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A comparison of levels and causes

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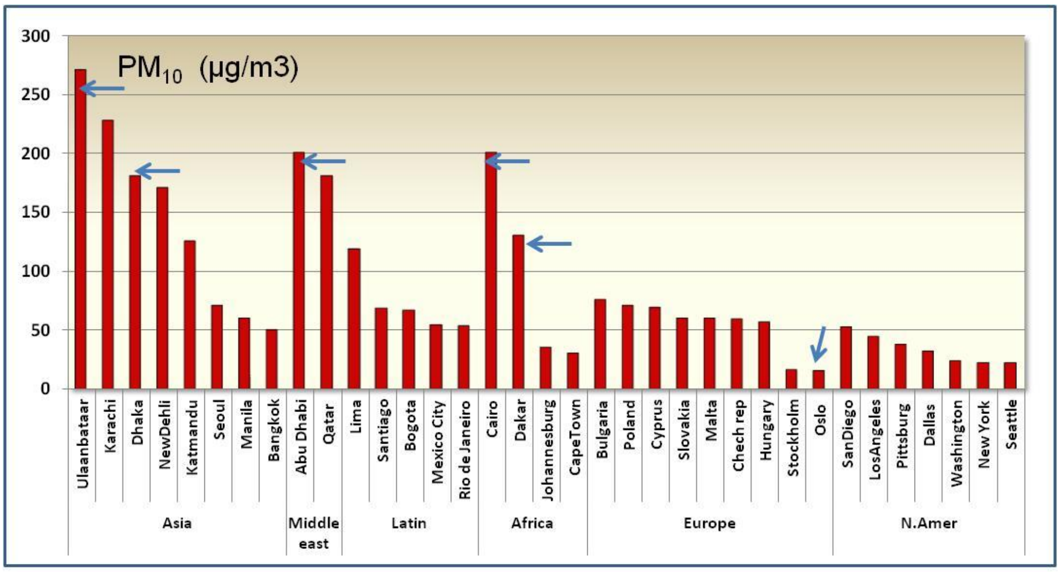

The 4th International WeBIOPATR WORKSHOP AND CONFERENCE, PARTICULATE MATTER: RESEARCH AND MANAGEMENT
WeBIOPATR2013, Belgrade 2 – 4 October 2013

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MEASUREMENTS OF PARTICLES IN URBAN AREAS AROUND THE WORLD, A COMPARISON OF LEVELS AND CAUSES

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ABSTRACT

Airborne particulate matter varies widely in its physical and chemical composition, source and particle size. PM_{10} particles (the fraction of particulates in air of very small size (<10 µm)) and $PM_{2.5}$ particles (<2.5 µm) are of major current concern, as they are small enough to penetrate deep into the lungs and so potentially pose significant health risks. The principal sources of airborne PM_{10} and $PM_{2.5}$ matter in urban areas are mainly from road traffic emissions, particularly from diesel vehicles. However, also, windblown dust, re-suspended dust from the surface, emissions from various industries, power plants, agricultural activities and fires are also causing high particulate matter (PM) concentrations. As presented in this paper the main sources strongly vary from one region to another.

Data from a few selected urban monitoring programmes have been selected for this presentation, mainly based upon studies performed by NILU. References to other investigations performed in similar urban areas have also been included. The presentation covers a range of PM levels from the relatively clean capital of Norway, Oslo, to the highly polluted cities such as Dhaka, Bangladesh and Ulaanbaatar, Mongolia. Some of the causes to the high PM concentrations may be easy to track, while other are based on rather complicated compositions. In data collected from the Middle East cities such as Abu Dhabi and Cairo, windblown dust from the desert areas is causing the highest PM_{10} concentrations, while brick factories in Dhaka seem to be the main source for PM_{10} in Dhaka. In some areas there is also a clear regional component of smaller particles as demonstrated from satellite images. In European urban areas traffic seems to be the main source for PM.

1. INTRODUCTION

In terms of potential to harm human health, PM is one of the most important pollutants as it penetrates into sensitive regions of the respiratory system and can lead to health problems and premature mortality. PM in the air has many sources and is a complex heterogeneous mixture whose size and chemical composition change in time and space, depending on emission sources and atmospheric and weather conditions.
PM in the atmosphere consists of:

- Primary particles emitted directly;
- Secondary particles produced as a result of chemical reactions involving so-called PM precursor gases: SO_2, NO_X, NH_3 and volatile organic compounds (VOC).

The measurements of airborne particles are normally grouped into two categories:
- "Inhalable coarse particles," such as those found near roadways and dusty industries, are larger than 2.5 micrometers and smaller than 10 micrometers in diameter.
- "Fine particles," such as those found in smoke and haze, are 2.5 micrometers in diameter and smaller. These particles can be directly emitted from sources such as forest fires or anthropogenic combustion sources, or they can form when gases emitted from power plants, industries and automobiles react in the air.

A large number of deaths and other health problems associated with particulate pollution was first demonstrated in the early 1970s by Lave et.al (1) and has been reported many times since. PM pollution is estimated to cause 22,000-52,000 deaths per year in the United States (from 2000) (2) and is assessed to have contributed to ~370,000 premature deaths in Europe during 2005 (3).

NILU –Norwegian Institute for Air Research has been undertaking measurements of airborne PM_{10} and $PM_{2.5}$ in several urban areas around the world. Some of the results from measurements of PM are presented in this paper in order to demonstrate regional differences and explain levels and causes. The presentation starts with relatively clean areas such as Norway and Europe, and continues with some of the most polluted urban areas in the world.

