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A Comparative Study of Air Pollution in Indian Cities

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Abstract Rapid and unplanned industrialization and urbanization has resulted in the deterioration of India's air quality according to air-quality monitoring carried out in seven major Indian cities in industrial and residential areas between 1995 and 2000. Suspended particulate matter (SPM) levels in Indian cities are in the range 50 to 550 μg/m^3. NO_x values are high in Delhi's residential areas, with values of 33 μg/m^3 in 1995 and 34.6 μg/m^3 in 2000, while in an industrial area values of 29.4 μg/m^3 were found in 1995, increasing to 33.7 μg/m^3 in 2000. SO_2 values are very high in Pune city, ranging from 43.3 μg/m^3 in residential to 43.69 μg/m^3 in an industrial area in 2000.

Keywords Anthropogenic activities · Air quality · Vehicular pollution · Industrial activities

The majority of Indian cities suffer from extremely high levels of urban air pollution, particularly in the form of suspended particulate matter SO_2 and NO_x. Levels of all pollutants are increasing due to industrial processes, agricultural activities, building construction, and road traffic, as well as reductions in natural habitat and other natural sources. The rapid and controlled growth of industry is blamed for this tremendous negative degradation in ambient urban air quality. The majority of SPM emissions to the atmosphere are attributable to natural and anthropogenic sources, such as suspended terrestrial dust, oceans, forest fires, and natural gaseous emissions (Morawska and Zhang, 2002). Earlier studies showed that SPM play an important role in global climate change, and regional cooling effects. Pollution sources can be divided into two types: mobile sources such as various vehicles and stationary sources such as municipal power plants, solid and liquid wastes, and residential combustion. Several industrial processes, such as iron and steel production, combustion of fossil fuels, biomass-burning power plants are major polluters in the cities (Laschober, 2004). It was found that less than 5% of vehicular particulate matter emissions were due to resuspension and road abrasion during a traffic tunnel study in Vienna, Austria. Air pollution is viewed as the most serious problem in many cities in India. The transport sector and human interference is held largely responsible for the air pollution in the cities with particulate matter being the most polluting agent. However, there are many other sources of particulate emissions, including large industrial plants, medium- and small-scale industries, refuse burning, household burning of biomass for cooking and heating, vehicular exhausts, resuspended road dust, construction, particles migrating from other regions, and naturally occurring dust. According to a European survey, the annual mineral dust load in SPM varies from 13 to 37% in Europe, (Ptaud, 2004; Van Dingenen, 2004). Southern Mediterranean countries experience several transient episodes (2 to 4 days) of transported Saharan dust each year, leading to levels exceeding 25 μg/m^3 and 10 to 15 μg/m^3 (Rodriguez, 2002; 2004).

