PM_{10} CONCENTRATIONS IN URBAN AMBIENT AIR

Trends in Helsinki and Tampere from 2006 to 2010

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ABSTRACT

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RITOLA; Roosa: PM_{10} CONCENTRATIONS IN URBAN AMBIENT AIR – Trends in Helsinki and Tampere from 2006 to 2010

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The aim of the work was to study how the concentrations of PM_{10} sized particles have developed in two big cities in Finland from 2006 to 2010. Further aim was to compare air quality data with the data from the KAPU project that studied the PM_{10} emissions from street surfaces during springtime dust periods in 2006 – 2010. It has been showed in earlier studies that street dust contributes significantly to urban PM_{10} concentrations. In addition, a statistical analysis was used for detecting and estimating trends in the data.

The air quality data used in this study is the official data from the measuring stations in Mannerheimintie, Helsinki and Pirkankatu, Tampere. The PM_{10} emissions from street surface have been measured with the Sniffer vehicle, a mobile laboratory especially designed for the purpose. The statistical analysis was carried out using the Microsoft Excel template, MAKESENS, developed at the Finnish Meteorological Institute for detecting and estimating trends in specific time series.

Similar type of statistical analysis has been previously conducted for trends in the concentrations of main air pollutants in urban, industrial and rural environments for the time period 1994-2006. At that time, the results showed no significant reductions regarding street dust emissions. The KAPU project (2006-2010) was aimed at in particular to combat street dust, and the trend analysis was now carried out for the period 2006-2010 in order to find out if the situation has improved. Regarding air quality data, a downward trend was detected in both cities. In Helsinki the trend was tested statistically significant. Instead, in Tampere the results from the KAPU project did not show a downward trend. The difference between the cities may be attributable to differences in dust control measures, and the sources of particles. Longer time series together with extensive and regular measurements would produce even more fruitful information. Information gained from thesis as such can bring added value for the cities in their air quality protection work.

Key words: PM_{10}, urban air quality, respirable particles, street dust, air quality trends, urban aerosol particles, particulate matter

TIIVISTELMÄ

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Työn tavoitteena oli tutkia, miten ilmassa olevat PM_{10}-hiukkaspitoisuudet ovat kehittyneet kahdessa eri kaupungissa Suomessa vuosina 2006-2010. Lisäksi tavoitteena oli verrata ilmanlaatuasemilta kerättyä tietoa KAPU-projektin (Katupölyn päästöt ja torjunta) tuloksiin. KAPU-projektissa mitattiin tienpinnan pölypäästöä siihen erikseen suunnitellulla ajoneuvolla. Projekti toteutettiin vuosina 2006 - 2010. Työssä käytetty ilmanlaatuaineisto on kaupunkien ympäristöviranomaisten mittaamaa dataa, Tampereelta ja Helsingistä. Aikaisemmissa tutkimuksissa on osoitettu, että katupöly on merkittävä lähde kaupunkien PM_{10}-pitoisuuksissa.

Aineistolle tehtiin myös tilastollinen analyysi käyttäen Ilmatieteen laitoksen kehittämää Microsoft Excel-mallinetta (MAKESENS), joka on kehitetty ilmanlaatutrendien havaitsemiseen ja arviointiin. Sama testi on jo aiemmin toteutettu PM_{10} pitoisuuksille ajanjaksolla 1994–2006. Tuolloin tutkijat päätyivät toteamaan, ettei merkittäviä päästöalenemia katupölyyn liittyen ole saavutettu. KAPU-projektin (2006–2010) tavoitteena oli erityisesti löytää tehokkaampia katupölyn torjuntamenetelmiä, ja näitä menetelmiä on otettu käyttöön etenkin Helsingissä. Tämän vuoksi oli mielekästä toteuttaa samantyyppinen trendianalyysi vuosille 2006–2010. Kyseisellä ajanjaksolla molempien kaupunkien ilmanlaatudatassa on havaittavissa laskeva trendi koskien kevätkauden PM_{10}-pitoisuuksia. Helsingissä kehitys on tilastollisesti merkitsevä. Myös KAPU-mittaustulosten huippupitoisuuksien osalta Helsingissä on havaittavissa alenema. Sen sijaan Tampereen KAPU-mittaustulosten osalta pitoisuudet eivät osoita laskua vuosien välillä. Kaupunkien välisiä eroja selittää muun muassa erot katujen kunnossapidossa, sekä hiukkasten lähteistä johtuvat erot. Pidemmät aikasarjat, sekä säännölliset ja kattavat mittaukset mahdollistaisivat entistä täsmällisempien analyysien laatimisen. Opinnäytetyössä saatuja tietoja voidaan kuitenkin jo sellaisenaan käyttää tukemaan kaupunkien tekemää ilmansuojelutyötä.

FOREWORD

Writing this thesis was a welcomed challenge and a natural continuation to my inspiring and educational practical training period in Nordic Envicon Oy, a company where I have also had the unique opportunity to work for the past year. I want to give special thanks to my supervisor Kaarle Kupiainen from the air quality unit of Nordic Envicon Oy, for the expertise and time, for giving me the credit and for all the support.

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Special thanks to Väiski for the dreams, for the breaks, for making me happy, for making me believe in myself and especially for reminding me what is important.

Helsinki May 2011

Roosa Ritola

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1. INTRODUCTION

The air quality in Finland can be considered in general good. Exceedances in the limit concentrations set by EU for the protection of human health are rare. However, air pollution still is a potential threat and a lot of work is being carried out in Finnish cities in order to maintain good air quality, or to improve the quality of air especially in the bigger cities. Airborne particulate matter (PM) is one of the pollutants, the concentration of which is regulated by EU. Particulate matter has adverse effects on human health and can for example contribute to a number of respiratory problems.

When compared to other European air quality monitoring results the pollutant concentrations in Finland are generally low. For sulphur dioxide, nitrogen dioxide, particulate matter and carbon monoxide both long-term follow-up of annual averages as well as short-term concentrations stay below the levels measured in big European cities or industrialized areas. The background concentration of ozone is high, however the annual averages of ozone are approximately in the middle of the European comparison material (Anttila et al. 2003.)

Of the air quality challenges faced in Finland, the most problems are related to particles and nitrogen dioxide. These pollutants are strongly associated to emissions from traffic. Traffic causes emissions in the form of exhaust gases, but traffic also causes so called non-exhaust emissions. Non-exhaust emissions include for example wear particles from the engine, and wear particles from the pavement–tyre interface. Also particles that are deposited on the road during winter and spring end up airborne due to traffic induced turbulence. Non-exhaust particles from traffic also contribute to a more widely understood and common concept of street dust. (Kupiainen 2007.)

There are also other sources of respirable particles than traffic; they originate from different types of industrial combustion processes as well as straight from the nature's own erosion processes. In Finland, there is annual variation in the PM_{10} concentrations in ambient air due to the sources as well as the changing weather and atmospheric conditions. During periods when certain atmospheric conditions prevail, particularly atmospheric inversions in winter and spring, concentrations of pollutants in the air in Finnish cities rise high. Concentrations may even compare to those observed in cities of similar size elsewhere in Europe, where the concentrations in general are on a much higher level, see figure 1. (Anttila et al. 2006, Kupiainen 2007.)

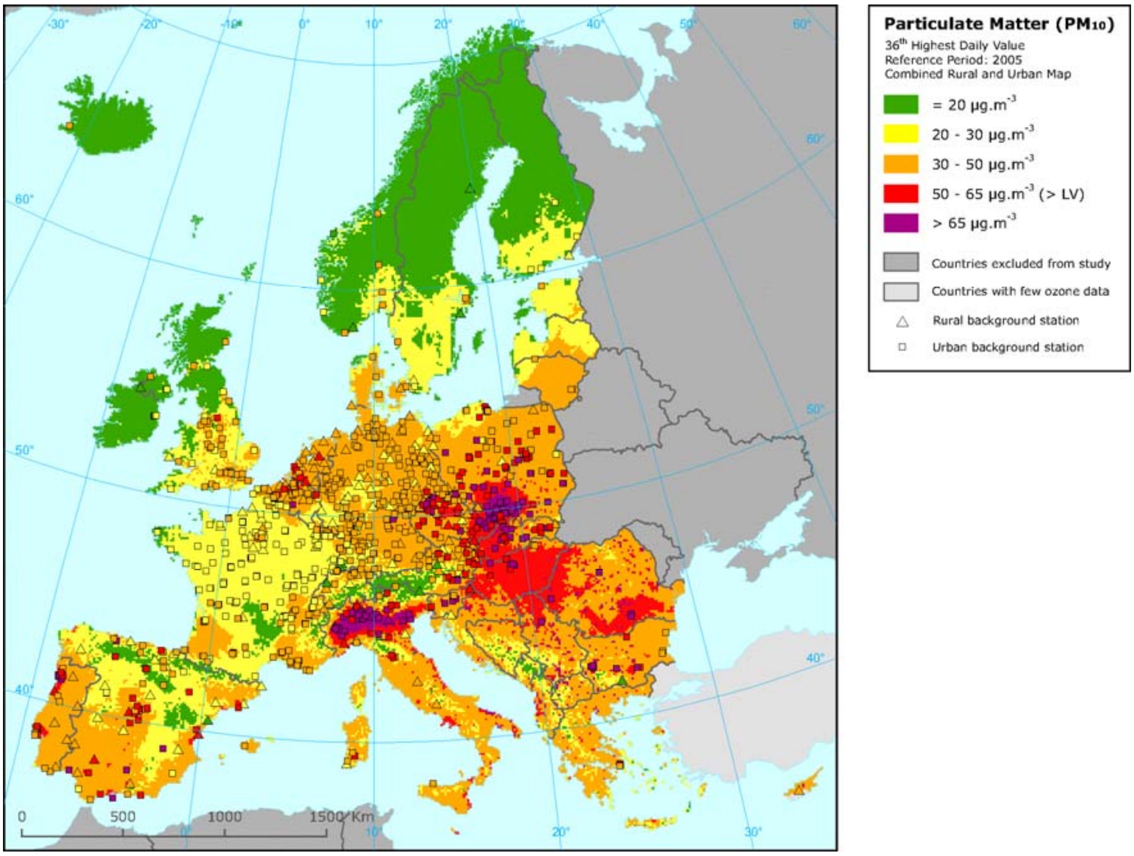

Figure 1. Map of Europe showing the 36th highest daily value of PM10 in 2005 in European cities. (European Environmental Agency, 2011.)

Most of the exceedances take place during spring months. In urban areas, including smaller towns, local concentrations of particulate matter may persist at high levels for weeks during the springtime dust period. In Finland and other sub-arctic areas, the springtime dust period is generally the period that extends from the melting of the snow and ice, until the streets have been cleaned. Also sporadic and episodic transboundary pollution from wildfires may cause high PM concentrations over large areas. This may be a problem especially during summertime. Air quality in Finnish cities has now and then momentarily worsened due to the wildfire smokes from Russia. (Finnish Meteorological Institute.)

In majority of the cases when the air quality limit values are exceeded, the pollutant in question is either particulate matter or nitrogen dioxide. The daily limit value set by EU for the concentration of PM_{10} is 50 µg/m^3. The limit value was exceeded in Helsinki (Mannerheimintie air quality monitoring station) in 2006 37 times, in 2007 33 times, in 2008 35 times, in 2009 30 times, and year 2010 24 times. In Tampere (Pirkankatu measuring station) the daily limit value for PM_{10} was exceeded in 2006 13 times, in 2007 11 times, in 2008 12 times, in 2009 12 times and in 2010 10 times. The daily limit value is a number value that is allowed to be exceeded maximum 35 times in a calendar year, after that further actions are required in order decrease the emissions. (Elsilä 2007, 2008, 2009 & 2010, Malkki et al. 2010, Myllynen et al. 2007, Niemi et al. 2007, Niemi et al. 2009, Finnish Meteorological Institute.)

There is also an annual limit value (40 µg/m^3) for PM_{10} set by EU. This is not usually a problem in Finnish cities. The annual mean concentration of PM_{10} in Finnish cities ranges between less than 10 µg/m^3 and approximately 30 µg/m^3. In 2008 the annual mean was highest in Helsinki and lowest in Muonio in Lapland (see figure 2).