2. A "CLEAN" CITY - OSLO, NORWAY

Air quality monitoring in Oslo is carried out in a cooperation of the Norwegian Agency for Urban Environment and the Public Roads Administration. A network of 11 monitoring stations across the city monitor pollutants such as nitrogen dioxide (NO_2), particulates (PM_{10}, $PM_{2.5}$), ozone (O_3), benzene, sulphur dioxide and carbon monoxide. Nine of these sites cover PM_{10} (4).

The European AQ limit values are being used in Norway. This states that the daily average concentration of PM_{10} not to be exceeded more than 35 times per calendar year.

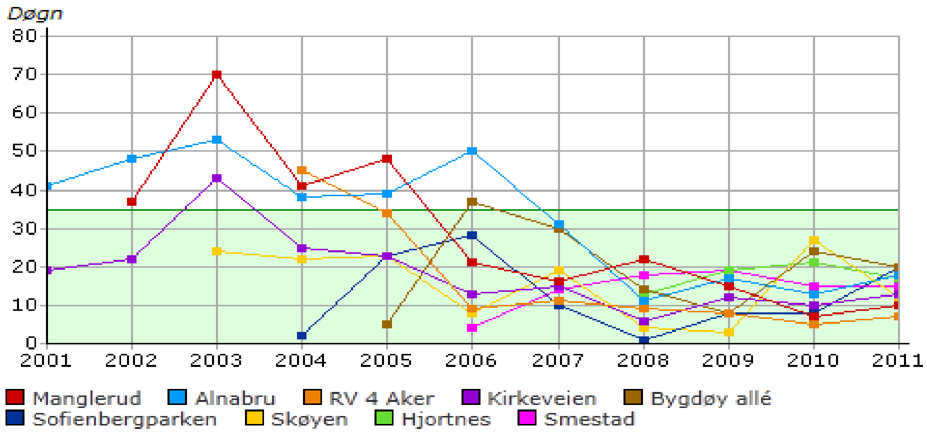

Figure 1. Number of days per calendar year of PM_{10} concentrations above 50 µg/m^3 at 9 stations in Oslo, 2001-2011 (5).

Figure 1 shows that before 2007 the limit values were not met at some of the 9 monitoring stations in Oslo. After 2007, there have been no violations of the PM_{10} EU limit value in Oslo.

Typical daily average PM_{10} concentrations in Oslo during the year 2012 were between 15 and 37 µg/m^3. The annual average $PM_{2.5}$ concentrations were observed between 8 and 14 µg/m^3 (5). This is a story quite different from what we see in other large cities of the world. The main sources for the PM levels in Oslo are traffic emissions and in cold periods, with surface inversions, wood burning (6).

3. PARTICULATE MATTER IN EUROPE

Fixed sampling points for PM measurements in Europe are situated at four types of sites:

- traffic-related locations;
- urban (and sub-urban background) (non-traffic) locations;
- industrial locations (or other less defined locations);
- rural background sites.

The total number of monitoring stations in Europe (EU + non EU countries) reporting PM_{10} was 3040 stations in 2012. 997 stations reported $PM_{2.5}$ concentrations (7).

In 2010, the PM_{10} 24-hour limit value (to be met by 2005) was exceeded at 33 % of traffic sites, 29 % of urban background sites, and 17 % of 'other' sites (mostly industrial) and even at 14 % of rural sites within the EU (8).

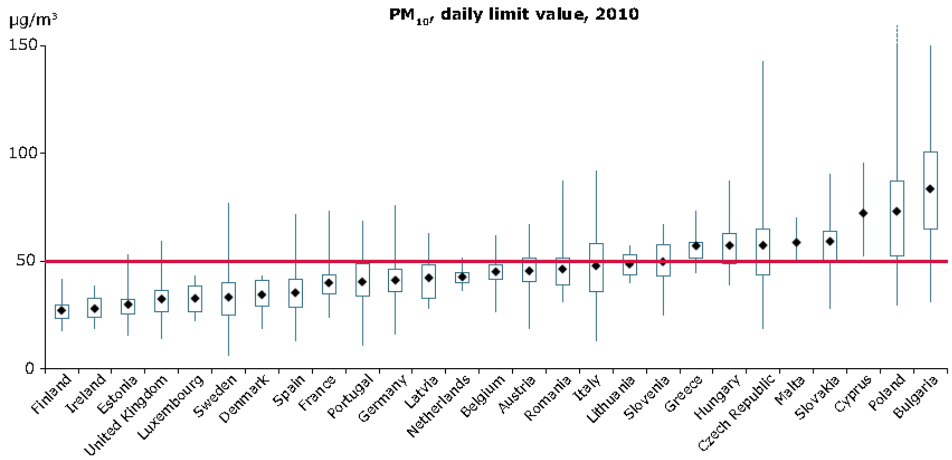

Figure 2. PM_{10} concentrations measured in EU countries 2010 (in µg/m^3). The dot indicates the 36th highest daily mean, the vertical bar the range of concentrations at all station types officially reported by the EU Member States The horizontal line indicates the EU limit value (9).

The annual average concentrations of PM_{10} in European cities varied from 25 to 80 µg/m^3, while the average $PM_{2.5}$ concentrations observed in 2010 was between 8 and 30 µg/m^3.

Emissions of primary PM_{10} and $PM_{2.5}$ decreased by 14 % and 15 % respectively in the EU and in the EEA-32 countries between 2001 and 2010 (EEA, 2013). The small reduction observed in ambient PM concentrations reflects the slowly declining emissions of primary PM and NH_3 (9).

Twenty one per cent of the EU urban population lives in areas where the EU air quality 24-hour limit value for particulate matter (PM_{10}) was exceeded in 2010. For EEA-32 countries the estimate is 41 %.