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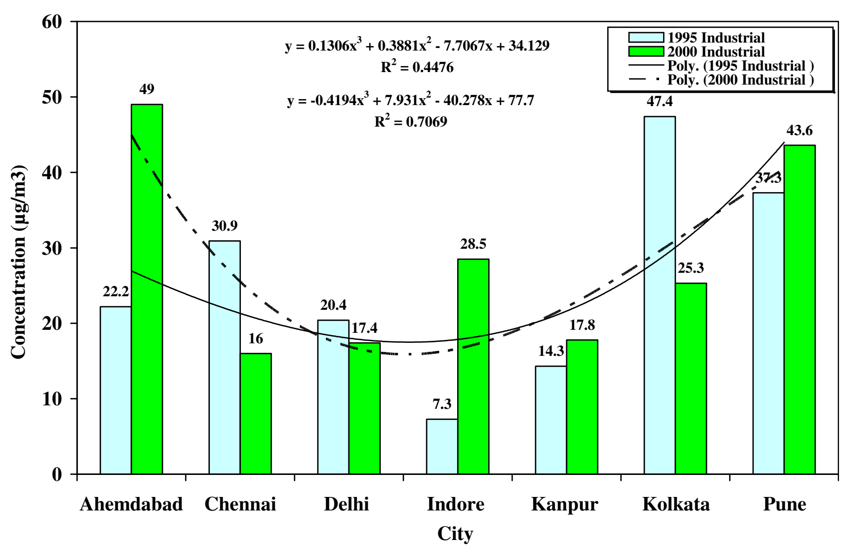
The health effects of particulates are strongly linked to particle size. Small particles, such as those from fossil-fuel combustion, are likely to be most dangerous, because they can be inhaled deeply into the lungs, settling in areas where the body's natural clearance mechanisms cannot remove them. SO_2 is emitted from coal combustion, high-sulfur oil, and diesel fuel. Local traffic and combustion have been identified chiefly based on high loadings of NO_x, or specific point source near the measurement site. (Hildemann, 1991; Swietlicki, 1996; Adachi and Tainosho, 2004) and have been proposed as potential markers for traffic-related emissions. Suspended particulate matter is a major urban air pollutant. Particulate levels in North America and Western Europe rarely exceed 50–400 µg/m^3, and major Indian cities are following similar paths. The present study uses methods based on chemical sources and their purity to give estimates, aimed at describing vehicular and human exposure as anthropogenic for selected air pollutants in major Indian cities. Nitrogen oxides (NO_x) and sulphur dioxide (SO_2) have been chosen as indicator substances to estimate urban air quality. Soot particles from vehicular exhaust react with other species in the ambient air to produce polluation. Sulphur dioxide (SO_2) has damaging effects on human health. These effects include premature death, as well as increases in the incidence of chronic heart and lung disease. New Delhi has three times higher levels of most hazardous particles that can penetrate a face mask (SPM, particulate matter (PM), respirable suspended particulate matter (RSPM), and PM_{10}) than Hong Kong. The city that comes closest to being classified as the most polluted in the world is Mexico City, depending on the season. Jakarta and Chongqing in south-west China follow close behind. These study findings were compared at one of the largest gatherings on air-quality management in Agra, India: Better Air Quality 2004. The main results of this event was the conclusion that there was a moderate to slight increase in pollution levels for SO_2, total suspended particulates (TSP) and fine particulates (PM_{10}); the results from these comparative studies are just above the WHO guidelines. Of all the cities surveyed, Singapore is the only one that falls within the safety limits for all key pollutants. It happens to be the only city in Asia that restricts the number of cars on the road by auctioning the right to own a vehicles. This contrasts with the case of New Delhi, where 10,000 cars are being added to the city's traffic every month.

Materials and Methods

In this study, only seven Indian cities were considered, but the reality is startling for the entire country. According to B. Sengupta, member-secretary of the Central Pollution Control Board, there are 53 cities in India that do not reach the relevant standards, and there are 24 critically polluted areas. Most of this pollution is attributed to uncontrolled growth of vehicle population, and poor inspection and maintenance systems in the study areas. The Central Pollution Control Board (CPCB) and State Pollution Control Board (SPCB) play a major role and apply monitoring methods for ambient air-quality criteria and pollutant levels in India's major cities. The Central Pollution Control Board (CPCB) provides annual average data on air pollution levels collected in the seven monitored cities. Concentrations of SPM, SO_2, and NO_x are shown for industrial and residential areas for the years 1995 to 2000 in Figs. 1 to 6. The sample was collected using a high-volume sampler at a constant flow rate of 1.5 m^3 per minute on Whatman paper number 41. The main reasons for choosing only seven cities in the whole of India was: (i) the availability of secondary data, (ii) rapid industrialization and urbanization activities at these locations, and (iii) climate and weather changes have occurred over the last 20 years in Indore city.