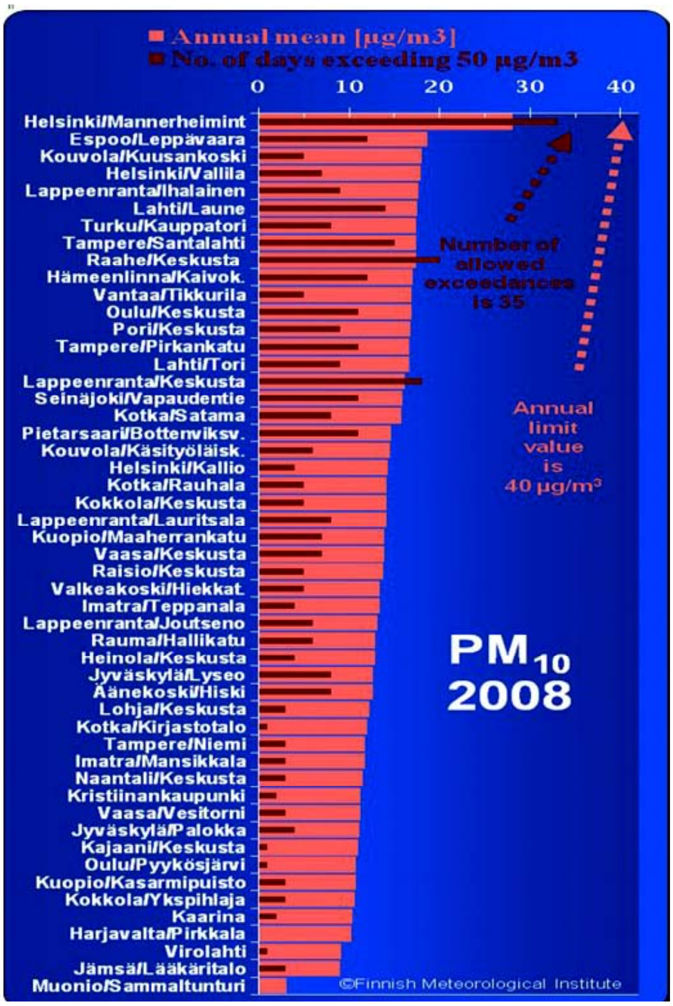

Figure 2. Annual mean concentrations of PM_{10} in Finnish cities in 2008. (Finnish Meteorological Institute.)

However it is important to note, that according to studies, there is no limit value under which particle concentrations could be considered to be on a “safe level”, in other words to have no adverse effect on human health. Even if the concentrations of particles in urban ambient air in Finnish cities, including Helsinki, can be considered to be low, studies performed by for example the National Public Health Institute (KTL) indicate that even in Helsinki a strong correlation between high particle concentration and increasing risk of heart attacks and strokes has been recorded. (Lanki et al. 2008.)

A lot of development work has been done in order to reduce the PM_{10} emissions from vehicular combustion processes. That work has been successful in many ways. The European emission standards, defining the acceptable limits for exhaust emissions of new vehicles sold in EU member states, have introduced increasingly stringent standards since 1990's. However the particle emissions caused by traffic and transportation remain a problem due to non-exhaust particle emissions.

Anttila & Tuovinen (2010) studied the trends of pollutant concentrations in Finland in 1994 – 2007. They conclude that the role of street dust during the PM_{10} concentration peaks is clearly depicted in their data. For PM_{10}, five of the 12 urban time series that they studied showed decreasing mean levels from 1994 to 2007. However, the highest concentrations (in their study Anttila & Tuovinen used 95th percentiles), typically attributable to springtime street dust, did not decrease as significantly and they end up suggesting that "the measures taken to reduce the yearly street dust problem have not in general been successful".

Both Helsinki and Tampere took part in KAPU project in 2006 – 2010. The aim of the KAPU project was to study the impacts of winter maintenance and springtime street cleaning activities on the amount and composition of street dust. In addition to the prevailing practices, some new methods were tested. A general goal was to figure out measures to decrease high spring-time PM_{10} concentrations in the ambient air of Finnish cities. The data from 1994 – 2007 used in the study by Anttila & Tuovinen (2010), is from a period during which no remarkable or novel techniques in street cleaning were harnessed. Only after 2006, especially in the cities that did participate the KAPU project, the emphasis has been in developing more efficient practices to combat the street dust problem.

The aim of this thesis was to study how the concentrations of PM_{10} sized particles have developed in two big cities in Finland from 2006 to 2010. Further aim was to compare air quality data with the data from the KAPU project that studied the PM_{10} emissions from street surfaces during springtime dust periods in 2006 – 2010. It has been showed in earlier studies that street dust contributes significantly to urban PM_{10} concentrations. In addition to qualitative comparison between the two data sets, a statistical analysis was used for detecting and estimating trends in the data. The idea for the statistical analysis came from the work of Anttila & Tuovinen (2010). Aim of this part was to analyze data, similarly to Anttila & Tuovinen, from a period when the tools for more efficient street cleaning have been introduced, especially in Helsinki (Mannerheimintie).

2. THEORY

It is important to note that street dust is not a synonym for PM_{10} sized particles. In this chapter, the definition of PM_{10} sized particles, sources of airborne particles, their health effects, air quality measurements and relevant legislation are discussed in more detail.

2.1 Definition of PM_{10} sized particles

Particles that have an aerodynamic diameter of less than 10 microns (µm) are called respirable particles, PM_{10} sized particles or simply referred as PM_{10}. Particles of this size cannot be seen by bare eyes (see figure 3). Particles this small can easily pass via inhaled air all the way to the human bronchi, which is why the name respirable particles.

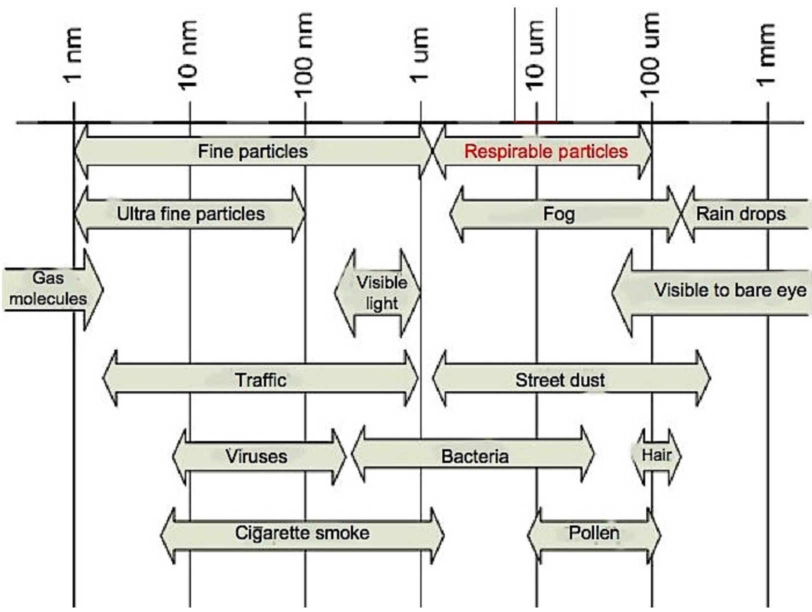

Figure 3. The size of respirable particles (PM_{10}) in relation to other small-scale units and objects. (Modified from the original picture: Helsingin Yliopisto. Hiukkastieto)

The amount of PM_{10} sized particles in the atmosphere can be expressed by using mass or number units per volume. Concentrations of PM_{10} are usually expressed by mass concentration c_m. The unit is normally µg/m^3 (or sometimes mg/m^3).

$$c_m = \frac{m}{V} \quad (1)$$

$$[c_m] = \frac{[m]}{[V]} = \frac{\mu g}{m^3}\left(= \frac{mg}{m^3}\right) \quad (2)$$

The definition of PM_{10} particles includes all the particles that have an aerodynamic diameter of less than 10µm, and thus it also includes $PM_{2,5}$ (particles that have an aerodynamic diameter of less than 2,5µm). This fraction of particles is also called fine particles, and as well as PM_{10} particles they belong to urban ambient air pollutants. $PM_{2,5}$ and PM_{10} particles have different sources and also different health effects, thus they are generally handled as separate groups or pollutants, and they are also measured separately. (Palosuo 2008.)

2.2 Formation of airborne particles

Urban air PM_{10} is a complex mixture of particles originating from different sources. Airborne suspended particulate matter is described either as primary or secondary particles according to their source. Primary particles are emitted directly into the atmosphere by natural or anthropogenic processes. Secondary particles are usually of man made origin and they are formed in the atmosphere from oxidation and subsequent reactions of sulfur and nitrogen oxides, ammonia and volatile organic compounds (VOCs). In most European countries, industrialization and high volumes of traffic mean that anthropogenic sources predominate, especially in urban areas. (Eerens et al. 2007.)

Sources of anthropogenic particles are similar throughout Europe. The most significant of these are traffic, power plants, industrial and residential combustion sources, industrial fugitive dust, loading and unloading of bulk goods, mining activities, human-started forest fires and, in some local cases, non-combustion sources such as building construction and quarrying. The main natural sources of airborne particulates in Europe are sea spray and soil resuspension by the wind. In addition, in some specific areas Saharan dust and volcano emissions can play an important role as natural sources of particles. (EC 1997.)

2.3 Sources of airborne particles in Finland

In general, In Finland, energy and transport are the biggest sources of emissions of other pollutants than greenhouse gases. From the total PM_{10} emissions in 2007, energy sector was accountable to 29% and transport sector 12% (see table 1.). The share of transport sector (12%) only includes the PM_{10} from exhaust emissions. Within transport sector road traffic is the biggest contributor of particle emissions. Vehicular traffic causes both exhaust and non-exhaust particle emissions and the amount of non-exhaust emissions should also be considered of importance. The difference between exhaust and non-exhaust emissions is explained in more detail in chapter 2.3.2 .

Table 1. PM_{10} emissions in Finland by sectors in 2007. (Modified from the original table: Finnish Environment Institute (SYKE), April 2009)

Sector	**PM_{10} (Gg)**
Energy	29
Transport [1)]	12
Production processes	5
Solvent and other product use	0,4
Agriculture	1,4
Waste	0
Total	**48**

[1)] includes emissions from construction machines and from domestic transport

2.3.1 Energy production

The emissions from energy production usually discharge from tall pipes. The emissions diffuse in wide areas and do not normally cause locally risen concentrations of particles. Even if the amount of total energy production in Helsinki Metropolitan area has increased in recent years, the total emissions of pollutants (other than CO_2) have experienced a downward trend. There are several reasons behind the decrease, for example the introduction of desulphurization plants, and changes in fuels and fuel techniques. (Malkki et al. 2010.)

2.3.2 Traffic

Traffic and transport sector causes high particle emissions. As an example the particle emissions from traffic in 2009 in Tampere and Helsinki were as follows: in Tampere, 60 tonnes (65%) of the total 93 tonnes of particulate matter emissions came from the traffic, the rest came from point and area sources. In Helsinki the particle emissions from road traffic were 116 tonnes (33%) of total 345 tonnes. (Elsilä 2010, Malkki et al. 2010.)

Exhaust emissions from road traffic

Vehicular traffic can affect the concentration of ambient particles in many ways. Exhaust emissions include particles that are formed in the internal combustion engines, and wear particles from the operation of the engine.

Technical Research Centre of Finland (VTT) has implemented a database called LIPASTO that collects data and creates forecasts about the energy consumption and exhaust emissions of different traffic modes (road-, air-, rail- and water) in Finland. Data from 2009 (figure 4) shows that from all different transport modes, road traffic is accountable for almost 60 % of the PM emissions and thus is by far the biggest single source of PM emissions in traffic sector. However the PM emissions from traffic are forecasted to continue decreasing , and the single biggest contributor to this is road traffic (see figure 5).

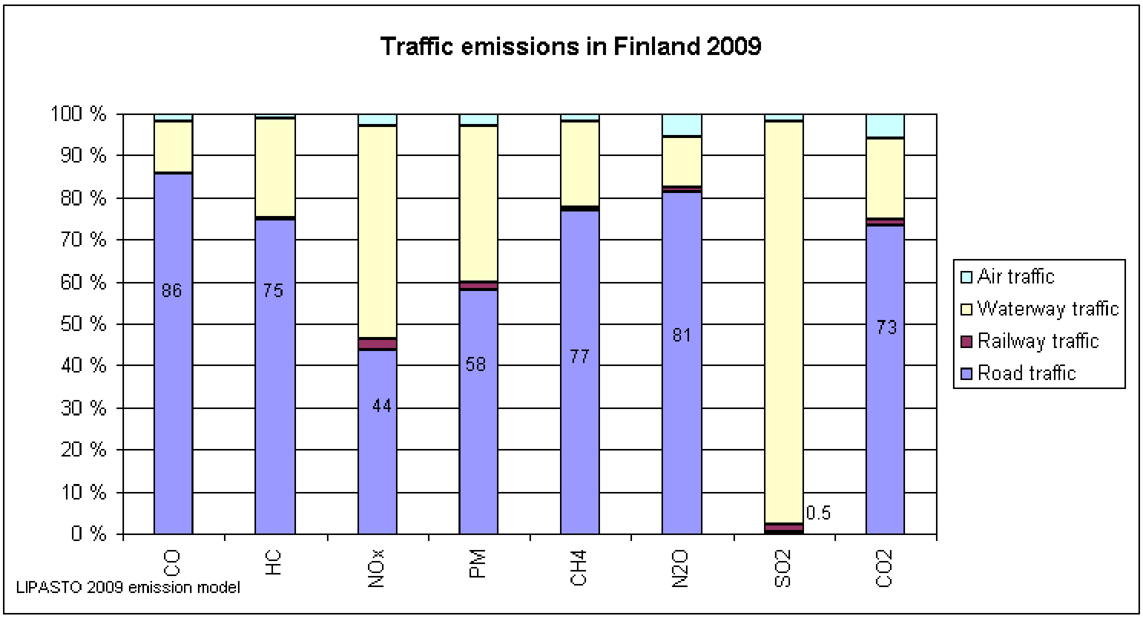

Figure 4. Exhaust emissions by different modes of traffic for different pollutants in Finland in 2009. PM stands for all particulate matter regardless of the size. (VTT, LIPASTO.)