EU urban population exposure to PM_{10} levels exceeding the WHO Air Quality Guideline (AQG) (10) is significantly higher, comprising 81 % of the total urban population in 2010.

4. AFRICA

Large differences in reported PM_{10} concentrations are found in Africa. Well-developed cities such as Cape Town and Johannesburg in South Africa report rather low annual average PM_{10} concentrations of around 30–40 µg/m^3. In the greater Cairo area, however, the typical annual average concentrations in urban and residential areas ranged from 60 µg/m^3 to 200 µg/m^3. In industrial areas concentrations measured were between 200 µg/m^3 and 500 µg/m^3 (11).

Cairo, Egypt

Suspended dust is considered a major air pollution problem in Egypt. PM_{10} concentrations can reach daily average levels of more than 4 to 14 times the Air Quality Limit value for Egypt of 70 µg/m^3 (12). The highest concentrations are normally observed in the streets of Cairo, and in industrial areas.

Measurements of PM performed in Cairo from 2000 to 2004 indicated that annual average PM_{10} concentrations in urban areas ranged between 100 and 300 µg/m^{3}as shown in Figure 3.One type of sources, typical for Egypt, was the open air waste burning, which was observed in several areas of Egypt. This type of burning may have considerable health impact to the population. Especially in the Nile Delta it is anticipated that the toxic compounds associated with the PM concentrations may be deposited in the farming areas giving rise to large exposure to the population consuming vegetable and crops grown in these areas.

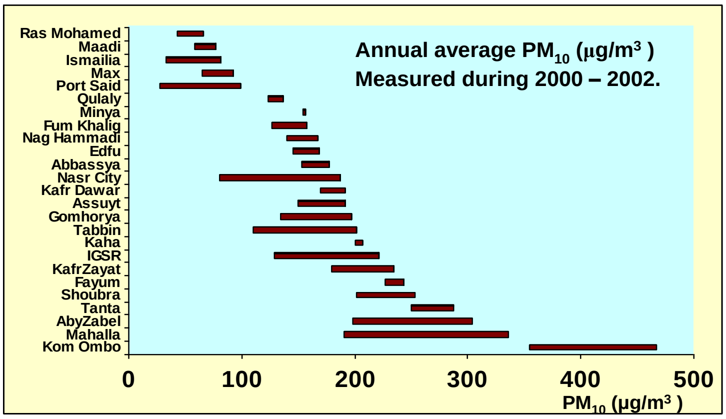

Figure 3. Annual average concentrations of PM_{10} measured at 25 sites in Egypt, 2000-2002 (11).

Towns in arid areas with surrounding deserts frequently receive a considerable amount of dust consisting of wind-blown fine sand. An early study of suspended dust in Cairo revealed that the typical background PM_{10} concentrations averaged 45 to 65 $\mu g/m^3$ during average wind speed conditions (13, 14). It has also been found based on continuous measurements over several years that the daily background level seems to be around 70 $\mu g/m^3$, which is equivalent to the Air Quality Limit values given by the Law no. 4 of Egypt (12). These levels can be found also in areas where local anthropogenic sources do not impact the measurements (15, 16).

It has also been found based on a source attribution study that a major contribution to the PM_{10} concentrations included geological material, mobile source emissions and open air burning (17). Even inside the urban area of Cairo it was found that large fractions of the PM_{10} might be attributed to fine sand particles. During air pollution episodes, however, the burning of agricultural and other waste also contributed. In the city centre during prevailing wind from north a large fraction of the fine particle mass was produced by oil combustion.

The air pollution episodes of Cairo (later called the “black clouds”) were first identified by measurement data in October 1997 (18). These episodes are characterized by low winds, high pressure conditions and elevated inversions. These elevated inversions were established in the subsiding air mass above the Delta and the greater Cairo area.

Air pollution episodes seem to occur repeatedly every year around the month of October. Satellite pictures have also revealed that during these days fires were observed over the eastern part of the Delta (19). Wind trajectory analyses also indicated transport of air from the northerly directions towards Cairo (20). During these episodes hourly PM_{10} concentrations often were recorded above 500 $\mu g/m^3$.

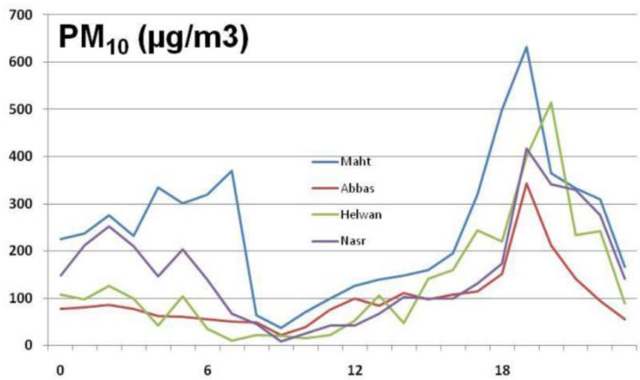

Figure 4. Concentrations of PM_{10} at four stations in greater Cairo area on 3 October 2009.

On 3 to 6 October 2009 very high concentrations of PM_{10} were recorded at sites in the Delta area, at Abbaseya and Nasr City in Cairo and later also in Helwan south of Cairo. The winds were from the north at

2 m/s at night and in the morning hours. A cloud of particles passed Cairo during night time, concentrations decreased at day time and raised again after sunset to reach Helwan, south of Cairo, two hours later at 20:00 hrs. The peak concentrations in the early evening reached 400 to 600 µg/m^3.

Studies of PM in Cairo and in other areas of Egypt have revealed that there is a need to address garbage burning and industrial emissions. Inside the urban areas also transportation measures are important for future attainment.

