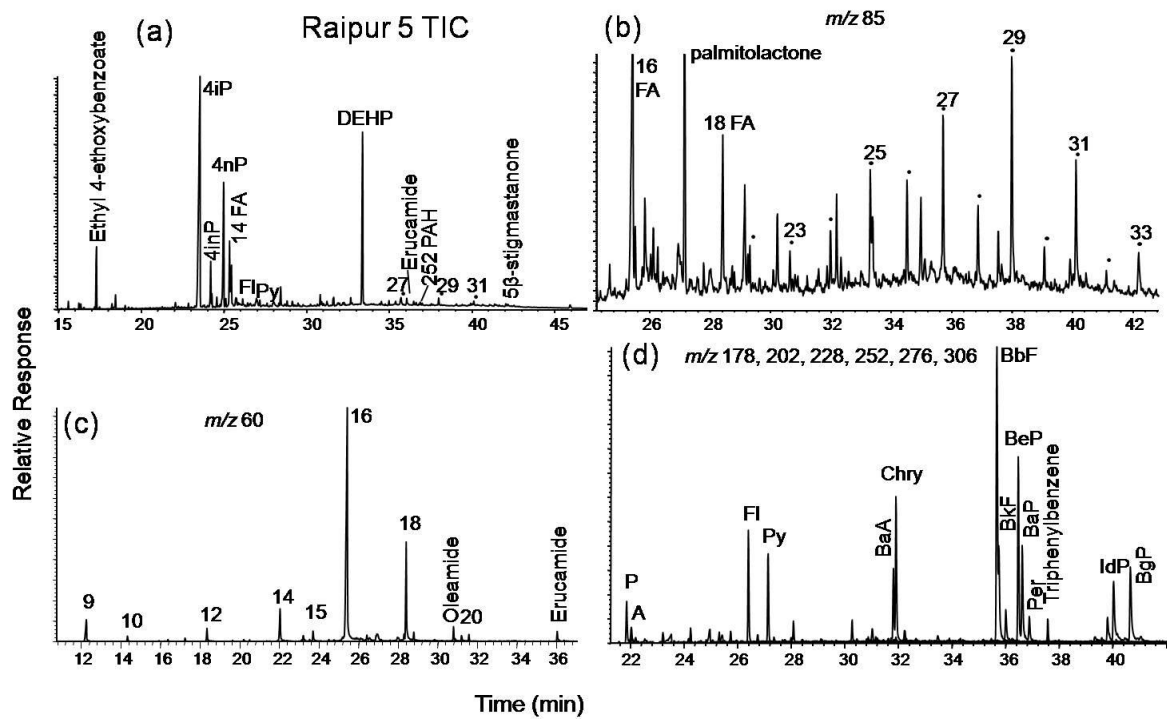


Fig 2

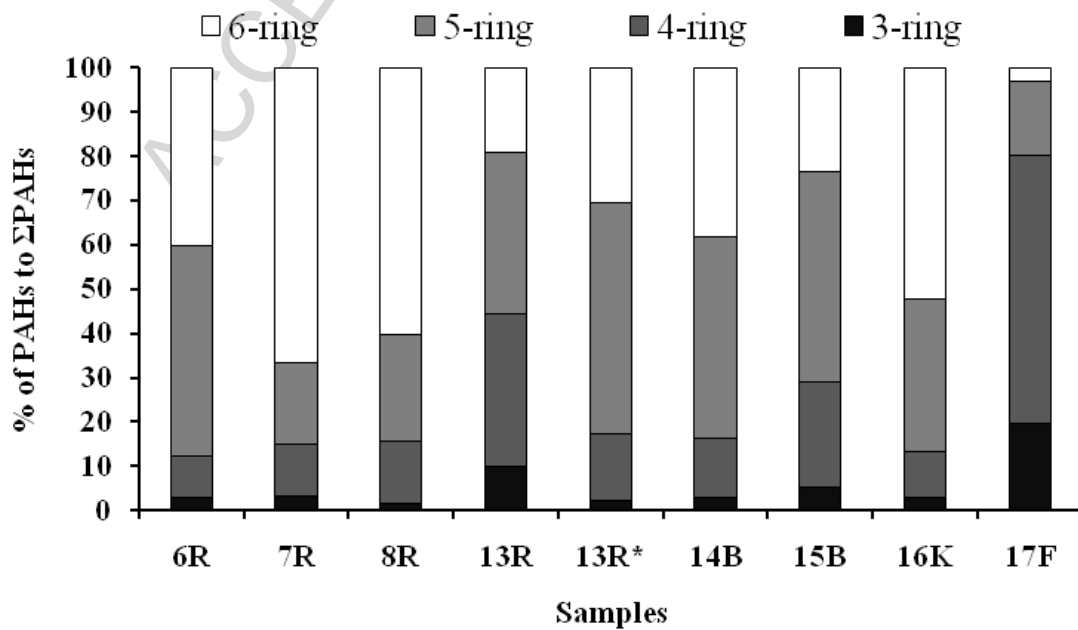


Fig 3

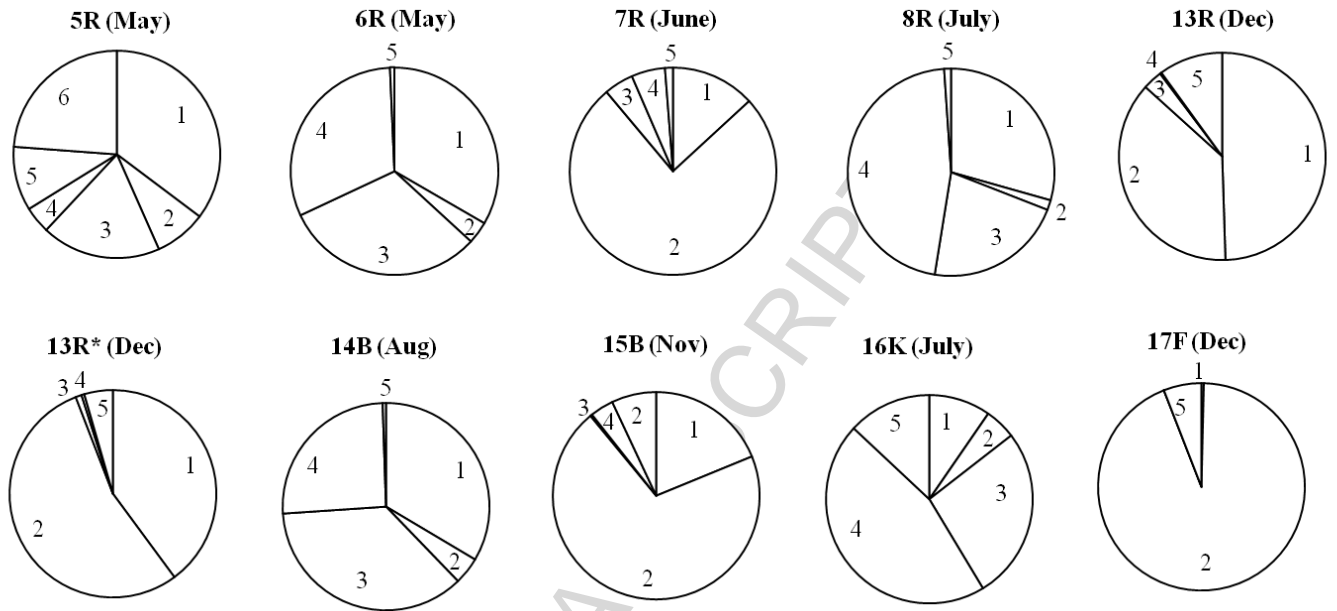


Fig 4

Table 1. Sampling site descriptions

S. No.	City	Sampling location	Site description	PM collection
1	Raipur	Dagania (21°14'N 81°36'E)	Residential area, western part of city	SPM, PM ₁₀ and PM _{2.5}
2	Bhilai	Kursipar (21° 13'N 81° 26'E)	Close to BSP steel plant	PM ₁₀
3	Korba	Jamnipali, NTPC	Close to thermal power plant	PM ₁₀
4	Raipur	Arang (21° 12' N, 81° 58' E)	Social forest	PM ₁₀

SPM = suspended particulate matter, PM₁₀ = coarse particulate matter, and PM_{2.5} = fine particulate matter.