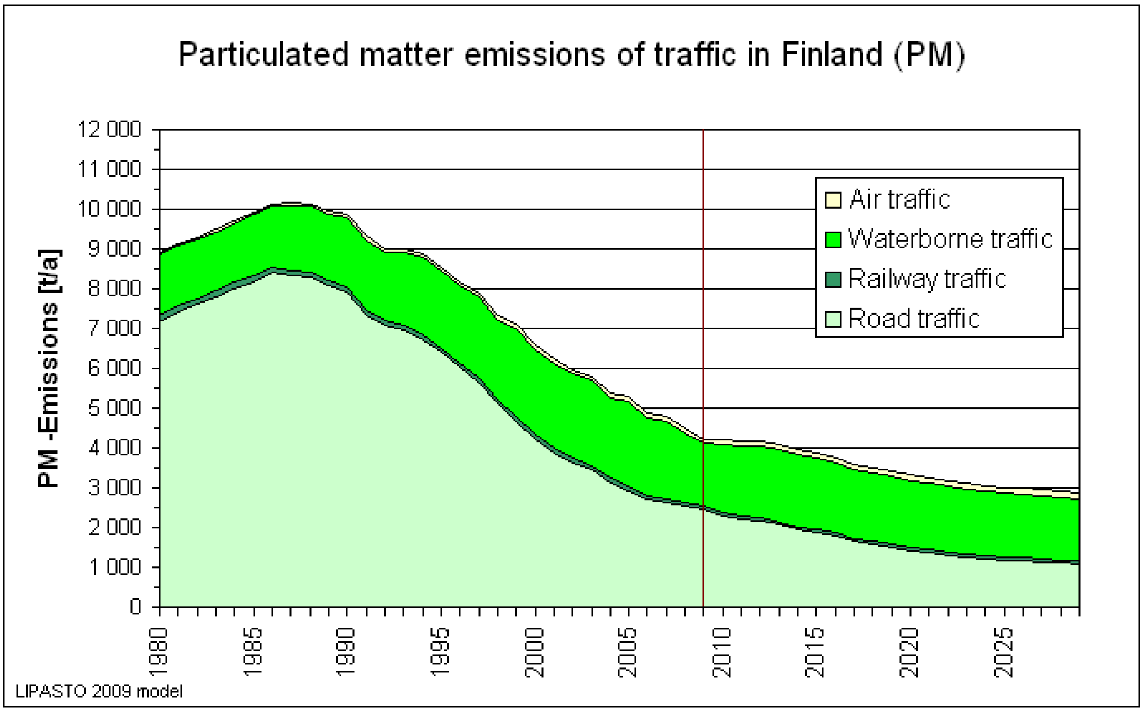

Figure 5. The PM emissions from traffic exhausts are forecasted to continue decreasing. (VTT, LIPASTO.)

PM emissions from road traffic have already decreased significantly since late 1980's, which has a lot to do with new, and constantly developing cleaner technologies in car manufacturing aiming to reduce the PM_{10} emissions from vehicular combustion processes. The European emission standards have also been very efficient in decreasing the exhaust emissions. These Euro standards define the acceptable limits for exhaust emissions of new vehicles sold in EU member states. They have been defined in a series of EU directives staging a progressive introduction of increasingly stringent standards. However the traffic related particle emissions remain a problem due to non-exhaust particle emissions and it is of great importance to pursue similar success in reducing the overall particle emissions.

Non-exhaust emissions from road traffic

Non-exhaust particles can be considered problematic especially in springtime in sub-arctic regions. In these regions traction control is needed during wintertime to enable the safe use of streets and sidewalks. Traction control methods include the use of traction sand and melting of ice with saline solutions. In addition, special winter tyres are used in cars, either studded winter tyres or specially designed friction tyres. Several of these methods enhance the formation of mineral particles from the pavement wear or traction sand. These particles accumulate on the road environment during winter. Despite of efficient street cleaning measures that are performed usually in early spring to remove the remaining sand and dust from the streets and from their vicinity, a big part of the particles end up airborne and concentrations of particles tend to rise high. (Kupiainen 2007.)

There are differences in the emission levels between different tyre types. Street cleanness is also an important factor affecting the emission level between different tyre types. In general, emission from a studded tyre is higher than that from a summer or friction tyre. However, when the street surface is dirty, friction tyre causes the dust on the street surface to rise up more efficiently, compared to summer or studded tyre. When there is no visible dust on a street surface, studded tyres cause higher dust emission by slowly "grinding" the surface material. (Kupiainen 2007.)

There are already examples from other Nordic countries where the use of studded tyres have been limited by for example collecting fees (Oslo, Norway) or by banning the use of studded tyres in certain streets (Stockholm, Sweden). Studded tyres restriction can be seen as an additional tool to tackle the PM emissions, once all other feasible measures have already been introduced, or, as in Sweden, to tackle local emissions in the street where the limit value is constantly exceeded.

In Finland, the use of winter tyres is required between December 1st and February 28th. The use of studded winter tyres is allowed between November 1st and March 31st or until the first Monday after Easter, the latter day being determinative. The use of studded tyres is allowed outside the fixed dates if the weather or street surface conditions require so. Since winter tyres can often be used well before or after the streets have any snow or ice cover, it is obvious that studded tyres begin to wear the surface material. This is considered to be one of the reasons why PM_{10} concentrations tend to rise high, and even exceed the limit values. This is not true only in springtime, but there are signs that studded tyres might play a role in the exceedances that take place during late autumn, around the time when people switch into studded tyres but the streets do not yet have the snow or ice cover. In springtime the utilization rate of studded tyres tend to decrease simultaneously with decreasing street surface emissions (see figure 6). (Kupiainen et al. 2009.)

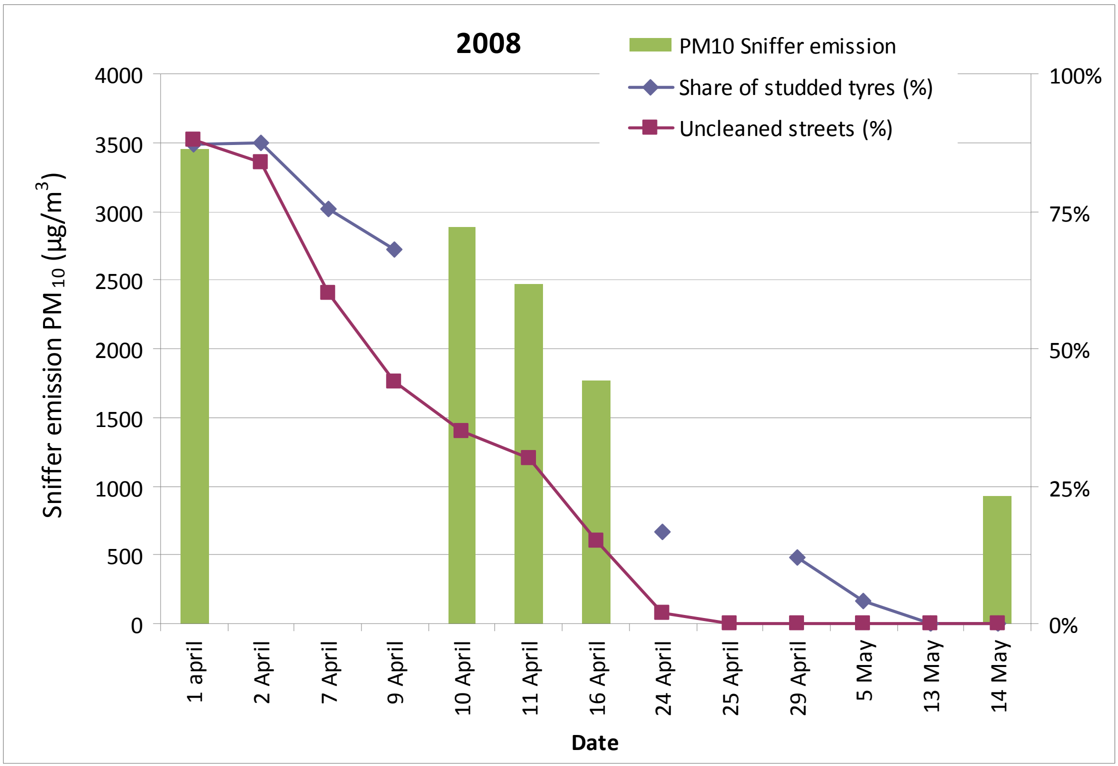

Figure 6. Average street surface emission levels, share of winter tyres (%, rough calculations) and proceeding of the street cleaning in some specific streets in Helsinki in spring 2008. (Modified from the original picture, Kupiainen et al. 2009.)

Other methods to reduce the dust emissions from non-exhaust sources include for example wet sieving of sanding material to achieve certain grain size distribution without fine dust. Traction sanding should also only be used in areas where it is necessary, and often what is done in the cities is that the traction sand is only applied to bus stops, hills, cross roads or other sites of special importance. (Kupiainen 2007.)

2.3.3 Long range transport

The location of Finland, in northernmost Europe, separated from the main continent by the Baltic Sea, reduces the transboundary influence of the major European source areas, for example industrial areas. However, sporadic and episodic transboundary pollution from wildfires may cause high PM concentrations over large areas. This may be a problem especially during summer time. In Finland, a big portion of small particles (< PM_{10}) is long-range transported. Coarse fraction of particles PM_{10} does not normally travel long distances except in some special cases. (Anttila et al. 2010, Laakso 2003.)

One of these episodes took place in July and August 2010, when the concentration of PM_{10} exceeded the daily limit value in several measuring stations in Helsinki Metropolitan area (on 29.7., 30.7. and 9.8.) and the exceedances were considered to be at least partly due to the wildfire smokes from Russia. (HSY 2011.)

2.4 Meteorological, atmospheric and seasonal factors affecting the concentrations of airborne particles

Meteorological and seasonal changes affect the emissions and particle concentrations in ambient air. Springtime high concentrations of PM_{10} particles is related to the traction control methods during winter and the melting of the ice and snow that release the deposited dust, as well to the use of studded tyres. However this is not the only possible reason behind risen concentrations. During the times when certain atmospheric conditions prevail, concentrations of pollutants in urban ambient air in Finnish cities tend to rise. These atmospheric conditions include atmospheric inversions that are common in winter and spring. (Kupiainen et al. 2009.)

Heating of houses and other small scale burning of biomass can also be considered as a seasonally changing source of emissions. Natural primary emissions like sea spraying have annual cycle that in Finland is related to ice cover and wind speeds. The formation of secondary particles (formed in the atmosphere from oxidation and subsequent reactions of sulfur and nitrogen oxides, ammonia and volatile organic compounds) also depends on the weather and meteorological conditions. (Laakso 2003.)

Particles are removed from ambient air in principle by three different mechanisms; sedimentation, dry deposition and rain. Very large particles have a short atmospheric existence; they tend to fall to the ground because of gravity and wind-driven impaction processes. In practice there are few particles in the atmosphere exceeding 20 µm in diameter, except in areas close to sources of emission. For small particles the sedimentation process is slower and it can take up even years. In dry deposition particles collect or deposit themselves on surfaces such as trees, rocks or buildings. Particles that are close to the ground or other surfaces are more efficiently removed by dry deposition than sedimentation. Rainout is a process where particles coagulate with raindrops and subsequently fall to the ground. (Jacobson 2002, Griffin 2007.)

Rainout is an effective and important removal process, and it can in some cases have a temporary positive effect on local air quality. Same kind of effect can be achieved with dust binding, in other words spreading saline solution on dusty street surfaces. Studies show that dust binding is an efficient, or even the only method to combat acute dust episodes. However the effect can sustain depending on circumstances only around 3-5 days, after which the action is preferable to repeat in case needed. Dust binding is a common practice to combat acute dust episodes in many Finnish cities, including Helsinki. (Johansson et al. 2007, Kupiainen et al. 2009.)

2.5 Health effects

Large particles (> PM_{10}) normally deposit in the upper airways (nose and throat) whereas particles that have a diameter of less than 10 microns (µm) can easily pass via inhaled air all the way to the human bronchi. The evidence on airborne particulate matter and its public health impact is consistent in showing adverse health effects at exposures that are experienced by urban populations in both developed and developing countries. All population is affected, but susceptibility to the pollution varies with health and age. There is little evidence to suggest a threshold below which no adverse health effects would be anticipated. (WHO 2005.)

The health effects of fine particles ($PM_{2,5}$) are also widely studied. They are even smaller in size and thus when they end up in human airways, they can penetrate even deeper than PM_{10} particles and cause different types of health effects. Since this thesis discusses mainly PM_{10} and street dust, also the health effects of fine particles are more or less excluded from this work.

It is important to note, that according to studies, there is no limit value under which particle concentrations could be considered to be on a "safe level", to have no adverse effect on human health. Even if the concentrations of particles in urban ambient air in Finnish cities, including Helsinki, can be considered to be low, studies show that even in Helsinki a strong correlation between high particle concentration and increasing risk of heart attacks and strokes has been recorded. (Lanki et al. 2008.)