Dakar, Senegal
NILU designed and established an air quality monitoring programme in Dakar, Senegal. As a part of a screening study, PM_{10} and $PM_{2.5}$ were monitored in one heavily trafficated street. Some samples of PM_{10} and $PM_{2.5}$ were analysed for trace elements, elemental and organic and water-soluble components to provide knowledge on the chemical composition of the particulate matter.

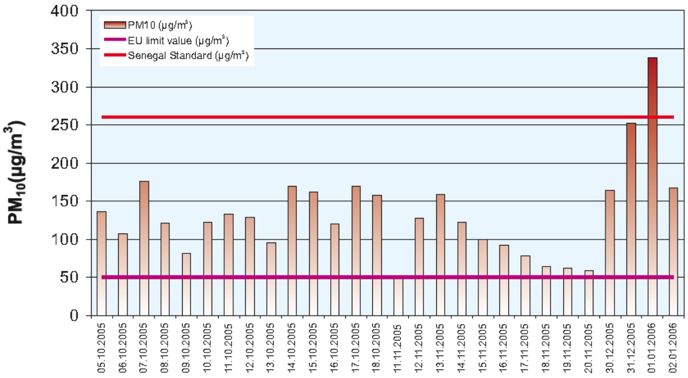

Figure 5. Daily PM_{10} concentrations at an urban traffic site in Dakar, Senegal, Oct 2005 (22).

The daily concentrations of PM_{10} exceeded the daily EU limit value (21) every day of the sampling period (22). The PM_{10} levels ranged from 52 to 338 µg/m^3, with an average value of 133 µg/m^3. The $PM_{2.5}$ levels in Dakar were also high compared to concentration levels observed in other urban areas in the world (23). The average $PM_{2.5}$ concentration in the 4 weeks sampling period was 38 µg/m^3.

The analysis of trace elements identified no exceedances of EU limit and target values (21) and WHO guideline values (10, 23).

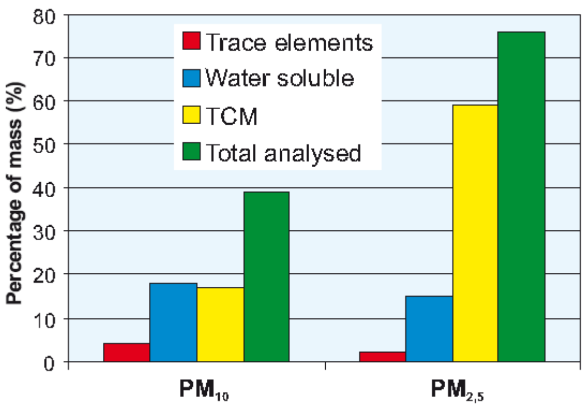

Figure 6. The chemical composition of particles was analysed to determine their origin and potential health impact. Elemental Carbon/Total Carbon ratios (0.30-0.36) show that carbon originates mainly from combustion sources, which means greater health impact.

The elemental carbon/total carbon (EC/TC) ratios indicate that the fine particles in Dakar originate mainly from combustion sources. The average percentage of water-soluble components was 18% for PM_{10} and 15% for $PM_{2.5}$. The measured daily averages of PM_{10} concentration were 2 to 7 times higher than the EU limit values and the daily averages of $PM_{2.5}$ were also high (22). A large fraction of the $PM_{2.5}$ originates from combustion sources, while a large part of the PM_{10} coarse fraction is soil dust and sea salts. This screening study shows that the major air pollution source in Dakar is traffic, although industry is also an important source in some areas. The car fleet is old, not well maintained and contain a number of micro buses run on bad quality diesel.

5. MIDDLE EAST

Abu Dhabi, United Arab Emirates

A number of air quality monitoring stations, owned by the Environment Agency – Abu Dhabi (EAD), are being operated throughout the Abu Dhabi Emirate. The monitoring network, as well as equipment and quality assurance are being operated and maintained by NILU (24).

The Abu Dhabi air quality monitoring network has shown that the air quality in the Emirate of Abu Dhabi is generally good. However, it experiences occasional exceedances for some air pollutants especially PM. One of the main sources is linked to dust from the desert areas and to the occurrence of sand storms. These "natural" sources normally give rise to the highest concentrations of suspended particles. Also particulate matter from combustion sources such as traffic and industries can be identified in the data based on chemical analyses.

The PM_{10} daily average limit value of 150 µg/m^3 was regularly exceeded every year since 2010 at all monitoring stations in Abu Dhabi. Exceedances of the PM_{10} limit value varied between 33% and 47% of the measurement time in 2012. In the urban area of Abu Dhabi, exceedances occurred between 33% and 39% of the time at the different monitoring sites (25).

While the monthly average concentrations of PM_{10} normally ranged between 100 and 200 µg/m^3 at the different monitoring stations it has been seen every year that the concentrations of PM_{10} raised to hourly averages of between 800 and 1200 µg/m^3 (daily up to 800 µg/m^3) during periods with sand storms (dust clouds) sweeping over the area. This phenomenon is similar to what is observed over Cairo.