Table 2. Mass concentrations of PM in ambient air of the Raipur region, India ($\mu\text{g m}^{-3}$)

S. No.	Site	Date	PM concentration in ambient air		
			SPM	PM ₁₀	PM _{2.5}
1	Raipur	03-01-2006	1237	589	311
2	Raipur	09-02-2006	589	254	108
3	Raipur	16-03-2006	752	328	112
4	Raipur	13-04-2006	516	215	117
5	Raipur	06-05-2006	416*	192	102
6	Raipur	18-05-2006	546	248*	115
7	Raipur	14-06-2006	729	347*	156
8	Raipur	03-07-2006	360	150*	67
9	Raipur	15-08-2006	231	92	40
10	Raipur	09-09-2006	298	119	52
11	Raipur	15-10-2006	447	186	84
12	Raipur	15-11-2006	491	223	101
13	Raipur	01-12-2006	551	261*	124*
14	Bhilai	17-08-2006	-	216*	-
15	Bhilai	13-11-2006	-	320*	-
16	Korba	01-07-2006	-	166*	-
17	Forest fire, Raipur	25-12-2006	-	730*	-

* Analyzed for organic tracers

Compound	Formula	MW	Sample no. from Table 2 (R = Raipur, B = Bhilai, K = Korba and F = Forest fire)									
			5R	6R	7R	8R	13R	13R	14B	15B	16K	17F
UCM			390	9.2	12	18	584	970	30	710	8	266
Percent of total EOM			34.3	44.5	7.7	39.2	12.4	7.1	27.2	3.9	2.8	0.2
n-Alkanes												
n-octadecane	$\text{C}_{18}\text{H}_{38}$	254			0.20	0.03			0.05		0.11	
n-nonadecane	$\text{C}_{19}\text{H}_{40}$	268		0.02	0.70	0.06	2.0		0.14		0.20	3.0
n-eicosane	$\text{C}_{20}\text{H}_{42}$	282		0.04	1.64	0.13	2.4	7.6	0.22	27.0	0.40	7.0
n-heneicosane	$\text{C}_{21}\text{H}_{44}$	296		0.11	2.0	0.18	4.2	8.1	0.28	46.0	0.52	10.2
n-docosane	$\text{C}_{22}\text{H}_{46}$	310	0.2	0.16	1.8	0.22	12.1	15.2	0.30	70.5	0.60	22.9
n-tricosane	$\text{C}_{23}\text{H}_{48}$	324	0.3	0.09	1.0	0.15	24.0	25.4	0.21	88.0	0.42	34.0
n-tetracosane	$\text{C}_{24}\text{H}_{50}$	338	0.5	0.04	0.5	0.08	35.3	53.0	0.15	81.3	0.26	17.0
n-pentacosane	$\text{C}_{25}\text{H}_{52}$	352	1.0	0.01	0.1	0.03	36.8	47.7	0.08	88.5	0.14	13.0
n-hexacosane	$\text{C}_{26}\text{H}_{54}$	366	0.8				30.1	37.0	0.05	45.0	0.09	9.0
n-heptacosane	$\text{C}_{27}\text{H}_{56}$	380	1.5			0.04	36.3	40.4	0.04	95.4	0.10	10.4
n-octacosane	$\text{C}_{28}\text{H}_{58}$	394	0.6			0.01	19.4	25.7	0.02	34.0	0.09	1.0