The range of health effects is broad, but most often the effects are related to respiratory symptoms. Only after the mid 1990's air pollution was associated also with heart and cardiovascular diseases, when previously only respiratory diseases were considered as a threat. (Palosuo 2008.)

Lanki et al. (2008) have studied the connection between the variation in ambient air particle concentration and the daily variation of the health status of the population. When the concentration of fine or respirable sized particulate matter in the ambient air have been high, cardiac and cardiovascular diseases-related deaths and hospital admissions have increased consistently, on the same and on next few days. When the hospital admissions were studied in more detail, it has been found that exposure to particulate matter affects almost all cardiac and cardiovascular diseases: myocardial infarction, other ischemic cardiac diseases, congestive heart failure, arrhythmias, stroke and peripheral blood circulation.

2.6 Air quality monitoring in Finland

Finland has a total of about one hundred permanent air quality monitoring stations in the area of approximately 60 municipalities (Finnish Meteorological Institute). Monitoring is carried out within the framework of EU legislation.

2.6.1 Legislative background - EU

The European Parliament and the Council set a new Directive 2008/50/EC on ambient air quality and cleaner air for Europe on May 21. 2008. The new Directive entered into force on June 11. 2008, and the aim is to:

1. "Define and establish objectives for ambient air quality, designed to avoid, prevent or reduce harmful effects on human health and the environment as a whole.
2. Assess the ambient air quality in Member States on the basis of common methods and criteria.
3. Obtain information on ambient air quality in order to help combat air pollution and nuisance and to monitor long-term trends and improvements resulting from national and Community measures.
4. Ensure that such information on ambient air quality is made available to the public.
5. Maintain air quality where it is good and improve it in other cases.
6. Promote increased cooperation between the Member States in reducing air pollution." (EU 2008.)

EU has set different types of threshold values for Member States in its directive on air quality. These values are either to guide or to oblige every Member State to act within same framework. Limit values have been drawn up to protect human health, and they are the highest allowable concentrations, beyond which the authorities must take steps to reduce the levels. (EU 2008.)

In the directive, there are also information and alert threshold levels defined for certain pollutants (sulfur dioxide, nitrogen oxides and ozone), and a critical level of protection of vegetation (sulfur dioxide and oxides of nitrogen).

- ‘A limit value’ is a level fixed on the basis of scientific knowledge, with the aim of avoiding, preventing or reducing harmful effects on human health and/or the environment as a whole. According to the EU Directive, this level is to be attained within a given period and not to be exceeded once attained (in Finland this value for PM_{10} was to be attained by 1 January 2005).

- ‘A target value’ is a level fixed with the aim of avoiding, preventing or reducing harmful effects on human health and/or the environment as a whole. Target value is to be attained where possible over a given period. A target value is not as binding as the limit value. A target value is set for example for ozone, that transports efiiciently and does not obey national boundaries, and thus cannot be controlled by national actions alone.

- ‘An alert threshold’ means a level beyond which there is a risk to human health from brief exposure for the population as a whole and at which immediate steps are to be taken by the Member States. In Finland, alert threshold is set for ozone, sulphur dioxide and nitrogen dioxide. In Finland, concentrations this high are extremely rare.

- ‘An information threshold’ is a level beyond which there is a risk to human health from brief exposure for particularly sensitive sections of the population and for which immediate and appropriate information is necessary. In Finland an information threshold is set for ozone. The exceedances are extremely rare in Finland. (EU 2008.)

In Finland, under the prevailing conditions, the most relevant limit values are the annual limit value for nitrogen dioxide and the daily limit value for respirable particles. Other values are likely to be exceeded only as a result of a serious failure in industrial environments or under exceptional meteorological conditions of traffic environments. (The Finnish Meteorological Institute.)

2.6.2 Air protection legislation in Finland

In Finland, air quality monitoring has been regulated by The Air Protection Law and Regulation dating from the 1980's. The Air Protection Law and Regulation were offset by the Environmental Protection Act and Regulation that came into force on March 1. 2000. The requirements for air protection remained roughly the same, and most of the legal provisions concerning air protection are included in the Environmental Protection Act. Most of the general rules and guidelines given by the Air Protection law itself will stay in effect even if the Air Protection Law and regulation were repealed. (The Ministry of the Environment.)

Air quality monitoring in Finland is decentralized, and is taken care by municipalities, in some cases together with industry, and the Finnish Meteorological Institute. The system is based on The Environmental Protection Act (86/2000). Monitoring information must be made public and communicated to necessary extent.

Municipalities must be prepared with available means to prevent the exceedances of the limit values set by EU. If a limit value (a number value) is exceeded, people must be informed or warned. The information shall include an indication of the relationship between the measured concentrations and thresholds of these pollutants, and their health effects. If the alert threshold is exceeded, the public must be informed about the risks of the air pollution in question. If the air quality limit value is exceeded, the municipality must take the necessary steps or lay down provisions to restrict traffic and reduce emissions. A paragraph from The Environmental Protection Act, concerning the protection of air quality, is presented in appendix 1.

Finnish air quality objectives include binding limit values and non-binding national guideline values for different compounds related to air quality. The mandatory air quality limit values correspond to those of the European Union's new Air Quality Directive 2008/50/EC.

At the moment there are 14 different compounds related to air quality that are regulated in Finland. In addition to particulate matter (PM_{10}) these are:

- Sulphur dioxide, SO_2
- Nitrogen dioxide, NO_2
- Nitrogen oxides, NOx
- Lead, Pb
- Benzene, C_6H_6
- Carbon monoxide, CO
- Ozone, O_3
- Arsenic, As
- Cadmium, Cd
- Nickel, Ni
- Benzo(a)pyrene, B[a]P
- Total suspended particles, TSP

(The Finnish Meteorological Institute)

The mandatory air quality limit values are set for sulphur dioxide, nitrogen dioxide, particles (PM_{10}), lead, carbon monoxide and benzene. The limit values are presented in table 2. Rest of the compounds is regulated by less binding target values, warning threshold values and guidance values. Target values are slightly less stringent than the limit values. To reach the target values the best available technology and other cost-effective ways should be used. Target values are given, for example for ozone, for which long-range transport is a significant source, and whose concentrations can not be reduced only at national level measures. A warning threshold is the concentration level above which even a short-term exposure can endanger the health of the population. Warning thresholds has been issued for ozone, sulfur dioxide and nitrogen dioxide. In Finland, such high concentrations are extremely rare. Information threshold in turn is the level above which there may be danger to a health of particularly vulnerable groups. (The Finnish Meteorological Institute.)

Table 2. Values defined in the EU DIRECTIVE 2008/50/EC on"Ambient air quality and cleaner air for Europe".

Compound	Averaging period	Limit value µg/m^3 (293 K, 101,3 kPa)	The allowed amount of exceedances within one calendar year	Time by which the limit values should be met
Sulphur dioxide (SO_2)	1 hour	350	24	1.1.2005
	24 hours	125	3	1.1.2005
Nitrogen dioxide (NO_2)	1 hour	200	18	1.1.2010
	Calendar year	40	-	1.1.2010
Particles (PM_{10})	24 hours	50 1)	35	1.1.2005
	Calendar year	40 1)	-	1.1.2005
Lead (Pb)	Calendar year	0,5 1)	-	15.8.2001
Carbon monoxide (CO)	8 hours 2)	10 000	-	1.1.2005
Benzene (C_6H_6)	Calendar year	5	-	1.1.2010

1) Results are expressed in normal temperature and pressure (NTP) conditions.
2) Maximum daily 8 hours mean from hourly running 8 hours. Each eight hour average so calculated will be assigned to the day on which it ends.

If the limit value is exceeded or is likely to be exceeded, the municipality must draw up and implement plans or programs, which aim to prevent the exceedance in prescribed time limits. As an example: the limit values for nitrogen dioxide were exceeded in Helsinki in 2005, 2006, 2007 and 2008 and limit values for airborne particulates in 2003, 2005 and 2006. As a result, the City of Helsinki prepared an Air Protection Plan. Helsinki's air protection action plan consists of long-term measures to lower the level of air pollutants. (Ilmansuojelutyöryhmä, 2008.)

Plans and programs which are subject to respirable particles (PM_{10}) concentrations must also be aimed to reduce fine particulate matter ($PM_{2,5}$) concentrations. Plans and programs, which may concern the entire municipality or its particular regions, should be prepared no later than 18 months after the end of the reference period on which the limit value is exceeded, or the risk of an exceedance has been detected. Plans and programs are delivered to the Centre for Economic Development, Transport and the Environment (ELY-keskus), which forwards them to the Ministry of the Environment. The plans and programs must be made public for the municipality or the residents of the certain region. Progress in the plans and programs must be reported to the Centre for Economic Development, Transport and the Environment and the Ministry of the Environment every three years. (The Ministry of the Environment.)

Contributions to exceedances of particulate matter PM_{10} limit values attributable to winter-sanding or -salting of roads may be subtracted when assessing compliance with air quality limit values provided that reasonable measures have been taken to lower concentrations (The Ministry of the Environment.)

2.6.3 Responsibilities regarding air quality monitoring

In Finland, the municipal authorities are responsible for air quality measurements. Municipalities implement local air quality monitoring and publicity, according to the Environmental Protection Act. Municipalities are responsible for establishing and maintaining the air quality measuring stations. Currently (in April 2011) there are 38 local networks and 124 measurement stations. PM_{10} is measured at 77 stations. (Finnish Meteorological Institute.)

In each municipality or measuring network, the monitoring stations should be placed so that they measure the air quality in the region that suffers the most loads, and the regions, which represent long-term human exposure. In practice, in the Finnish cities, this means that one station is usually located in congested urban commercial center, and other stations at different distances from the center, representing business and residential areas. In industrial areas, station or stations should also be placed close to the emitting industrial plants.

2.7 Air quality measurements in Helsinki and Tampere

HSY (Helsinki Region Environmental services Authority), which is the authority responsible of the air quality measurements in Helsinki Metropolitan area, measures air quality in several locations with stationary and mobile stations. There are five stationary measuring stations in Helsinki. In 2011 they are situated in Mannerheimintie (city centre), Töölö, Vallila, Kallio and Vartiokylä. There are four more stationary stations in the whole Helsinki metropolitan area. The locations of all 9 measuring stations are presented in figure 7. (HSY 2011.)

Figure 7. Air quality measuring stations in Helsinki Metropolitan area. The blue rectangles (5) in Helsinki area represent the permanent measuring stations. There are four more stations in the whole Helsinki Metropolitan area. (HSY 2010.)

In Tampere, the environmental authorities measure the air quality in two stationary and two portable stations. Stationary measuring stations are located in Pirkankatu and at the central bus station. The locations of the measuring stations are presented in figure 8. (Elsilä 2010.)

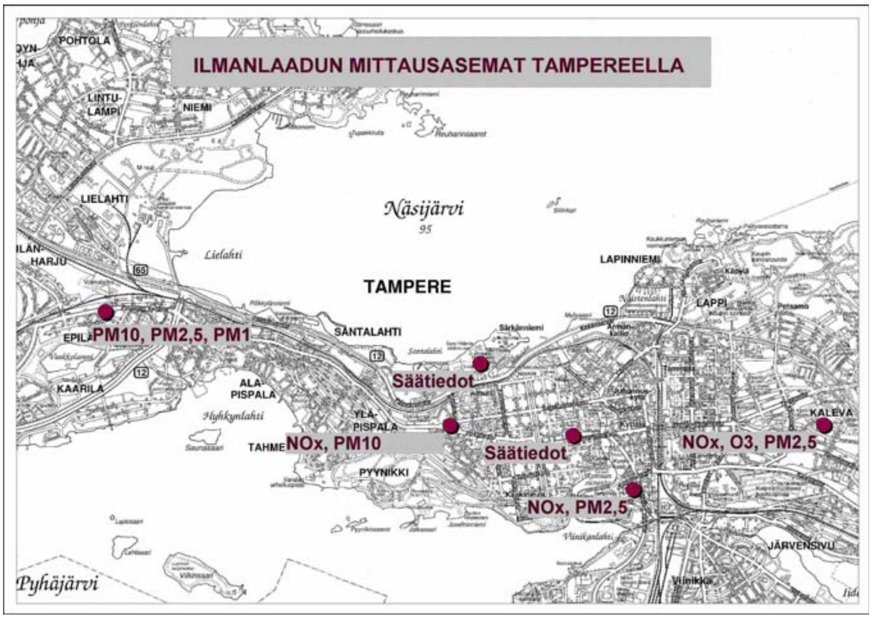

Figure 8. Air quality measuring stations in Tampere. In addition to the four air quality measuring stations, the map indicates the location of two weather stations (Säätiedot). (Elsilä 2010.)

2.8 Other stakeholders

In addition to the measurements conducted by local environmental authorities, Finnish Meteorological Institute (FMI) measures air quality in 20 background stations outside cities, away from urban emission sources. Industries that cause emissions may also be required to participate in the funding of local air quality monitoring. Ilmanlaatu.fi, an air quality portal maintained by the Finnish meteorological Institute, gathers information from all cities and the background stations to build up a comprehensive picture of the situation in the whole country.