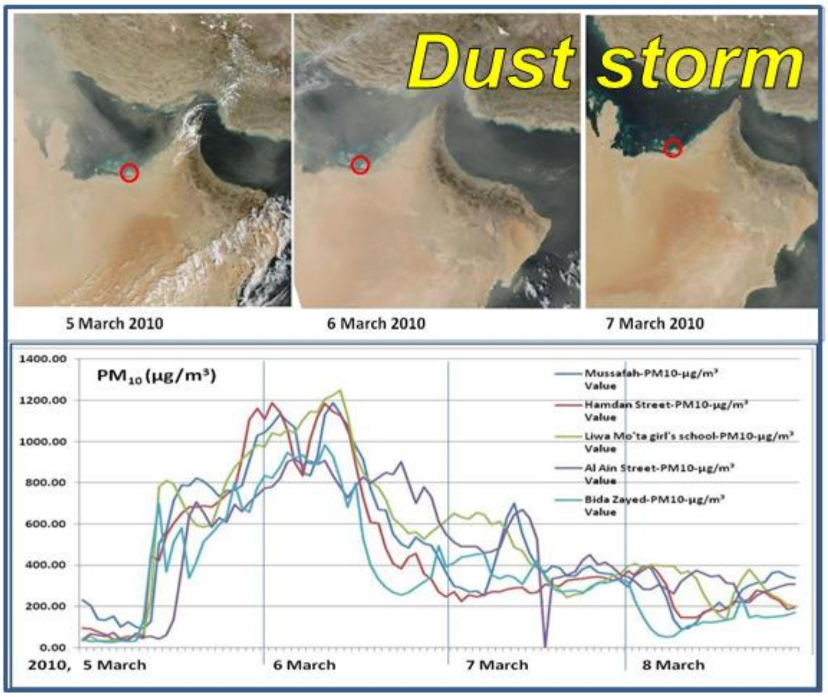

Figure 7. A dust storm sweeping across UAE on 6 March 2010 leading to PM_{10} concentrations exceeding 1000 µg/m3 during the passing of the cloud.

News media in Abu Dhabi published in June 2013 information that asthma sufferers will now be able to monitor which areas to avoid during days of dust storms through *the www.adairquality.ae* website (26). The website provides real time data on air quality in the Emirate. "Our research indicates that the key cause of poor air quality in Abu Dhabi is due to a natural cause; desert dust storms. So, while keeping an eye on these dust storms, we are also controlling and regulating industrial air discharges" (26).

6. ASIA

Dhaka, Bangladesh

Air pollution and health have been a major focus in Bangladesh in recent years. In Dhaka air quality monitoring since April 2002 has shown that concentrations of $PM_{2.5}$ and PM_{10} represent problems (27).

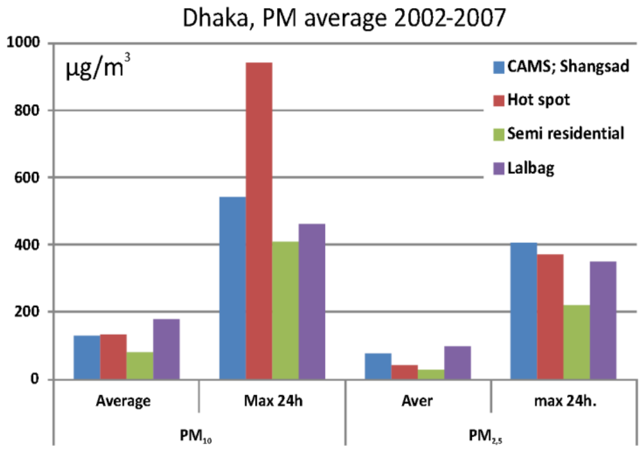

Figure 8. Six year average and 24-h average maximum concentrations measured at 4 sites in Dhaka from 2002 to 2007. (27)

The highest 24-hour average PM_{10} concentration in Dhaka from 2002 to 2007, as presented in Figure 8, ranged between 400 and 940 µg/m^3, while the highest $PM_{2,5}$ concentrations were observed between 200 and 400 µg/m^3. The PM_{10} average concentrations for the whole period in Dhaka were between 80 and 180 µg/m^3.

Although local sources of air pollution in Dhaka city are quite strong, there are also high PM concentrations originating from distant sources especially during the dry season. Source receptor modelling has indicated that apart from local contribution of pollution sources, there are also regional influences on fine PM levels in Dhaka (28).

NILU is working with the Clean Air and Sustainable Environment Project, Department of Environment (CASE/DOE) on an institutional building project financed by NORAD. As part of this project NILU performed two screening studies aimed at identifying the air pollution problem (29).

The screening studies were performed during the winter season because this is the dry period where air pollutant concentrations will be at their peak. The range of average PM concentrations from the rainy summer season till the dry winter season varies with a factor of ten (average PM_{10} summer: 20 to 100 µg/m^3, winter: 200 to 1000 µg/m^3) (30). The winter season is also the time of the year in which thousands of brick kilns are being operated in the areas surrounding Dhaka. Emissions from these kilns are suspected to be the single greatest local contribution to the air quality problems in Dhaka. Other possible sources of air pollution include re-suspension of road dust from traffic, open air burning, residential cooking, and industrial sources such as cement manufacturing and metal smelting. Regional haze south of the base of Himalaya in India including agricultural burning as well as the use of high-sulphur coal also contribute significantly to local concentrations of fine particles.

A total of 23 grab samples of PM_{10} and $PM_{2.5}$ (30 minute averages) were taken at different hours of the day and at different locations over the city of Dhaka during the month of February 2011 (31). The average 30-minute concentration values ranged from 258 µg/m^3 to 2039 µg/m^3, with an average concentration of 613 µg/m^3 for all sites. The average $PM_{2.5}$ concentration from the 23 grab samples taken was 439 µg/m^3 for all sites. The average concentrations for each type of micro environment are presented in Figure 9. Measurements were also collected at one site over a 24 h period, indicating that the average concentrations of PM in Dhaka exceeded national and international air quality limit values both day and night during the winter season.