n-nonacosane	C ₂₉ H ₆₀	408	2.0			0.03	40.0	35.4	0.06	60.4	0.22	11.2
n-triacontane	C ₃₀ H ₆₂	422	0.3			0.01	10.4	12.5	0.02	19.0	0.12	
n-hentriacontane	C ₃₁ H ₆₄	436	1.1			0.02	24.7	18.0	0.08	36.5	0.36	3.0
n-dotriacontane	C ₃₂ H ₆₆	450	0.1				4.5	4.0	0.02	8.0	0.10	
n-tritriacontane	C ₃₃ H ₆₈	464	0.4				7.3	5.5	0.03	12.2	0.16	
n-tetratriacontane	C ₃₄ H ₇₀	478	0.1								0.02	
Total			8.9	0.47	7.94	0.99	289.5	335.3	1.75	711.8	3.91	140.7
CPI(21-33) ^b			2.52	0.95	0.79	1.0	1.43	1.16	1.0	1.45	1.48	1.28
Percent of total EOM			0.8	2.3	5.1	2.2	6.2	2.5	1.6	3.9	1.4	0.1
Plant wax alkanes^c												
n-tricosane	C ₂₃ H ₄₈	324					0.3			12.1		14.1
n-pentacosane	C ₂₅ H ₅₂	352	0.35				4.1	2.7		25.4		
n-heptacosane	C ₂₇ H ₅₆	380	0.8			0.03	11.6	9.1	0.01	55.9	0.01	5.4
n-nonacosane	C ₂₉ H ₆₀	408	1.55			0.02	25.1	16.3	0.04	33.9	0.11	10.2
n-hentriacontane	C ₃₁ H ₆₄	436	0.9			0.01	17.3	9.8	0.06	23.0	0.25	3.0
n-tritriacontane	C ₃₃ H ₆₈	464	0.3				5.1	3.5	0.01	8.2	0.10	
Total			3.9			0.06	63.5	41.4	0.12	158.5	0.47	32.7
PAHs												

phenanthrene (Phe)	C ₁₄ H ₁₀	178	0.6	0.10	0.08	0.01	36.6	5.1	0.07	20.5	0.06	234.0
anthracene (A)	C ₁₄ H ₁₀	178	0.2	0.01	0.01		5.0	1.0	0.02	3.2	0.02	57.0
fluoranthene (Fl)	C ₁₆ H ₁₀	202	1.5	0.07	0.80	0.02	56.6	13.0	0.09	28.9	0.06	338.0
pyrene (Py)	C ₁₆ H ₁₀	202	1.2	0.15	1.12	0.03	45.5	16.0	0.13	1.7	0.08	41.0
benz[a]anthracene (BaA)	C ₁₈ H ₁₂	228	1.0	0.06	0.47	0.02	25.2	13.9	0.09	29.7	0.07	117.0
chrysene (Chry)	C ₁₈ H ₁₂	228	2.0	0.06	0.40	0.01	16.3	10.0	0.07	24.8	0.04	85.0
benzo[b]fluoranthene (BbF)	C ₂₀ H ₁₂	252	4.0	0.77	0.22	0.07	70.1	68.1	0.58	108.0	0.40	97.0
benzo[k]fluoranthene (BkF)	C ₂₀ H ₁₂	252	1.5	0.25	0.07	0.03	18.6	18.8	0.17	28.8	0.11	18.0
benzo[e]pyrene (BeP)	C ₂₀ H ₁₂	252	2.5	0.37	0.11	0.04	35.1	35.1	0.35	50.4	0.19	64.0
benzo[a]pyrene (BaP)	C ₂₀ H ₁₂	252	1.3	0.35	0.12	0.04	29.7	27.2	0.23	31.8	0.17	71.0
indeno[1,2,3-cd]pyrene (IdP)	C ₂₂ H ₁₂	276	0.8	0.67	0.90	0.21	40.5	43.3	0.55	48.9	0.58	45.0
benzo[ghi]perylene (BgP)	C ₂₂ H ₁₂	276	1.0	0.71	0.82	0.18	34.5	37.4	0.42	47.4	0.55	
dibenz[a,h]anthracene (DbA)	C ₂₂ H ₁₄	278		0.09	0.16	0.06	6.0	6.5	0.14	11.2	0.17	0.5
Total			17.6	3.66	5.28	0.69	419.7	295.4	2.89	435.3	2.50	1167.5
Percent of total EOM			1.5	17.7	3.4	1.5	8.9	2.2	2.6	2.4	0.9	1.0
n-Alkanoic acids												
n-nonanoic acid	C ₉ H ₁₈ O ₂	158	2.1				61.7	164.0				2210
n-decanoic acid	C ₁₀ H ₂₀ O ₂	172	0.5				29.4	80.4				110