Fig. 1 Industrial SO_2 concentration comparison for seven cities in India



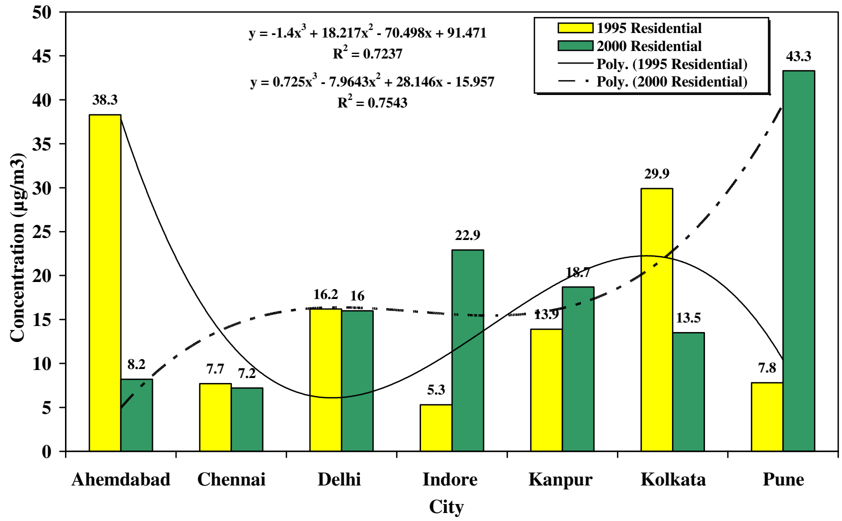


Fig. 2 Residential SO_2 concentration comparison for seven cities in India

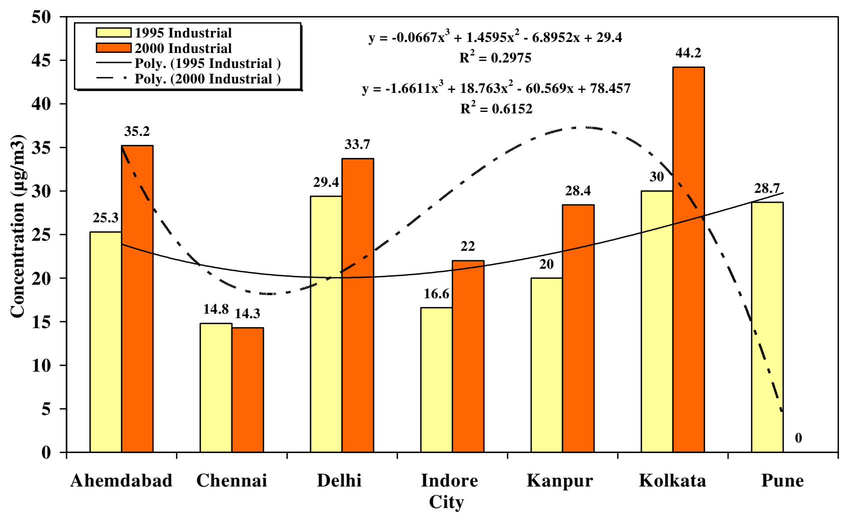


Fig. 3 Industrial NO_x concentration comparison for seven cities in India

The study carried out calculations of the ambient air-quality status with respect to total suspended particulate (TSP) and other related major pollutants and particulate matters.

Total suspended particulate matter was computed, comparing the before and after weights of Whatman papers. TSP is generally measured in µg/m^3 and the formulas used for its calculation are shown in Equations (1) and (2):

$$\mathrm{TSP} = \frac{W}{\mathrm{Va}} \times 100 \tag{1}$$

Where W = total dust load (mg)
V_a = volume of air sucked (m^3 per minute)

$$V_a = \frac{\left[\left(\left(\Delta H_2O \times \frac{T_a}{P_a}\right)^{1/2} - b\right)\right]}{m} \times t \tag{2}$$

Where H_2O = orifice water pressure drop (inches)
T_a = ambient temperature (K)
P_a = ambient pressure (mmHg)
b = intercept of the orifice calibration line (b = –0.01851)
m = slope of the orifice calibration line (m = 0.976162)
t = total time exposed in minutes

The total dust (TSP) load, W, i.e., the weight taken before and after the sampling was carried out, was measured using a microbalance (model A E 163), and the flow rate was measured with the help of a manometer. The suspended particulate matter was collected in the railway station of each city during the field work. The high-volume sampler was used for collecting the average TSP load on Whatman papers with an average constant flow rate of 1.5 m^3/min. The sampler ran during daytime (e.g., 06:00 18:00 hrs) on all the sampling days (three days per week).