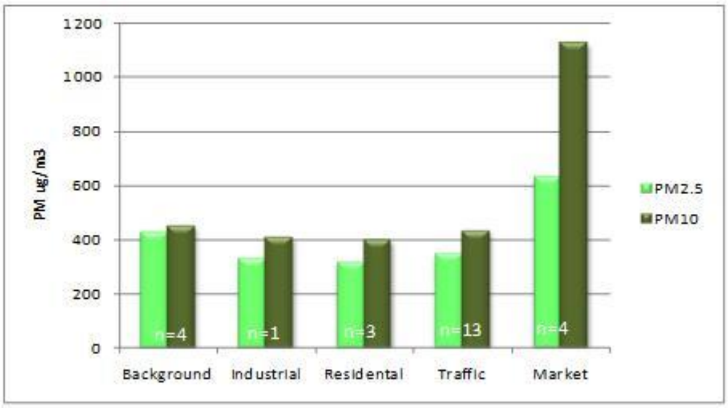

Figure 9. Average PM_{10} and $PM_{2.5}$ concentrations as measured in four different micro environments; background, industrial, residential, traffic and at a busy market.

Simultaneous measurements of $PM_{2.5}$ and PM_{10} made it possible to study the ratio of the size fractions. The $PM_{2.5}/PM_{10}$ ratio of the concentrations for the samples ranges from 0.4 to 0.9, and the average for all sites was 0.8. This indicates that during the winter season PM levels in the atmospheric air are dominated by $PM_{2.5}$ fraction and smaller, and combustion sources are major contributors to the particulate air pollution in Dhaka city. It also indicated that the regional component of aerosols may play an important role.

In order to study the regional haze issue, satellite data were analyzed for Aerosol Optical Depth (AOD). This approach gave us a synoptic view of regional spatial patterns of PM beyond the boundaries of Bangladesh. While PM concentrations cannot yet be retrieved directly from satellite data, AOD is an operational product derived for a wide variety of satellite sensors and is closely linked to PM concentrations as seen in Figure 10. This empirical relationship between AOD and PM has been applied in the past in order to map PM from satellite images. Available AOD data was collected every day during the study period (31).

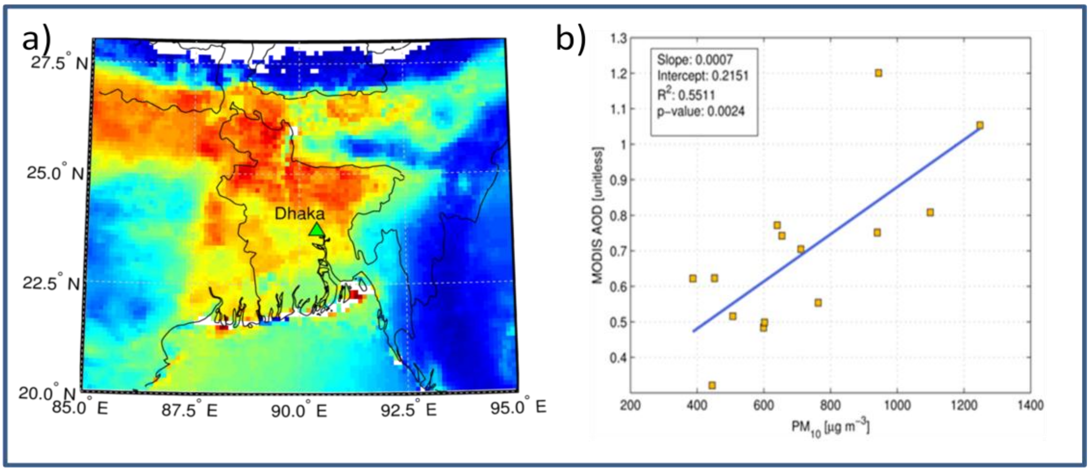

Figure 10. a) Mean MODIS-derived AOD over Bangladesh for the study period between 31 January 2011 and 15 February 2011. b) In situ observations of PM_{10} plotted against MODIS AOD. AOD was linearly interpolated to provide a matchup at the same time at which the in situ samples were taken. A few in situ samples had to be removed due to contamination by a local fire (32).

The Greenhouse Gas and Air Pollution Interactions and Synergies model (GAINS) (33) was used to perform a top-down assessment including PM emissions in Dhaka (34). The majority of PM emissions are originating from the brick production industry. However, it was surprising that residential cooking stoves also show a large contribution, making up almost 10 times the PM contribution compared to the transport related specific sectors. So it can be generally concluded that PM emissions come from the industry and residential sectors (industrial sources are slowly taking over as the dominant source sector), primarily from brick kiln production, and some cement production and from residential cooking stoves (residential sector).
A future projection of emissions indicated that there is a high reduction potential, making it possible to reduce up to 1/3 of the total PM emissions at relatively low costs per ton.

Ulaanbaatar, Mongolia

Ulaanbaatar is affected by serious air pollution caused by coal and wood burning stoves used for heating and cooking. The new market economy of the country and its very cold winter seasons has led to the formation of Ger districts, where 60% of the coldest capital city in the world's population resides. The resulting air pollution problem is characterized by very high concentrations of airborne particles.

Daily concentrations in Ulaanbataar are much higher than Mongolian or international standards. The extremely episodic nature of the PM pollution, which is caused by the combination of Ger heating practices and the meteorological situation, causes extremely high short-term PM concentrations. The highest hourly and daily concentrations may represent the highest urban scale PM levels anywhere, with hourly PM_{10} concentrations approaching 2500 µg/m^3 or higher and daily averages above 1000 µg/m^3 in the most polluted parts of the city, i.e. the Ger districts (35). The seasonal average particulate matter concentrations have been recorded as high as 279 µg/m^3 during the winter. To put this in perspective, the World Health Organization's recommended that the annual average PM_{10} level should not exceed 20 µg/m^3. This means that Ulaanbaatar's seasonal PM_{10} levels have been recorded 14 times higher than what is recommended as an annual mean.