FMI supports local air quality preparedness by for example implementing air quality forecasts. These forecasts aim to estimate the likelihood of weather conditions that might worsen air quality, or they aim to estimate when poor air quality is forecasted to improve. In addition to forecasts, Finnish Meteorological institute is involved in different air quality-related research.

In addition to FMI there are various other bodies and experts doing air quality related research in Finland. National Public Health Institute (KTL) has performed a long list of researches that are related to air quality and health, these are for example;

- Air pollution and inflammatory response in myocardial infarction survivors: gene-environment-interactions in a high-risk group (AIRGENE)
- Relationship between Ultrafine and fine Particulate matter in Indoor and Outdoor air and respiratory Health (RUPIOH)

Nowadays KTL is part of The National Institute for Health and Welfare (THL), a research and development institute under the Finnish Ministry of Social Affairs and Health with the aim to promote health and welfare in Finland. THL was formed in 2009, with the merger of KTL and the National Research and Development Centre for Welfare and Health (STAKES).

The Technical Research Centre of Finland (VTT) does among other things research on transport and energy sectors emissions and technologies, and has for example implemented the LIPASTO database which is presented in chapter 2.3.2.

Finnish Universities are also actively participating in air quality related education and research, for example the University of Helsinki, University of Eastern Finland, Tampere University of Techology and Metropolia University of Applied Sciences. The "Sniffer" mobile laboratory (Nuuskija in Finnish) was designed and built by Metropolia laboratory of automotive engineering and laboratory of physics with the objectives to study exhaust and non-exhaust traffic pollutants in city air by a mobile laboratory. (Metropolia.)

Nordic Envicon Oy is a Helsinki based consultancy company. The air quality and climate business unit is specialized in road dust emissions and mitigation research, urban air quality, traffic emissions and source estimations. The air quality and climate business unit provides expert services, R & D services of air pollutants, as well as measurement and research services. One of the longest and amplest projects was the KAPU project implemented in 2006 – 2010. The work will continue in the REDUST project, an EU Life+ funded four-year demonstration project benefiting from the KAPU project's results and experiences.

3. METHODOLOGY

3.1 KAPU project

KAPU project was aimed to study the impacts of winter maintenance and springtime street cleaning activities on the amount and composition of street dust in Finnish cities. A general goal was to find out measures to lower the high spring time PM_{10} concentrations in the ambient air of Finnish cities. Altogether eight Finnish cities took part in the project: Helsinki, Espoo, Kerava (2006-2009), Porvoo (2010), Riihimäki, Tampere, Turku (2008-2009) and Vantaa. A measuring route for the Sniffer mobile laboratory was designed in all cities, and road dust concentrations were measured during different meteorological conditions in different seasons. The measurements concentrated mainly on the spring time road dust period, when winter maintenance measures also took place, but also other seasons were covered for comparison. The results from the KAPU project are used in this work to compare the occurrences of high PM_{10} emissions. (Kupiainen et al. 2009.)

3.1.1 Sniffer vehicle

The measurements in the KAPU project were conducted with the Sniffer vehicle which is a mobile laboratory equipped with versatile air quality and meteorology measuring devices (and figure 10.). The idea of Sniffer measurements is to measure PM_{10} emission from the street surface. In KAPU project, PM_{10} mass concentrations have been used to interpret street dust results. Since measuring is done very close to the street surface and source, the sample has no time to dilute, and therefore, the term ‘emission’ or ‘Sniffer emission’ used in KAPU results refers to the measured mass concentrations. (Pirjola et al. 2004, 2010.)

The Sniffer vehicle (Volkswagen LT 35) collects dust sample behind its left rear tyre, approximately 5 cm from the tyre. A sampling air branch-off is constructed into the particle mass monitors TEOM and ELPI (Electrical Low-pressure Impactor; Dekati Ltd.).

Figure 10. The Sniffer vehicle used in KAPU project to collect PM_{10} emission data from street surface. (Pictures: Roosa Ritola)

3.2 Air quality monitoring stations

The air quality data (PM_{10} concentrations) used in this thesis is from the environmental authorities of Helsinki and Tampere. The data from 2006 to 2009 is validated official results. From 2010 only initial non-validated results were available for the time being. The official PM_{10} data was collected from certain measuring stations in Helsinki (Mannerheimintie) and Tampere (Pirkankatu). These specific measuring stations in Helsinki and Tampere were selected based on following criteria:

- Both of the measuring stations are situated in an urban environment and are type: urban, traffic stations
- From both of these stations, continuously measured concentrations of PM_{10} was available
- Both of these cities participated in KAPU project, and thus KAPU data was available for both cities for all five years

3.2.1. Helsinki, Mannerheimintie

Mannerheimintie is a broad 4-laned cobblestoned street. In between the driving lanes are two tramlines. The street is 47 meters broad. Mannerheimintie can be described as a street canyon since it is bordered by 6-storey buildings that are side by side creating wall-like barriers to both side of the road. This kind of structures can prevent, or slow down the mixing of the air and the dilution of the pollutants.

The distance from the nearest driving lane to the air quality measuring point is two meters, and from the nearest crossroads 35 meters (see figure 9.). Traffic and street dust are the most significant sources of emissions (Mannerheimintie 22 800 vehicles/d). The closest power plants are situated 2 kilometers from the measuring point, so the relevance of point sources to this measuring point is minor. The concentrations measured in the Mannerheimintie air quality station represent the levels to which people are exposed to along the busy streets in the centre of Helsinki. (Finnish Meteorological Institute.)

Figure 9. The air quality measuring point in Mannerheimintie, Helsinki city centre (left), is placed on the wall of a glass booth. Measuring station in Pirkankatu, Tampere (right) is placed inside a brick building situated in a small park area between two busy streets. (Pictures: Roosa Ritola)

3.2.2 Tampere, Pirkankatu

The measuring station is located between two busy streets, Pirkankatu (6000 vehicles/day) and Satakunnankatu (11 000 vehicles/day). The distance from the nearest driving lane to the air quality measuring point is 15 meters, and from the nearest crossroads 40 meters. There are two bus stops located on both sides of the measuring station. PM_{10}-concentrations are measured by a TEOM 1400-analyzer, that is equipped with pre-filters (see chapter 3.3.2).

3.3 Sampling and analytical methods

In the determination of the concentrations of air pollutants, a reference method, or any other method that gives similar results as the reference method should be used. In Finland, a large variety of automated measurement methods are used for PM measurements. In Mannerheimintie Helsinki, the device used for PM_{10} monitoring is Eberline FH 62 I-R Particulate Monitor, whereas in Pirkankatu Tampere a TEOM 1400 (Tapered Element Oscillating Microbalance) is used. TEOM 1400 device is also used in Sniffer vehicle to measure the street surface emissions.

3.3.1 Eberline FH 62 I-R Particulate Monitor

The Eberline Particulate Monitoring Instrument FH 62 I-R is used in Mannerheimintie air quality measuring station in Helsinki. This equipment utilizes the radiometric principle of beta-attenuation by a two-beam-compensation method.

3.3.2 TEOM 1400

The TEOM 1400 instrument (Tapered Element Oscillating Microbalance) incorporates a tapered element oscillating microbalance; a micro weighing technology that provides true mass measurements. The instrument can be configured to measure PM_{10}, $PM_{2.5}$, PM_1 or TSP concentrations. Air is aspirated through the TEOM-analyzer at a constant speed of $1m^3/h$ at ambient temperature. Large particles are removed from the flow with pre-filter. The flow is divided into by-pass flow (13.7 l/min) and the sample flow (3 l/min), which is fed through a filter at the tip of a conical element. Particles in the sample air remain on the filter and with decreasing amount of the particles the resonant frequency of a conical element decreases. Therefore the device measures the particle mass that is collected to the filter. Before the measurement the incoming air flow is heated to +50°C to remove the moisture from the air. (Elsilä 2010.)

3.4. Statistical analysis

In practice, the statistical analysis used in this thesis was carried out using the Microsoft Excel template MAKESENS developed at the Finnish Meteorological Institute (available at http://www.ilmanlaatu.fi/ilmansaasteet/julkaisu/julkaisu.php) for detecting and estimating trends in the time series of annual values of atmospheric and precipitation concentrations. The procedure is based on the nonparametric Mann-Kendall test for the trend and the nonparametric Sen’s method for the magnitude of the trend. (Salmi et al. 2002.)

The slope of the linear trend was estimated with Sen's method, and the Mann–Kendall test was used to evaluate whether the slope estimate is statistically different from zero. This two-phase method is applicable to a monotonically-increasing or decreasing trend within a time series in the absence of any seasonal variation or other cycles. In MAKESENS applications, the most common way to eliminate the seasonal variation is to limit the analysis to annually-averaged data or to time series of a specific month or season of the year. In this work the analysis is limited to a data from specific season. (Anttila et al. 2010.)

4. DESCRIPTION OF THE WORK

The aim of this thesis was to study how the concentrations of PM_{10} sized particles have developed in two big cities in Finland from 2006 to 2010. This was done using two different data sets, official air quality data and data from KAPU project. The air quality data used in this work is from the environmental authorities of Helsinki and Tampere. The KAPU data was delivered by Nordic Envicon Oy with the permission of the KAPU working group. In addition, a statistical analysis was used for detecting and estimating trends in the data.

4.1. Qualitative study

A qualitative approach was used to compare the air quality data with street dust emissions data from the KAPU project. Weekly averages for the air quality data (PM_{10}) were calculated from the daily averages, in order to compare between the air quality data and the results from the KAPU project. The occurrence of peak emissions levels between different years were compared for both Helsinki and Tampere.

In Helsinki, depending on the year, KAPU measurements have been conducted 9-14 times during springtime dust period. In Tampere KAPU measurements have been conducted 2-4 times per year during the five years of measurements (see table 3).

Table 3. KAPU measurement dates in Helsinki and Tampere years 2006 – 2010. The difference between the numbers of measurements can be explained by differences between the cities (e.g. size), different emphases and different budgets regarding the KAPU project.

Helsinki							
2006	21.3.	06.4.	20.4.	24.4.	27.4.	04.5.	07.8.
2007	07.2.	22.2.	23.2.	16.3.	27.3.	03.4.	12.4.
	17.4.	24.4.	03.5.	10.5.	06.6.	15.6.	11.9.
2008	01.4.	10.4.	11.4.	16.4.	14.5.	20.5.	23.5.
	27.5.	06.6.					
2009	16.1.	16.3.	19.3.	25.3.	01.4.	02.4.	09.4.
	16.4.	20.4.	24.4.	04.5.	07.5.	13.5.	18.5.
2010	09.3.	01.4.	08.4.	10.4.	15.4.	20.4.	26.4.
	27.4.	03.5.	12.5.	26.5.	07.6.		

Tampere				
2006	26.4.	12.5.	12.6.	
2007	26.3.	27.4.	4.6.	
2008	2.4.	17.4.	30.5.	
2009	26.3.	21.4.		
2010	08.4.	21.4.	06.5.	31.5.

4.2. Statistical analysis

The idea for the statistical analysis used in this thesis is based on the work of Anttila & Tuovinen (2010) who tested the trends of atmospheric concentrations of main gaseous and particulate pollutants in urban air for the period 1994-2007 using the MAKENSES template described in chapter 3.4. In order to find out the trends of street dust, Anttila & Tuovinen studied the monthly means calculated from the hourly PM_{10} concentrations. They also performed an analogous trend analysis for the 95th percentiles of the hourly means of PM_{10} concentrations during February–May, in other words the highest concentrations. 95th percentile is considered to be attributable to street dust. (Anttila et al. 2010.)

Aim of this part was to analyze data, similarly to Anttila & Tuovinen, from a period when the tools for more efficient street cleaning have been introduced, especially in Helsinki (Mannerheimintie). In addition to inspect the overall trends in PM_{10} concentrations, the purpose was to determine whether the observed trends in the research sites show that new methods and practices in street dust control could have decreased the concentrations of PM_{10}.

Weather conditions during spring are of great importance especially in terms of the occurrence of the peak emissions. Weather conditions also affect the transport and mixing of pollutants. Due to the limited scope and nature of this work, a more detailed analysis of the meteorological data was excluded from this thesis. However general information about the weather conditions in each winter and spring, which has been earlier collected for KAPU project, was used in this thesis. KAPU project also collected detailed information about the winter and spring maintenance in participating cities from 2006 to 2010 and to some extent that information is also utilized in this work.

5. RESULTS

In this chapter, air quality trends regarding respirable particles for both cities Helsinki and Tampere are presented. Qualitative analysis is performed regarding the trends in average concentrations in between years 2006 and 2010. Weather conditions during spring/winter seasons are shortly described in order to point out the natural variation between years of research.