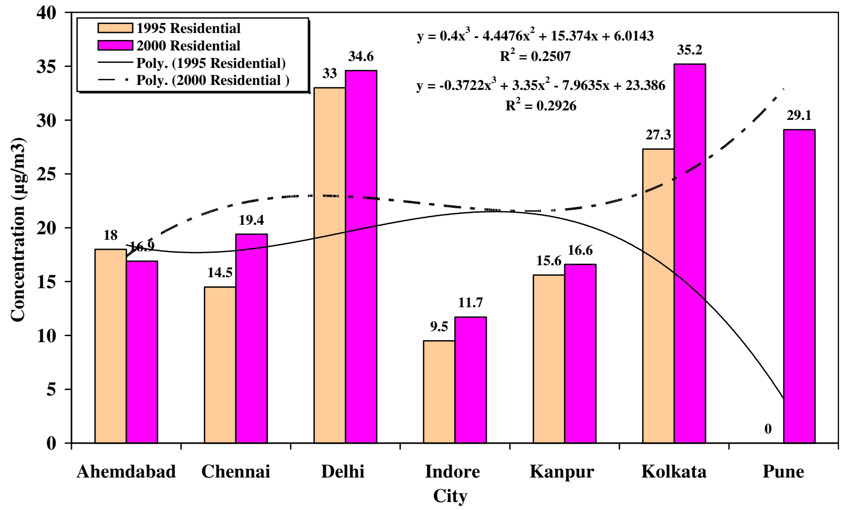


Fig. 4 Residential NO_x concentration comparison for seven cities in India

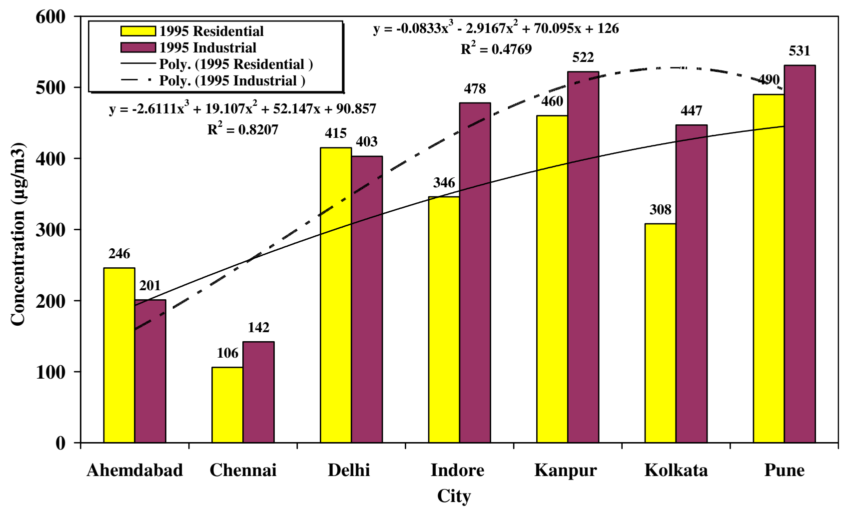


Fig. 5 Residential and industrial SPM concentration comparison for seven cities in India in 1995

The analyzed fortified sample recoveries were collected through CPCB and other official sources as secondary data and applied directly.

Results and Discussion

In Ahmedabad, an industrial city in Gujarat state, the SPM level shows an increasing trend due only to rapid urbanization and industrialization, ranging from 201 to 409 µg/m^3 during 1995 to 2000 in this industrial region. In residential areas the value was high, but no increasing trend was observed between the years 1995 and 2000. In Pune, an institutional educational and cultural city in south-west India, the 1995 data shows a high SPM concentration, but in 2000 it had decreased from 490 to 248 µg/m^3 in residential areas. This is because the Pune Municipal Corporation and Regional Transport Office banned auto (vikram) heavy vehicles from entering the residential and commercial areas of the city. Kanpur, the celebrated leather industry capital in the central part of Uttar Pradesh is also know for creating toxic and harmful contaminants that contribute to air pollution. There are large numbers of three wheelers (auto-vikram/tempo) with poor emissions efficiency serving the needs of commuter traffic. In the case of Delhi recent years have seen planning to improve fuel quality, and the use of compressed natural gas (CNG) has been undertaken in Delhi to prevent pollution problems. Chennai, a southern city and capital of Tamil Nadu, shows no such increasing trend over the study period. Indore, the biggest city in Madhya Pradesh, showed a slight increasing trend in residential areas, but was within the permissible standards in industrial areas. The comparative regression analysis and SO_2 concentration trends for industrial activities for seven major cities are shown in Fig. 1 for the years 1995 and 2000. The R^2 value for SO_2 concentration due to