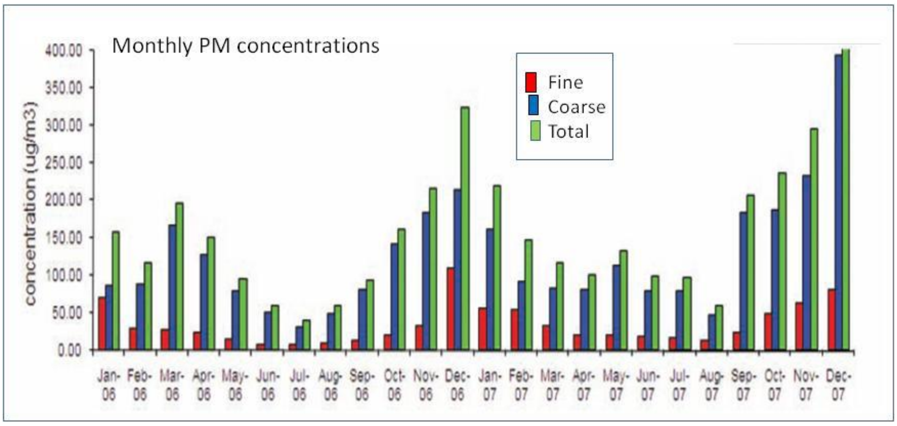

Figure 11. Seasonal variation of PM concentrations in Ulaanbaatar, Mongolia (32).

The calculated exposure of the population to $PM_{2.5}$ in the city was found to be, on average throughout the year, 10 times higher than the Mongolian Air Quality Standards and 6-7 times higher than the most lenient World Health Organization targets (36).

Ulaanbaatar's air pollution comes from many sources; dust from the desert, unpaved roads and open soil surfaces, lack of vegetation, ash and emissions from coal stoves, power plants, boilers, and vehicles. However, coal and wood burning for cooking and heating by the 175,000 households in Ger areas contributes to the severity of air pollution in wintertime. A source receptor study for 2007 showed that 40% of the $PM_{2.5}$ concentrations came from combustion (37). The PM concentrations during the summer season are much lower than in winter (38).

A Clean Air Project in Ulaanbaatar aiming to enable consumers in the Ger areas to improve the air quality has been launched in order to access heating appliances producing less particulate matter emissions and to further develop selected medium-term particulate matter abatement measures in coordination with development partners (39).

Ulaanbaatar has during the winter months exceeded the PM concentrations measured in Northern China's most polluted cities. Some cities in Northern China and South Asia also had annual average concentrations above 200 µg/m^3 until a few years ago.

Ho Chi Minh City, Vietnam

Ho Chi Minh City (HCMC), Vietnam is not the most polluted city in Asia when PM is concerned. Still the investigations performed by NILU from 2002 to 2005 showed annual average PM_{10} concentrations at the different monitoring sites ranging between 60 and 180 µg/m^3. The highest concentrations were recorded at a road side station in 2002 (40).

PM represented the main air pollution problem in HCMC when compared to international air quality standards. Model estimates were compared with measurements for the month of February 2007. The first model estimates showed average maximum PM_{10} concentrations of about 80 µg/m^3 over the city centre of HCMC. The measured levels were between 64 and 75 µg/m^3. (41)

The cumulative frequency distributions of daily PM_{10} concentrations, as presented in Figure 12 shows that the median values of daily PM_{10} concentrations ranged between 58 and 85 µg/m^3. The 90 percentile at one of the sites reached 150 µg/m^3 (42).

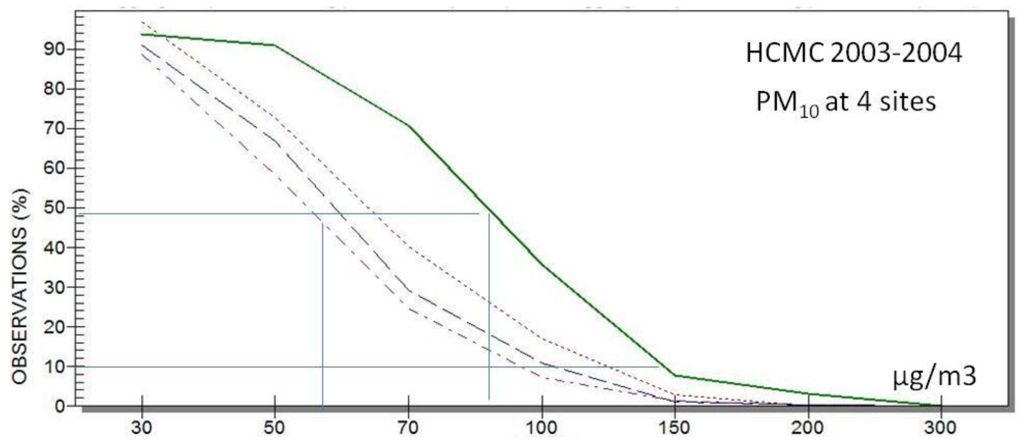

Figure 12: Cumulative frequency distribution of 24-h average PM_{10} concentrations at 4 sites in HCMC, 2003-2004. The lines indicate the percentage of observations less than concentrations given at abscissa.

The main sources for PM concentrations in HCMC are the traffic, and in particular the thousands of motor bikes and small trucks (43). HCMC seems to be different from the most polluted Asian urban areas, where industries and open air waste burning seem to play a larger role.