5.1 Weather conditions in 2006-2010

Information about winter and spring weather conditions during years 2006 – 2010 that are used in this thesis were originally collected for the KAPU project (Kupiainen et al. 2009). Weather conditions during spring are of great importance especially in terms of the occurrence of the street dust peak emissions, but also regarding PM_{10} in ambient air. During winter, weather conditions set the limits for traction control methods, how much sand or salt is used. Weather conditions, for example atmospheric inversions also affect the transport and mixing of pollutants. More detailed information about the weather conditions (amount of rainfall, wind directions etc.) is available for both cities for example in the air quality reports of the environmental authorities. Due to the limited scope and nature of this work, a more detailed analysis of the meteorological data is excluded from this thesis. However each winter season is briefly described in order to give examples of the differences between the years.

In **2006** January was somewhat milder than average, February and March on the other hand were colder. Early spring was cold and rainy, and the actual street dust period only started in late April.

Winter season **2006/2007** was warmer than average except in February. Springtime precipitation levels were normal. In March average temperatures were 3 degrees higher than average in the entire country. In Helsinki street cleaning actions started on the last week of March, and were finished by the end of April, 2-3 weeks earlier than previous spring.

Winter **2007/2008** was the mildest winter ever documented in Finland. Precipitation occurred mainly as rain. There was little or no need for traction sanding in the Helsinki metropolitan area.

In Tampere winter season **2007/2008** was different from that in the metropolitan area. Temperatures close to zero, mild rain- and snowfall together with nighttime frosts made the implementation of traction control challenging. These differences point out how the conditions between two cities during same year can highly affect the need of winter maintenance.

Winter season **2008/2009** in Southern Finland was milder and less rainy than average, although average temperatures in February-March were close to those of the reference period (1971-2000). Snow cover in the metropolitan area formed at the end of January and lasted until the end of March. In late March nighttime temperatures still dropped below zero and the last of the snow melt in mid-April. April was a dry month. There were substantially more dust binding registrations in Helsinki compared to the previous years. The effect of dust binding practices to air quality is explained earlier in chapter 2.5.

According to meteorological data, winter season **2009/2010** was colder than average and with more abundant precipitation. Temperatures stayed below zero from December until the end of February. The Helsinki metropolitan area had a snow cover from the beginning of the year until late March. January and February in the metropolitan area were clearly colder than average. January was approximately 6-7 degrees colder than the reference period 1971-2000, and February more than 3 degrees colder. In late January the coldest temperatures measured in the Helsinki area were between -27.7 and -22.6 degrees. March was still colder than average, whereas April was warmer than average. Spring was rainy, which means that street surfaces did not stay dry for long periods and this may have reduced resuspension from the street surfaces. (Kupiainen et al. 2009)

5.2 Respirable sized particles in ambient air, trends in Helsinki and Tampere in 2006-2010

Particles originate from various different types of sources and meteorological and seasonal changes affect the emissions and particle concentrations both in ambient air as well as in street surfaces. In this chapter trends in ambient air in both cities Helsinki and Tampere are presented.

5.2.1 Yearly trends presented as weekly averages in Helsinki and Tampere

Figures 11. and 12 indicate how the concentrations of PM_{10} develop in the course of years 2006 - 2010 in the centre of Helsinki and Tampere. To see the figures in bigger size, refer to appendix 2. Figures are based on weekly averages, which are calculated from daily averages. The levels of PM_{10} concentration is in principle at its highest during spring, when also most of the exceedances in the daily limit value (50 ug/m^3) take place. High concentrations may also occur during any other season, but usually there is an upward trend in the beginning of spring, which descends towards summer, which is also clearly visible in these two figures.

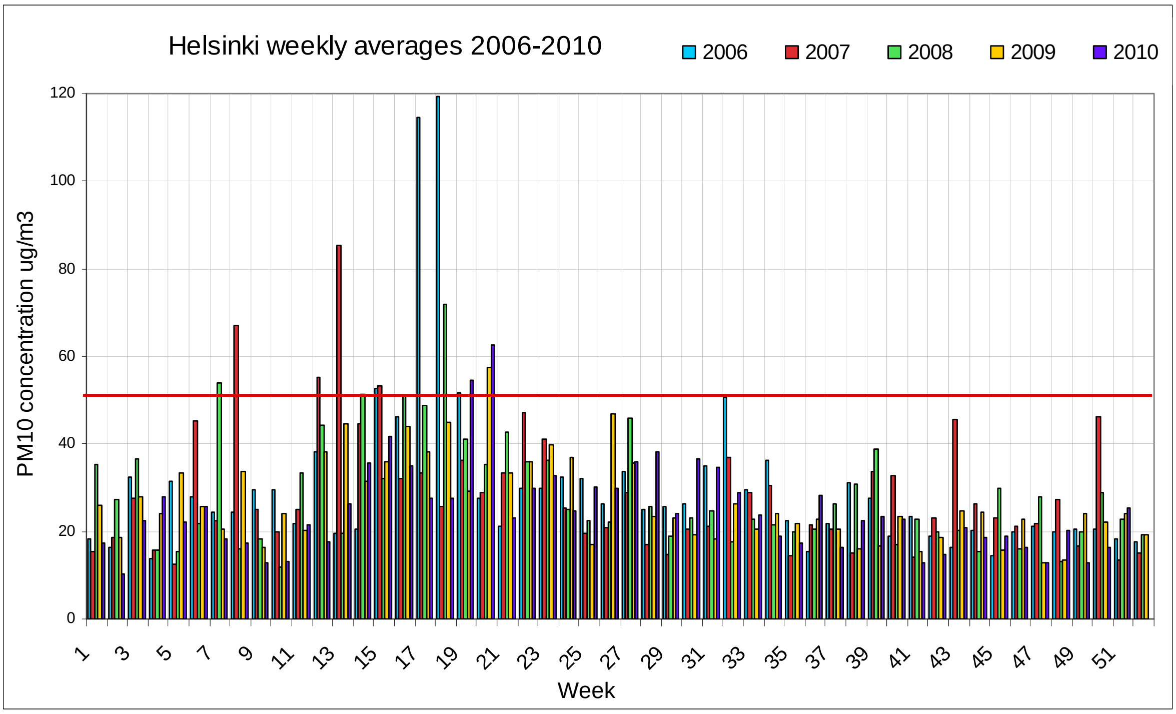

Figure 11. Weekly averages of PM_{10} concentrations in Mannerheimintie measuring station in Helsinki. Red line indicates the limit value for daily PM_{10} average concentration.

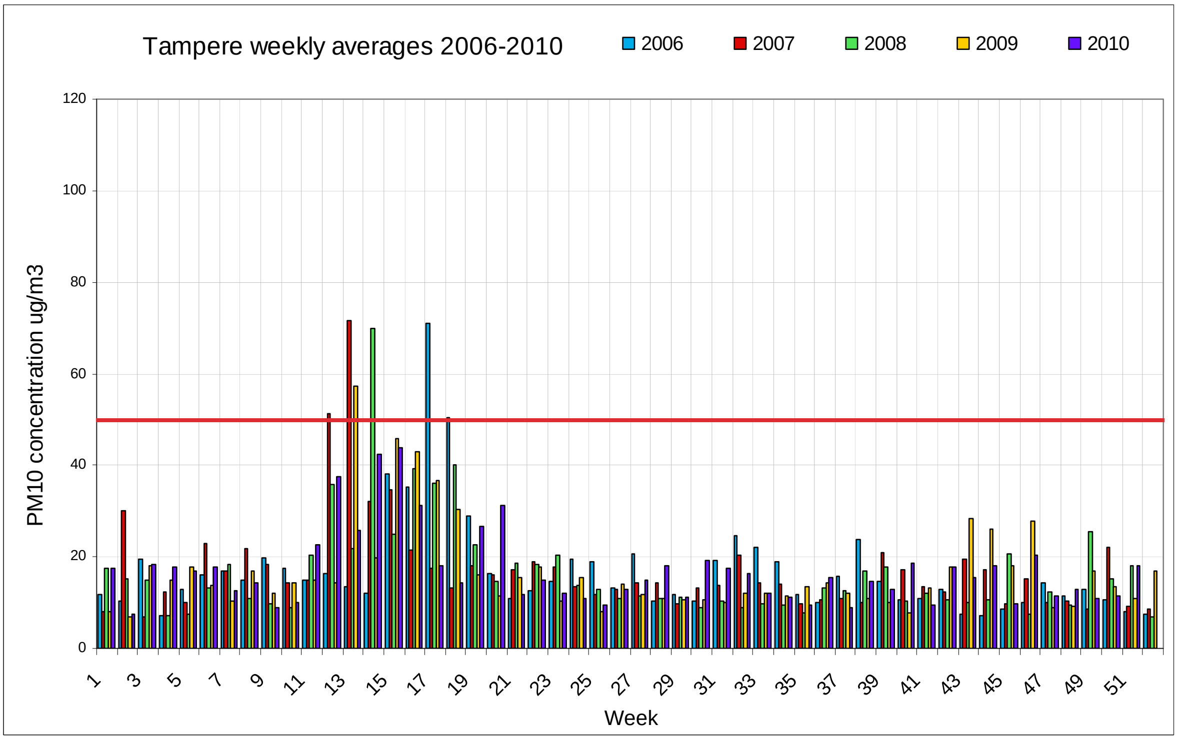

Figure 12. Weekly averages of PM_{10} concentrations in Pirkankatu measuring station in Tampere. Red line indicates the limit value for daily PM_{10} average concentration.

5.2.2 Springtime trends of PM_{10} in Helsinki and Tampere

Even though the PM_{10} peak values normally occur around same time each spring, the prevalence of PM_{10} peak values fluctuates in the course of years. Each spring is distinct and the occurrence of the peak values is dependent on for example weather and atmospheric conditions, as well as the nature of the preceding winter (see chapter 5.1 Weather conditions in 2006-2010). However the gap between the peak emissions is usually within weeks. Figures 13 and 14 illustrate the differences between springs, and how the emissions peak a little different time every year. To see the figures in bigger size, refer to appendix 2.

The period, from March 14. to April 30., is selected based on earlier experience about the occurrence of high concentrations, and also based on the previous figures (11 and 12) that present how the PM_{10} peak values are most likely to take place during that period. Also most of the KAPU measurements coincidence to that period. Air quality data is compared with the KAPU data in more detail in chapter 5.3.

In 2006 and 2007 in Helsinki there are clear peaks in late March (2007) and late April (2006) although high values occur throughout the period. In 2010 emissions peak around mid April, but the peak is clearly lower than for example in 2006 or 2007. It is also not visible in this graph, but PM_{10} emissions in May 2010 (week 20) are visibly higher than in preceding years.

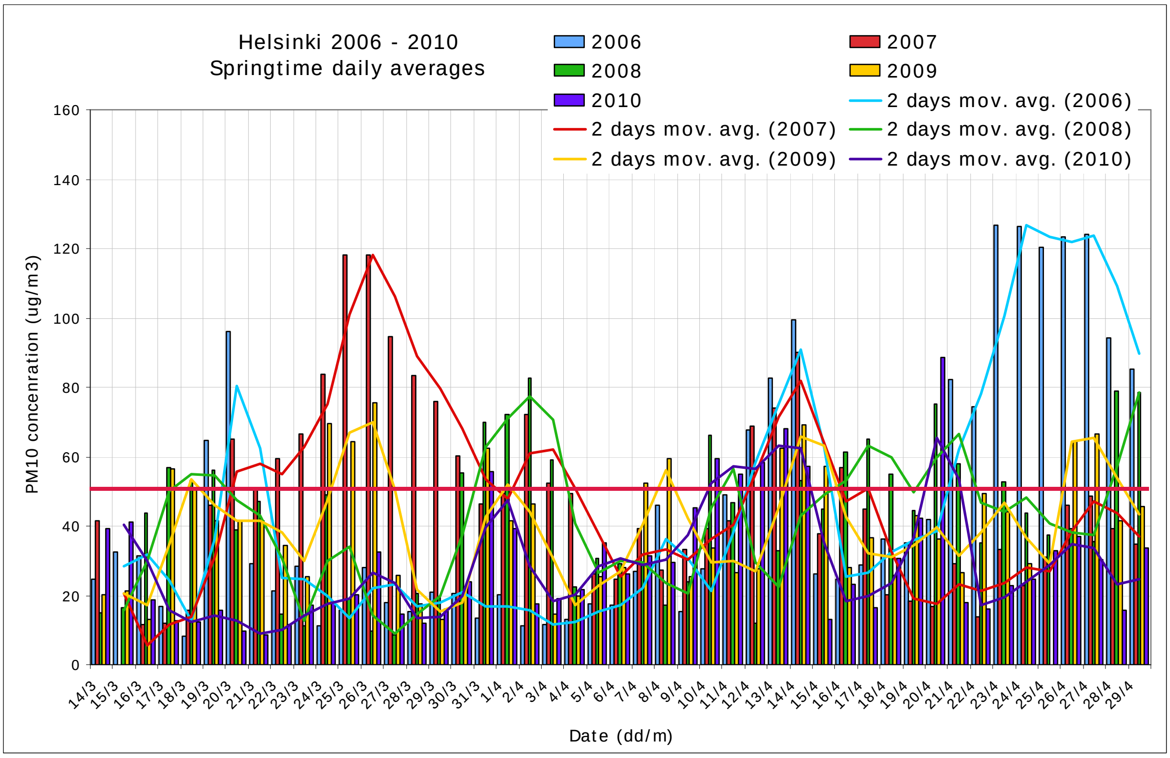

Figure 13. Daily concentrations and moving average of springtime PM_{10} concentrations in Helsinki (Mannerheimintie) from the March 15. until April 30. in 2006 – 2010.