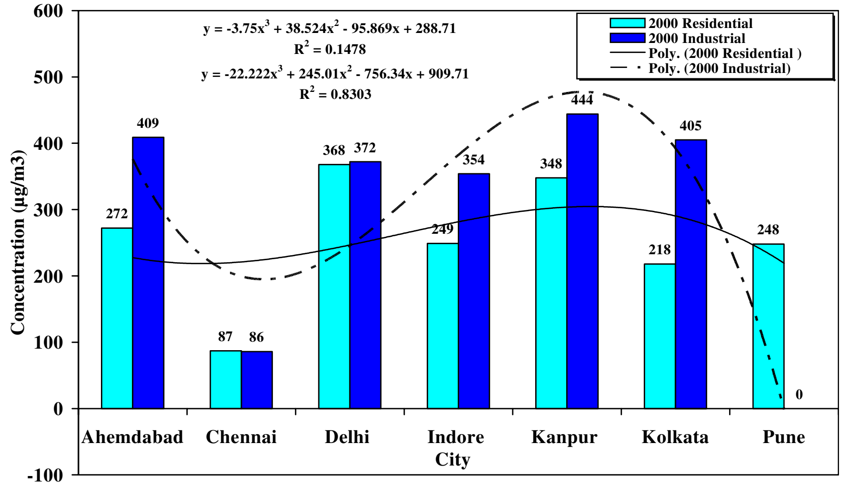


Fig. 6 Residential and industrial SPM concentration comparison for seven cities in India in 2000

industrial activity changed drastically over the last five years of the interval with $R^2 = 0.70$ (year 2000), being more significant than the value of $R^2 = 0.44$ in 1995. Similarly, the comparative SO_2 concentration regression and trend analysis was observed for residential areas in seven cities (Fig. 2) for the years 1995 and 2000. Here the R^2 value for residential activities shows only a very slight change in SO_2 concentration during the five years of the interval with $R^2 = 0.75$ (year 2000) being more significant than the value of $R^2 = 0.72$ in 1995.

Kolkata, a metropolitan city, shows the same trend as Indore. In 1995 Indore, Kolkata, Kanpur, Delhi, and Pune were the major polluted cities in the country amongst the seven studied. Between 1995 and 2000 the SPM values for Ahmedabad (201 to 409 µg/m^3), Kanpur (522 to 444 µg/m^3), and Kolkata (447 to 405 µg/m^3) changed as shown in Figs. 5 and 6. These data show that the pollution reduction is only occurring in residential areas but levels of pollutants in industrial areas are nearly the same. In Pune, SO_2 levels were very high in the year 2000: 43.3 µg/m^3 (residential areas) and 43.69 µg/m^3 (industrial areas). Annual average reductions in SO_2 levels are because oil companies have started to supply diesel containing 0.05% sulfur and petrol with a benzene content of 1% in the city areas. In Indore no such action has been taken recenltly. In residential areas in Indore SO_2 levels increased from 5.3 to 22.9 µg/m^3 from 1995 to 2000, and industrial areas follow the same trends during this period. In Ahmedabad SO_2 value ranges have changed from 38.3 µg/m^3 (residential 1995) to 8.2 µg/m^3 (residential 2000) and 22.2 µg/m^3 (industrial 1995) to 49 µg/m^3 (industrial 2000). This increment is due only to bad city planning, three wheelers, heavy vehicle, and use of old vehicles. In Delhi use of CNG is under controlled. The comparative regression analysis and NO_x concentration trends for industrial activities for seven major cities are shown (Fig. 3) for the years 1995 and 2000. The R^2 value for industrial activities shows a drastic change in NO_x concentration over the last five years of the study interval with $R^2 = 0.61$ (year 2000) being more significant than the value of $R^2 = 0.29$ in 1995. Similarly, the comparative NO_x concentration regression and trend analysis has been observed for residential areas in seven cities for the years 1995 and 2000 (Fig. 4). In this regard the R^2 value for residential activities has shown a minor change in NO_x concentration over the five years of the study interval: the valuen of $R^2 = 0.29$ in 2000 is still more significant than the value of $R^2 = 0.25$ in 1995.