7. PM AROUND THE WORLD

A survey of air pollution around the world was performed as part of the WHO air quality Guidelines update 2005 (44). In that study it was reported that the annual average PM_{10} concentrations in the selected Asian cities ranged from about 35 µg/m^3 to 220 µg/m^3 and in Latin America from about 30 µg/m^3 to 129 µg/m^3, while in Europe and North America the typical range of annual average PM_{10} concentrations was 15–60 µg/m^3. About 70% of the cities selected from these regions had annual average PM_{10} concentrations above 50 µg/m^3.

In general, the highest concentrations of PM_{10} were reported from Asia. This statement is also supported by more recent studies (45). This region also experience relatively high background concentrations owing to forest fires and local emissions of particles from the use of poor-quality fuels. A well-known meteorological phenomenon, associated with the winter monsoon, covering large regions of East Asia is causing the Asian brown cloud. Airborne particles originate from windblown dust in the deserts of Mongolia and China and add to the general level of PM in the region (46).

Chinese cities experience very high airborne particle concentrations due to primary particles emitted from coal and biomass combustion and motor vehicle exhaust, as well as secondary sulphates formed by atmospheric chemical reaction from the sulphur dioxide emitted when coal is burned. Typical annual average PM_{10} concentrations in Beijing have decreased from 160 µg/m^3 in 2000 to 120 µg/m^3 in 2010 (47). However, the PM concentrations in Chinese cities are still extreme during shorter periods, especially during the winter season. On January 12, 2013 the PM_{10} concentration level reached “an all-time high” in Beijing of 993 µg/m^3 (48).

A selection of typical annual maximum concentrations of PM_{10} measured around the world is presented in Figure 13.
Four of the highest annual average concentrations reported were identified in cities where NILU was asked to perform studies. This is of course related to the need for actions, and NILU was thus asked to support the local authorities in order to identify the problem and to indicate possible mitigation actions.

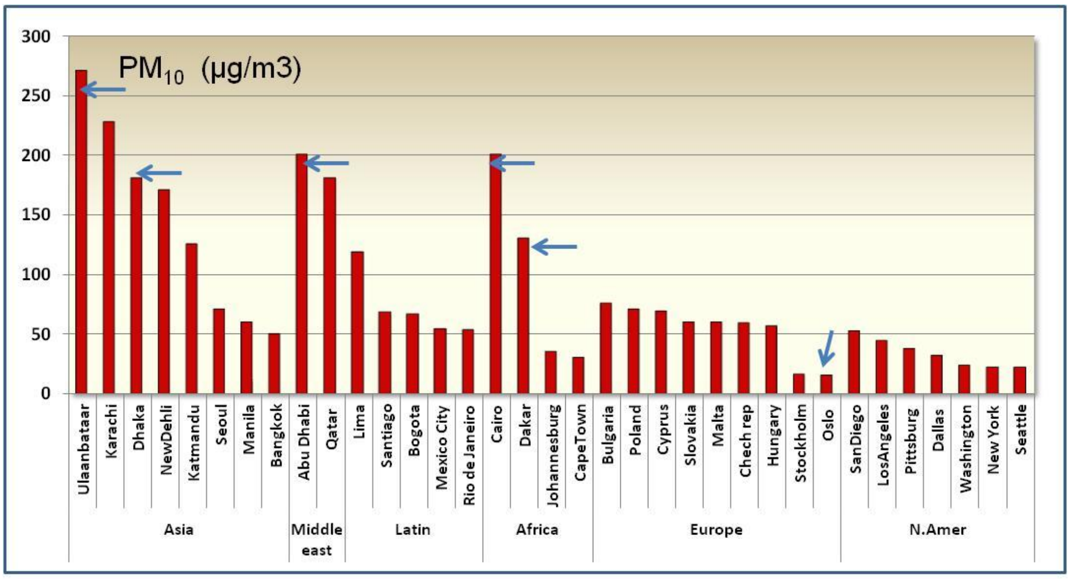

Figure 13: Some selected annual PM_{10} concentrations reported around the world. Six of the cities that were reported in this paper are marked.

The overview based on annual average concentrations, as seen in Figure 13, does not always give a complete picture of the situation in a city. We have seen that in some urban areas there are very large differences in daily maxima from one season to another, caused by changes in sources and emission rates, meteorological conditions and naturally occurring dust from desert areas. When comparing levels and the reasons for high impact one will have to understand the complete picture. The use of source receptor modelling together with the use of satellite images has been supporting this part of the research undertaken by NILU.

8. SUMMARY AND CONCLUSIONS

This study revealed that the levels of suspended particles in the air might vary considerably from one region to another, from one city to another and from one season to another. In developed countries, such as in large parts of Europe, the PM concentrations inside the urban areas seem to be mainly caused by traffic emissions.

The highest concentrations reported in developing countries are influenced by weather and burning of bad fuels, like in Ulaanbaatar and in Dhaka. In other areas like in the Middle East, windblown dust from desert areas are the main cause for the highest concentrations measured (both PM_{10} and $PM_{2.5}$).

The smallest particles, less than 2.5 micrometers, often originates from combustion sources leading to long range transported pollution and regional air pollution, while the larger particle fraction could come from local sources, local waste burning and re-suspended particles from the surface.

Measurement data collected in urban areas, aimed at assessing potential health impact, often show large temporal and spatial variations. When assessing the sources and the relative importance of different sources as a basis for regulations and mitigation measures, it is important to understand the complete picture. Annual average concentrations do normally NOT give the complete picture and the right answer.

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