n-undecanoic acid	$C_{11}H_{22}O_2$	186	0.01									30
n-dodecanoic acid	$C_{12}H_{24}O_2$	200	1.2	0.02	0.02	0.1	34.5	180.0		52.0		390
n-tridecanoic acid	$C_{13}H_{26}O_2$	214	0.15		0.01	0.01						81
n-tetradecanoic acid	$C_{14}H_{28}O_2$	228	3.3	0.4	0.11	2.6	101.0	95.0	2.4	442.0	3.6	829
n-pentadecanoic acid	$C_{15}H_{30}O_2$	242	0.9	0.01	0.02	0.13	19.0	70.5		182.4		220
n-hexadecanoic acid	$C_{16}H_{32}O_2$	256	25.5	2.3	0.68	6.3	295.0	1005	18.0	4540	80.5	1940
n-heptadecanoic acid	$C_{17}H_{34}O_2$	270	0.55	0.02	0.02	0.02	4.2	8.0		96.0		130
n-octadecanoic acid	$C_{18}H_{36}O_2$	284	9.0	1.12	0.50	5.9	152.0	622.0	9.5	2220	59.0	580
n-nonadecanoic acid	$C_{19}H_{38}O_2$	298										60
n-eicosanoic acid	$C_{20}H_{40}O_2$	312	0.65		0.26							192
n-heneicosanoic acid	$C_{21}H_{42}O_2$	326										110
n-docosanoic acid	$C_{22}H_{44}O_2$	340			0.25							678
n-tricosanoic acid	$C_{23}H_{46}O_2$	354										220
n-tetracosanoic acid	$C_{24}H_{48}O_2$	368			0.27							1230
n-pentacosanoic acid	$C_{25}H_{50}O_2$	382										70
n-hexacosanoic acid	$C_{26}H_{52}O_2$	396			0.02							700
n-octacosanoic acid	$C_{28}H_{56}O_2$	424										110
octadecenoic acids ($C_{18:1}$)	$C_{18}H_{34}O_2$	282	0.6	0.1	0.18	0.30	2.0	1.0	0.9	184	4.7	440

octadecadienoic acid (C _{18:2})	C ₁₈ H ₃₂ O ₂	280	0.1		0.02	0.40					0.5	100
Total			44.56	3.87	2.36	15.8	698.8	2226	30.8	7716	148.3	10430
Percent of total EOM			3.9	18.7	1.5	34.4	14.9	16.4	28.0	42.7	51.4	9.3
n-Alkanols												
n-hexadecanol	C ₁₆ H ₃₄ O	242	14.7	0.04	0.42	0.20			1.8		4.7	
n-octadecanol	C ₁₈ H ₃₈ O	270	23.4	0.18	0.66	0.40			2.2		9.0	
n-eicosanol	C ₂₀ H ₄₂ O	298										126
n-docosanol	C ₂₂ H ₄₆ O	326										284
n-tetracosanol	C ₂₄ H ₅₀ O	354	9.0		0.11							750
n-hexacosanol	C ₂₆ H ₅₄ O	382	19.0		0.11					38.0	0.48	1105
n-octacosanol	C ₂₈ H ₅₈ O	410	30.0		0.24					74.0	0.53	690
n-triacontanol	C ₃₀ H ₆₂ O	438	12.0		0.35						0.77	6.0
Total			108.1	0.22	1.89	0.6			4.0	112.0	15.48	2961
Percent of total EOM			9.5	1.1	1.2	1.3			3.6	0.6	5.4	2.6
Other lipids (cooking)												
1-myristin	C ₁₇ H ₃₄ O ₄	302	0.5		0.12	0.10			0.35		1.1	
1-palmitin	C ₁₉ H ₃₈ O ₄	330	3.6	0.17	3.84	0.55		2.2	2.30	160.0	4.2	
2-palmitin	C ₁₉ H ₃₈ O ₄	330			0.30					14.6		