In Tampere in 2008 the concentration of PM_{10} has been extremely high for few days in the beginning of April. The daily average concentrations during first three days of April in Pirkankatu measuring station were 75, 189 and 164 ug/m^3 respectively. According to registrations for the KAPU project, dust binding took place in the centre of Tampere in April 2. and 3. After that also the daily average concentrations of PM_{10} show a significant decrease (see figure 14.). From April 4. to April 8. the daily average concentrations were 50, 16, 17, 18 and 5 ug/m^3 respectively.

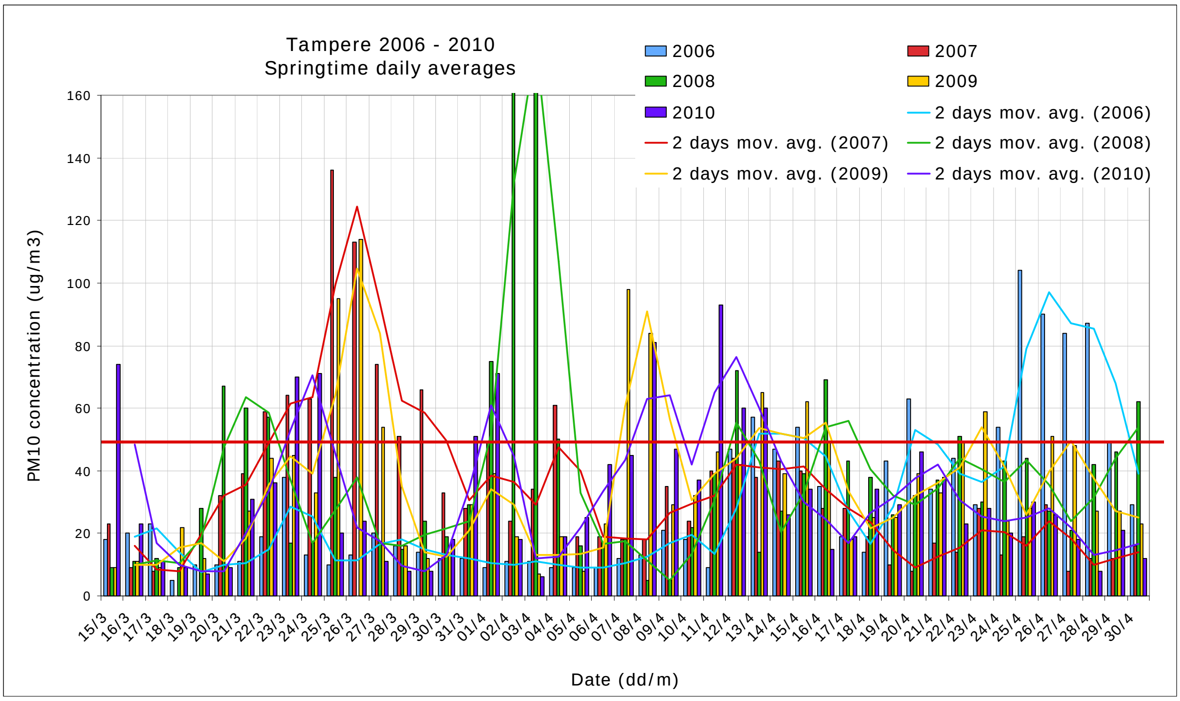

Figure 14. Daily concentrations and moving average of springtime PM_{10} concentrations in Tampere (Pirkankatu) from the March 15. until April 30. in 2006 – 2010.

There was substantially less information available from Tampere about the winter and spring maintenance practices, which makes it more challenging to interpret the changes and trends in Tampere data.

5.3 Comparison between the PM_{10} concentrations in the air quality data and PM_{10} emissions from the street surfaces (KAPU data)

The air quality data is available for all the dates and weekly averages can be calculated for each week in every spring. KAPU measurements have been carried out on far more irregular basis (see table 3.), the number of measurements per year is from 2 (Tampere 2009) to 14 (Helsinki 2007). However, the comparison was carried out with the available data. Special attention was given on the dates, when cities were known to have performed for example street cleaning activities, dust binding or other. In case more profound trend analysis or comparison between the air quality data and street dust emissions was to be achieved, it would also require more regular and continuous monitoring of the street dust emissions.

5.3.1 Air quality data compared with KAPU results, Helsinki 2006 – 2010

Weekly averages of air quality data and KAPU data were calculated from the daily averages. Each year has its own color, which makes it an easy and simple way to search for similarities in the timing and occurrence of peak emissions.

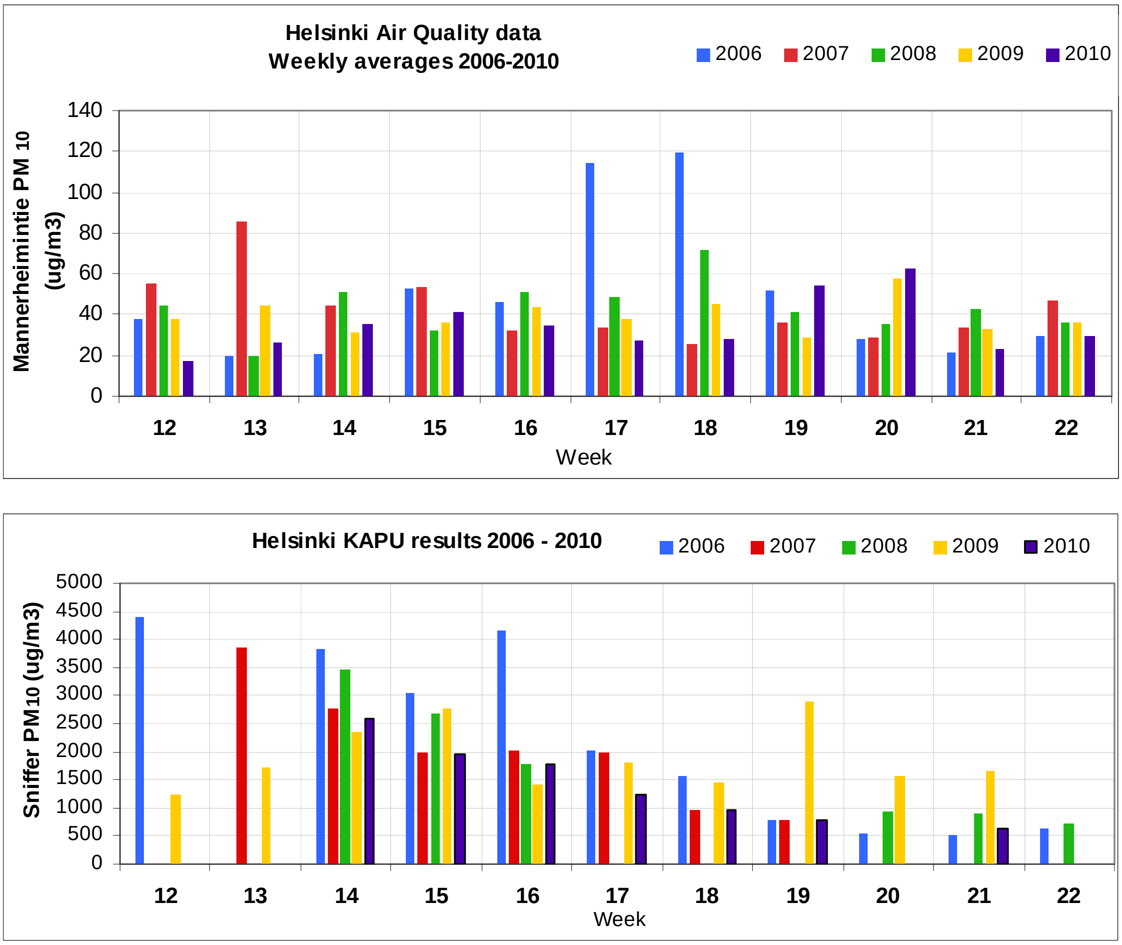

Figure 15. Weekly averages of PM_{10} in Helsinki, air quality data compared with KAPU results (PM_{10} emissions measured by Sniffer)

Dust binding was carried out in Mannerheimintie in April 12. and 13. 2010 (week 15). Also KAPU measurements were carried out in Helsinki before and after the procedure. A qualitative inspection of both air quality and KAPU data (see Figure 16.) reveals that emissions have decreased in 2010 from week 15 to 16. However, weekly averages of air quality data might be too rough to distinguish the effect of separate cleaning measure. To tell whether for example the dust binding that is performed in Mannerheimintie has had any effect on the air quality data, daily averages need to be inspected. KAPU measurements were carried out in April 10., 15. and 20. Corresponding figures in the air quality data (daily averages in Mannerheimintie measuring station) for April 10., 15. and 20. were 59, 13 and 89 ug/m^3 respectively.

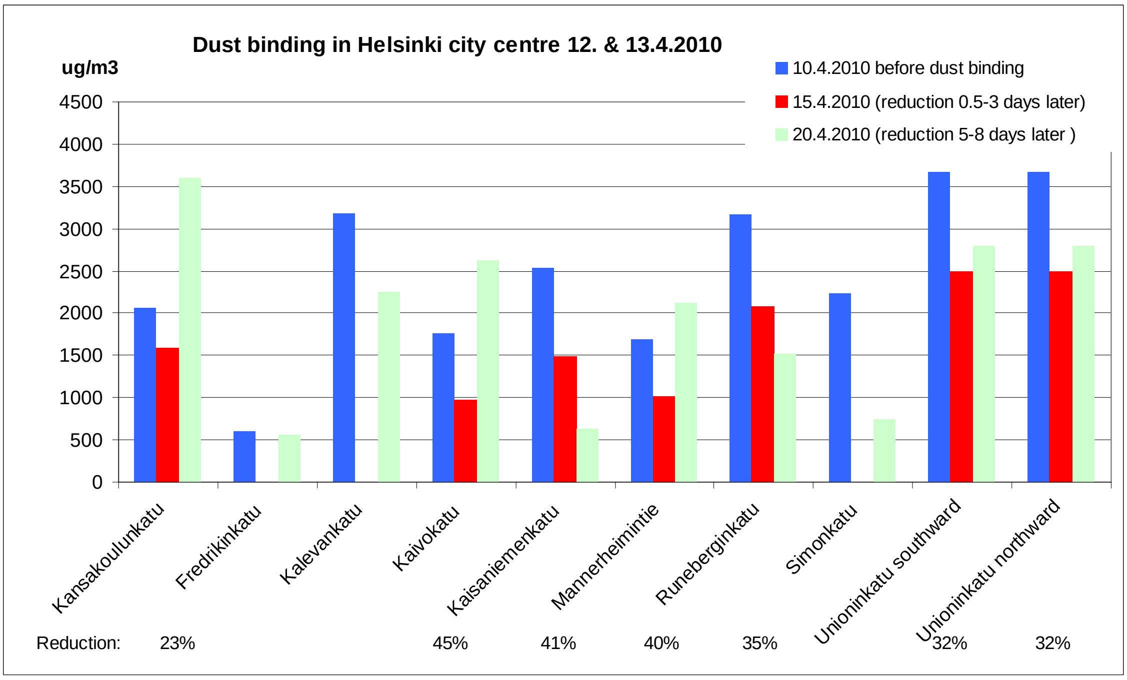

Figure 16. The results from KAPU measurements (street dust emissions) in April 2010, before and after dust binding. Dust binding was carried out in April 12. and 13.

It is obvious that dust binding has been very effective, but the duration of the effect is limited. The duration of the effect of dust binding is discussed in more detail in chapter 2.4.

5.3.2 Air quality data compared with KAPU results, Tampere 2006 – 2010

The weekly averages of the air quality data are available for each week in every spring. However KAPU measurements have been carried out on far more irregular basis (see table 3.), the number of measurements per year in Tampere is from 2 to 4. The comparison was carried out with the available data (see figure 17).