In Kanpur the SO_2 concentration has been also controlled due to appropriate city planning. NO_x levels are very high in Delhi residential areas: 33 µg/m^3 in 1995 and 34.6 µg/m^3 in 2000, while in industrial areas it was found to be 29.4 µg/m^3 (1995) to 33.7 µg/m^3 (2000). Ahmedabad's industrial regions show higher values of NO_x than the other cities in the study time period. To address this issue, it is necessary to remove older vehicles from the city and residential areas, and replace petroleum with liquid petroleum gas (LPG) and solar energy fuels or chargeable battery vehicle. Vehicular pollution is contributed by both intra- and inter-city vehicles. In India vehicle inspection and maintenance (I & M) systems are weak and it is felt that no one pays attention to control measure activities or equally to the introduction of stricter emission norms for new vehicles, which would help in controlling toxic air pollution. The comparative regression analysis and SPM concentration trends for residential and industrial activities for the seven major cities studied are shown in Fig. 5 for the year 1995. The R^2 value for industrial activities has shown a drastic change in SPM concentration during the last five years of the study interval with $R^2 = 0.82$ (industrial) being more significant than the value of $R^2 = 0.47$ for residential areas in 1995. Similarly, the comparative SPM concentration regression and trend analysis for residential and industrial areas in the seven studied cities for the year 2000 are shown in Fig. 6. Thus the R^2 value for industrial activities has shown an extreme change in SPM concentration over this five-year interval with the $R^2 = 0.83$ value being more significant than that in the residential activities (R^2 = 0.14 in 2000). Highways contribute to the maintenance of ambient air quality in cities. The government has planned a number of national and state highways that are reducing the fuel consumption, traffic load, and local air pollution, plus the abatement of coal-fired power plants, a large motor vehicle population, chemical and cement industries located within the city, which contribute most to the SPM, SO_2, NO_X levels in Delhi and Pune as well as in Indore, while in Kanpur leather industries are producing higher SPM concentrations according to the present study.

Hence, using Equations (1) and (2) a range of tasks may be performed and applied. Particulate matter has followed a downward trend in Delhi over three years because of the success of the CNG program. Experts feel that this is not enough and that, if a city like Delhi deals only with the technology of vehicles and fuels, the effects will quickly be nullified. The growing number of vehicles and poor inspection and maintenance of in-use vehicles can completely undo the effects of, say, a clean fuel like CNG. Emitted industrial or vehicular pollution and carbon is black like coal, but our vision for the planet Earth must be green, neat and clean… forever… through clean-air initiatives. However, the decreasing trends highlighted in this study show that successful air pollution control measures can be implemented. Although particulate matter remains at harmful levels for health, more-stringent studies can prove that ambient air-quality management can work in Asia.

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References

Adachi K, Tainosho Y (2004) Characterization of heavy metal particles embedded in tire dust. Environ Int 30:1009–1017

Hildemann LM, Markowski GR, Cass GR. (1991) Chemical-Composition of Emissions from Urban Sources of Fine Organic Aerosol. Environ Sci Technol 25:744–759

Laschober C, Limbeck A, Rendl J, Puxbaum H. (2004) Particulate emissions from on-road vehicles in the Kaisermuhlen-tunnel (Vienna, Austria). Atmos Environ 38:2187–2195

Morawska L, (Jim) Zhang J. (2002) Combustion sources of particles. 1. Health relevance and source signatures. Chemosphere 49:1045–1058

Putaud J, Raes F, Van Dingenen R, Brüggemann E, Facchini M-, Decesari S, Fuzzi S, Gehrig R, Hüglin C, Laj P, et al. (2004) A European aerosol phenomenology 2: chemical Characteristics of particulate matter at kerbside, urban, rural and background sites in Europe. Atmos Environ 38:2579–2595

Rodriguez S, Querol X, Alastuey A, Viana M, Alarcon M, Mantilla E, Ruiz CR. (2004) Comparative PM10–PM2.5 source contribution study at rural, urban and industrial sites during PM episodes in Eastern Spain. Sci Total Environ 328:95–113

Swietlicki E, Puri S, Hansson H, Edner H. (1996) Urban air pollution source apportionment using a combination of aerosol and gas monitoring techniques. Atmos Environ 30:2795–2809

Van Dingenen R, Raes F, Putaud J, Baltensperger U, Charron A, Facchini M-, Decesari S, Fuzzi S, Gehrig R, Hansson H. (2004) A European aerosol phenomenology 1: physical characteristics of particulate matter at kerbside, urban, rural and background sites in Europe. Atmos Environ 38:2561–2577