1-stearin	$C_{21}H_{42}O_4$	358	1.6	0.04	1.81	0.20			0.50	42.5	0.8	
palmitolactone	$C_{16}H_{30}O_2$	254	2.8									
palmitamide	$C_{16}H_{33}NO$	255	2.0								1.3	
oleamide	$C_{18}H_{35}NO$	281	3.6			0.12					2.2	
stearamide	$C_{18}H_{37}NO$	283	0.9									
erucamide	$C_{22}H_{43}NO$	337	1.8			0.43			0.12		6.0	
Total			16.8	0.21	6.07	1.4		2.2	3.27	217.1	15.6	
Percent of total EOM			1.5	1.0	3.9	3.1		0.02	3.0	1.2	5.4	
Steroids												
cholesterol	$C_{27}H_{46}O$	386		0.01							0.49	330
5 β -stigmastanone	$C_{29}H_{48}O$	412	0.50			0.02						895
sitosterol	$C_{29}H_{50}O$	414		0.03		0.01						612
24-ethylcholesta-3,5-diene	$C_{29}H_{48}$	396										777
24-ethylcholesta-4,6-diene	$C_{29}H_{48}$	396										190
Total			0.5	0.04		0.03					0.49	2804
Percent of total EOM			0.04	0.2		0.07					0.2	2.5
Anhydrosaccharides												
glycerol	$C_3H_8O_3$	92	5.8		0.11		76.5	220	0.23			15

galactosan	$C_6H_{10}O_5$	162	1.6									3600
mannosan	$C_6H_{10}O_5$	162	2.2	0.01	0.30		9.7	45.0				4180
levoglucosan	$C_6H_{10}O_5$	162	54.0	0.31	110.0	0.55	486.0	1440	1.27	3900	1.24	31000
anhydroglucofuranose	$C_6H_{10}O_5$	162	9.0		0.9		28.3	8.5		98.0		3900
Total			72.6	0.32	111.3	0.55	600.5	1713.5	1.5	3998	1.24	42695
Percent of total EOM			6.4	1.5	71.6	1.2	12.8	12.6	1.4	22.1	0.4	37.9
Methoxyphenols (from lignin)												
methoxycatechol	$C_7H_8O_3$	140										1120
vanillin	$C_8H_8O_3$	152										2400
syringol	$C_8H_{10}O_3$	154										1400
acetovanillone	$C_9H_{10}O_3$	166	1.6									1220
4-hydroxybenzoic acid	$C_7H_6O_3$	138			0.09					244.0		
vanillic acid	$C_8H_8O_4$	168			0.52		10.3	4.2		115.0		4080
guaiacyl acetone	$C_{10}H_{12}O_3$	180										4120
syringaldehyde	$C_9H_{10}O_4$	182					31.3	5.8		160.0		1670
veratric acid	$C_9H_{10}O_4$	182										775
phloacetophenone	$C_9H_{10}O_4$	182										2440
methoxyeugenol	$C_{11}H_{14}O_3$	194										1720

syringyl ethanal	$C_{10}H_{12}O_4$	196									3650
acetosyringone	$C_{10}H_{12}O_4$	196							71.0		2880
syringic acid	$C_9H_{10}O_5$	198			0.38		11.7	1.3		142.0	2325
syringyl acetone	$C_{11}H_{14}O_4$	210									4400
syringyl propanal	$C_{11}H_{14}O_4$	210									2560
methyl syringate	$C_{10}H_{12}O_5$	212									720
3,4,5-trimethoxybenzyl methyl ether	$C_{11}H_{16}O_4$	212									895
syringyl propanol	$C_{11}H_{16}O_4$	212									660
trimethoxymandelic acid	$C_{11}H_{14}O_6$	242									2850
3,3'-dimethoxy-4,4'-dihydroxystilbene	$C_{16}H_{16}O_4$	272									408
bisguaiacylthane	$C_{16}H_{18}O_4$	274									830
bisguaiacylpropane	$C_{17}H_{20}O_4$	288									60.0
disyringyl	$C_{18}H_{22}O_6$	304									305
guaiacylsyringylmethane	$C_{17}H_{20}O_5$	334									224
Total			1.6		0.99		53.3	11.3		732	43712
Percent of total EOM			0.1		0.6		1.1	0.08		4.1	38.8
Diterpenoids (resins)											

retene (Re)	$C_{18}H_{18}$	234			0.02		1.70	1.70		1.40		
dehydroabiatic acid	$C_{20}H_{28}O_2$	300	2.1	0.03	0.33	0.80				120.0		
pimaric acid	$C_{20}H_{30}O_2$	302				0.10						
isopimaric acid	$C_{20}H_{30}O_2$	302				0.20						
7-oxodehydroabiatic acid	$C_{20}H_{26}O_3$	314		0.02		0.12						
abieta-8,11,13,15-tetraenoic acid	$C_{20}H_{26}O_2$	298				0.40						
Total			2.1	0.05	0.35	1.62	1.7	1.7		121.4		
Percent of total EOM			0.2	0.2	0.2	3.5	0.04	0.01		0.7		
Triterpenoids												
ursana-2,12-diene	$C_{30}H_{48}$	408										1100
oleana-2,12-diene	$C_{30}H_{48}$	408										322
lupenone	$C_{30}H_{48}O$	424										2660
lupeol	$C_{30}H_{50}O$	426										224
friedelin	$C_{30}H_{48}O$	426										508
α -amyrin acetate	$C_{32}H_{52}O_2$	468										1660
β -amyrin acetate	$C_{32}H_{52}O_2$	468										552
sawamilletin	$C_{31}H_{50}O$	440										785
ursolic acid	$C_{30}H_{46}O_3$	456										110

Total												7921
Percent of total EOM												7.0
Plastic burning/fugitives												
ethyl 4-ethoxybenzoate	C ₁₁ H ₁₄ O ₃	194	17.0		0.74	0.13	32.0	148.0	3.6	22.0	17.5	
diphenyl sulfone (127-63-9)	C ₁₂ H ₁₀ SO ₂	218		0.50	2.30	2.40	465.0	2055	4.50	1320	19.5	
phenindione (83-12-5)	C ₁₅ H ₁₀ O ₂	222					98.0	39.0				
dodecyl acrylate	C ₁₅ H ₂₈ O ₂	240					182.0	8.0				
7,9-di- <i>tert</i> -butyl-1-oxaspiro[4.5]deca-6,9-diene-2,8-dione (82304-66-3)	C ₁₇ H ₂₄ O ₃	276	5.2									
diisobutyl phthalate	C ₁₆ H ₂₂ O ₄	278	99.0	0.10	1.09	0.41	310.0	270.0	6.2	220.0	4.8	150
dibutyl phthalate	C ₁₆ H ₂₂ O ₄	278	33.0	0.18	1.60	1.12	440.0	375.0	6.1	368.0	8.5	220
2,2,4-trimethylpentane-1,3-diol diisobutyrate	C ₁₆ H ₃₀ O ₄	286	1.80									
1,3,5-triphenylbenzene	C ₂₄ H ₁₈	306	0.3		0.82	0.54	4.3	4.0		5.0		
triphenyl phosphate	C ₁₈ H ₁₅ PO ₄	326							0.33		0.40	
dioctyl adipate	C ₂₂ H ₄₂ O ₄	370			0.13	0.12	240.0	476.0	0.40	920.0	1.11	
decamethylcyclopentasiloxane	C ₁₀ H ₃₀ O ₅ Si ₅	370				0.42	64.0	122.0	0.60		0.75	
di(2-ethylhexyl)phthalate	C ₂₄ H ₃₈ O ₄	390	52.0	1.85	0.52	0.82	182.0	338.0	14.0	460.0	40.3	

hexadecamethylcyclooctasiloxane	$C_{16}H_{48}O_8Si_8$	592				0.23	31.7	98.0	0.21		0.14	
Total			208.3	2.63	7.2	6.19	2049	3933	35.9	3315	93.0	370
Percent of total EOM			18.3	12.7	4.6	13.5	43.6	28.9	32.6	18.3	32.2	0.3
Saccharides (in soils)												
α -+ β -glucose	$C_6H_{12}O_6$	180	37.0									
inositol	$C_6H_{14}O_6$	182	21.0									
sucrose	$C_{12}H_{22}O_{11}$	342	198.0									
mycose	$C_{12}H_{22}O_{11}$	342	9.0									
cellobiose	$C_{12}H_{22}O_{11}$	342										225
Total			267.0									225
Percent of total POM			23.5									0.2
Pesticides												
metribuzin	$C_8H_{14}N_4OS$	214										26.0
hexachlorobenzene	C_6Cl_6	282										0.1
chlorpyrifos	$C_9H_{11}Cl_3NO_3PS$	349										0.7
endosulfans	$C_9H_6Cl_6O_3S$	404										3.0
Total												29.8
Total all compounds (EOM)			1138.1	20.67	155.4	45.87	4696.5	13601	110.1	18069	288.5	112723

^aAll concentrations have been corrected for background levels found in blanks.

^bCPI, carbon preference index: $(C_{21}+C_{23}+C_{25}+C_{27}+C_{29}+C_{31}+C_{33})/(C_{20}+C_{22}+C_{24}+C_{26}+C_{28}+C_{30}+C_{32})$ for *n*-alkanes.

^cCalculated by subtraction of non-biogenic *n*-alkanes (Simoneit et al., 1991).

Table 4: Comparison of concentrations of organic compound groups in PM of the Raipur region with other urban areas (ng m⁻³)

Compound class	Raipur ¹		Madras ²	Los Angeles ³	Santiago ⁴	Guangzhou ⁵	Beijing ⁶
	Mean	Range					
UCM	303	8-970	700	3700	20400	1600	4150
<i>n</i> -alkanes	150	0.5-712	160	57	5400	580	1140
PAHs	132	0.7-435	21	17	1890	110	260
<i>n</i> -alkanoic acids	1210	2-7116	400	284	3000	510	
<i>n</i> -alkanols	72	0.4-330	68		4000	120	
levoglucosan	722	0.3-3998	130	2100		310	
plasticizers	1072	7-3933	420			405	
UCM/ <i>n</i> -alkanes	2.02		4.4	65	65	2.8	3.6
<i>n</i> -alkanes/PAHs	1.14		7.6	3.4	2.9	5.3	4.4

¹This study excluding sample 17F; ²Fu et al. (2012); ³Rogge et al. (1993); ⁴Didyk et al. (2000);

⁵Bi et al. (2008); ⁶Zhou et al. (2008).

Highlights of this manuscript are listed below.

1. One of the very few studies on organic aerosol composition in Indian sub-continent
2. 14 compound classes containing 148 organic species reported
3. Multi-tracer concept of assessing organic compound sources in aerosol particles
4. Six possible major emission source categories of organic tracers in aerosol particles

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