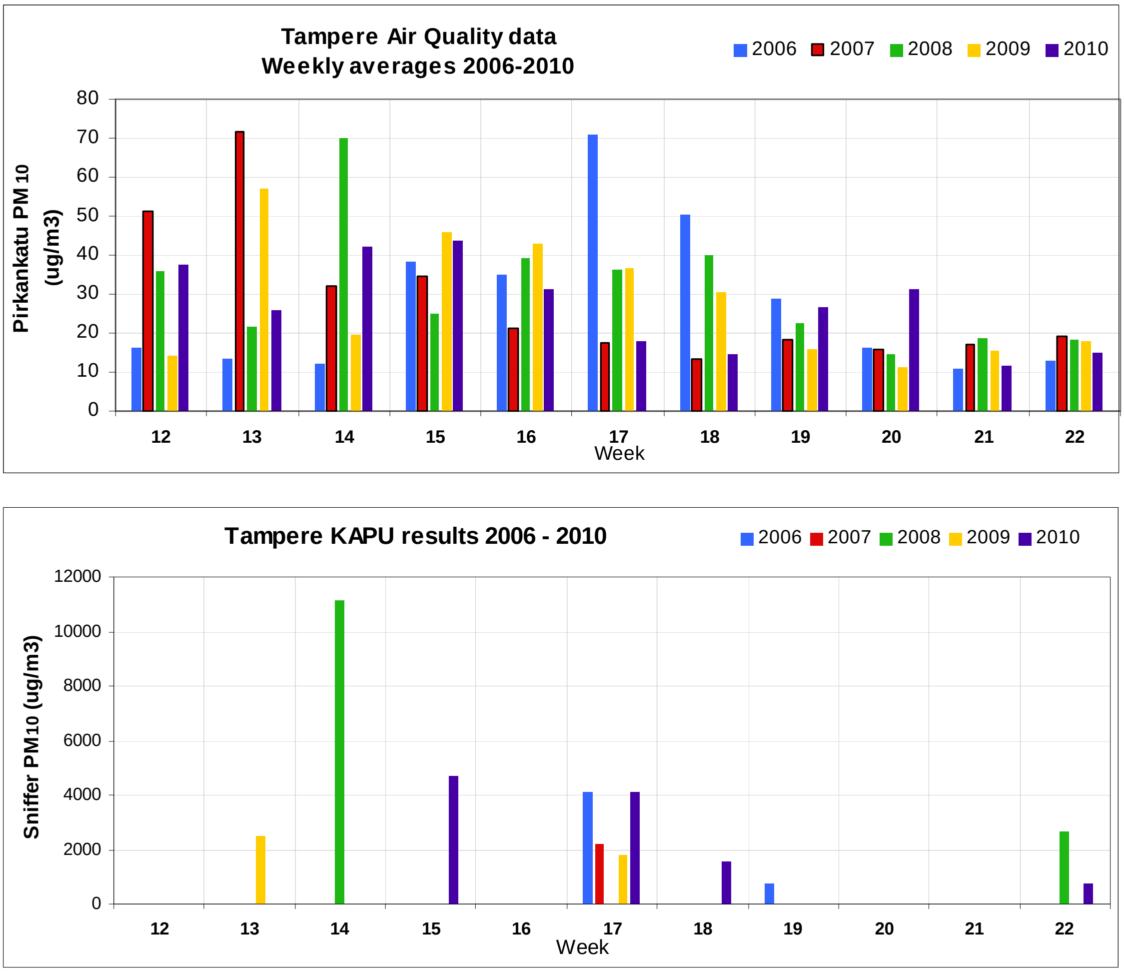

Figure 17. Weekly averages of PM_{10} in Tampere, air quality data compared with KAPU results (PM_{10} emissions measured by Sniffer).

5.4. Statistical analysis

5.4.1 Statistical trend analysis on a weekly level for the air quality data

When weekly concentrations of PM_{10} (air quality data) from 2006 to 2010 were inserted to MAKENSES template, the only week under which the trend show a significant change (increasing trend) in the course of years is week 20 (in Helsinki). See table 4.

Table 4. Statistical analysis for the weeks 11 – 21 from 2006 to 2010. Statistical significance is appointed by a star in the Column "Signific." (Salmi et al. 2002)

	Week	First year	Last Year	n	Test S	Signific.
Helsinki	11	2006	2010	5	-2	
	12	2006	2010	5	-6	
	13	2006	2010	5	2	
	14	2006	2010	5	2	
	15	2006	2010	5	-2	
	16	2006	2010	5	-2	
	17	2006	2010	5	-6	
	18	2006	2010	5	-4	
	19	2006	2010	5	0	
	20	2006	2010	5	10	*
	21	2006	2010	5	0	
Tampere	11	2006	2010	5	3	
	12	2006	2010	5	0	
	13	2006	2010	5	2	
	14	2006	2010	5	4	
	15	2006	2010	5	2	
	16	2006	2010	5	2	
	17	2006	2010	5	-2	
	18	2006	2010	5	-4	
	19	2006	2010	5	-2	
	20	2006	2010	5	-1	
	21	2006	2010	5	0	

5.4.2 95th percentiles

Due to the differences between springtime weather conditions and occurrence of peak emissions it is perhaps more reasonable to examine the overall trend between the years and not to compare specific weeks from year to another. Springtime averages were compared to each other using 95th percentiles of the data.

A percentile is the value of a variable below which a certain percent of observations fall, thus 95th percentile can be defined as the lowest reading that is greater than 95% of the readings. 95th percentile here is used to exclude the effect of weather or other external factors, and to compare only the maximum concentrations between the years, regardless of their timing. Regarding the air quality data, the 95th percentile of the PM_{10} concentrations is considered to be attributable to street dust. (Anttila et al. 2010.)

95th percentile was calculated for each spring, from the daily averages between weeks 11 and 21. When inserting the 95th percentiles from 2006 to 2010 into the MAKENSES template, a downward trend can be detected for the air quality data of both cities. For Helsinki, this downward trend is clear and also statistically significant (see table 5.). In Tampere case, the slope is not steep, the emissions have stayed more or less in a same level (what comes to 95th percentiles). One of the explanations could be that according to maintenance records, Helsinki has put more emphasis on introducing new and effective methods in combating the dust problem. It also has to bear in mind that the initial airborne particle emissions in Tampere are significantly lower than in Helsinki, the difference in initial street dust emissions is not as significant though.

Table 5. Statistical analysis for 95th percentiles from 2006 to 2010. For the air quality data weeks 11 – 21 are used, and for the KAPU data all results from one year. Statistical significance is appointed by a star in the Column “Signific.” (Salmi et. Al 2002)

Data	**Time series**	**First year**	**Last Year**	**n**	**Test S**	**Signific.**
Air Quality	Helsinki	2006	2010	5	-10	*
	Tampere	2006	2010	5	-2	
KAPU	Helsinki (Sniffer emission)	2006	2010	5	-10	*
	Tampere (Sniffer emission)	2006	2010	5	2	

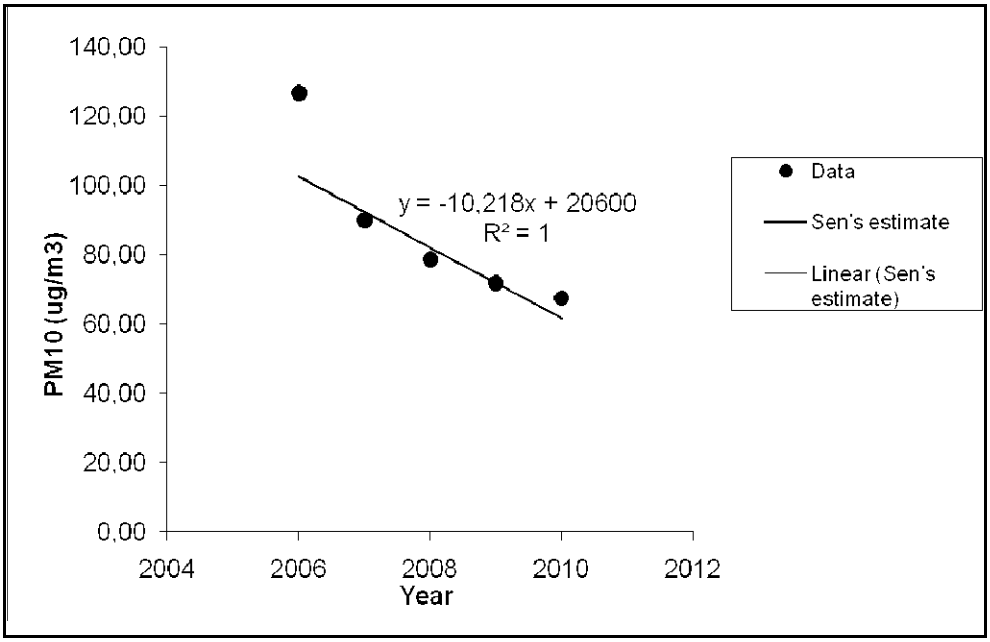

Figure 18. The trend for the springtime concentrations of PM_{10} (air quality data) in 2006 – 2010 in Helsinki is decreasing. The trend is calculated by using the 95th percentiles, which is attributable to street dust.

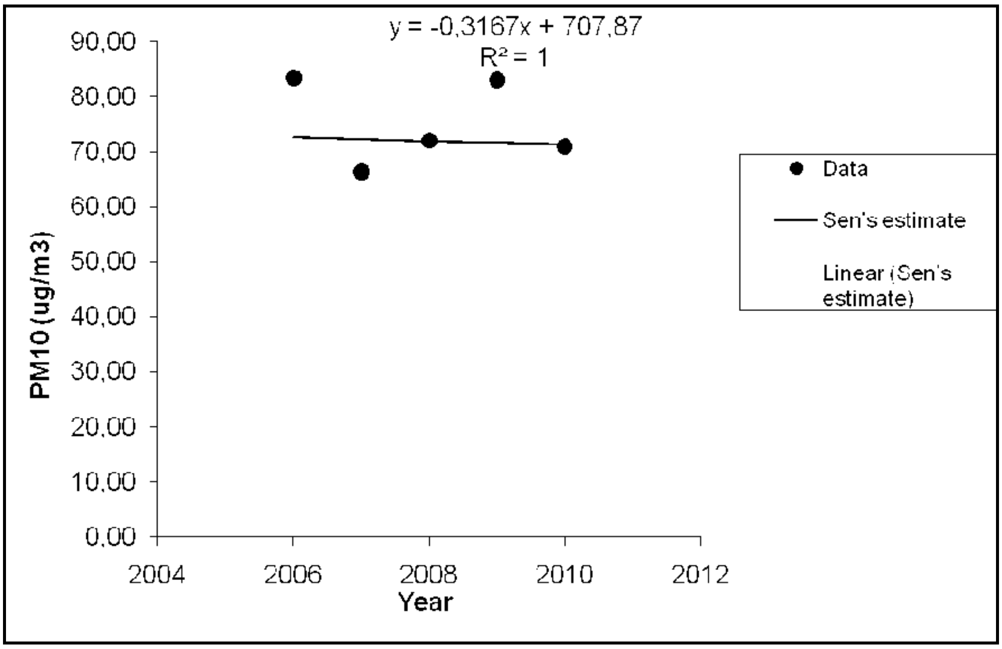

Figure 19. The trend for the springtime concentrations of PM_{10} (air quality data) in 2006 – 2010 in Tampere is decreasing, but only slightly. The trend is calculated by using the 95th percentiles.

Comparison between the years 2006-2010 using the 95th percentiles of KAPU data was also studied. 95th percentile was calculated for each year, for all the measurement results during one year. Using 95th percentiles regarding the KAPU data, the lowest of the measuring results are excluded, which might be attributable to rainfall or other seasonal or meteorological factors.

A downward trend can be detected only for Helsinki. The downward trend is clear, similar to that of the air quality data, and according to MAKENSES statistics, it is also statistically significant (see figure 20 and table 5). In Tampere case, the trend for 95th percentiles of KAPU results is actually upward (see figure 21).

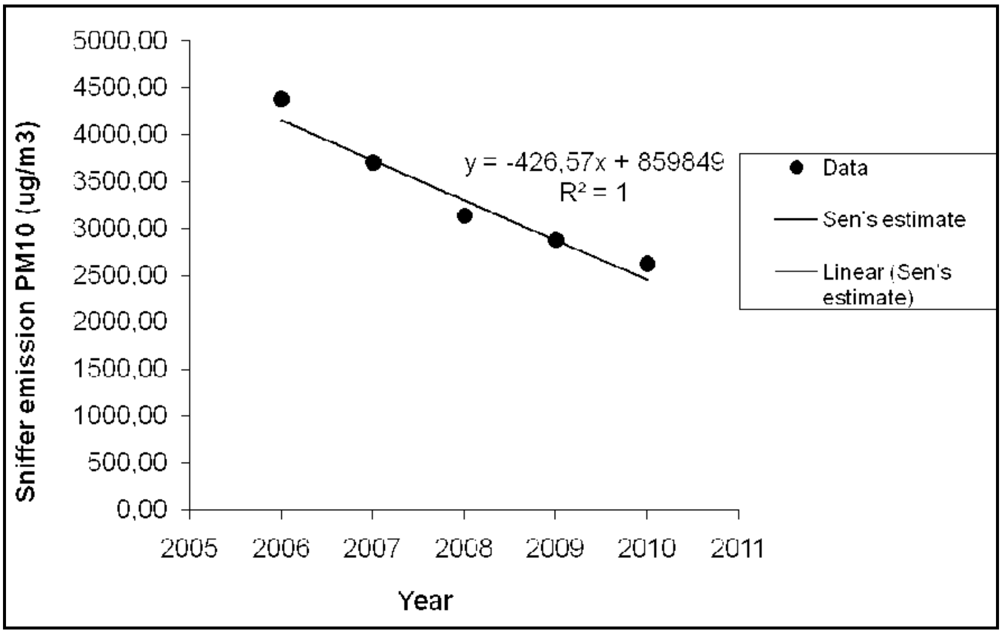

Figure 20. The trend for the concentrations of KAPU street dust emission measurements in 2006 – 2010 in Helsinki is decreasing. The trend is calculated by using the 95th percentiles.

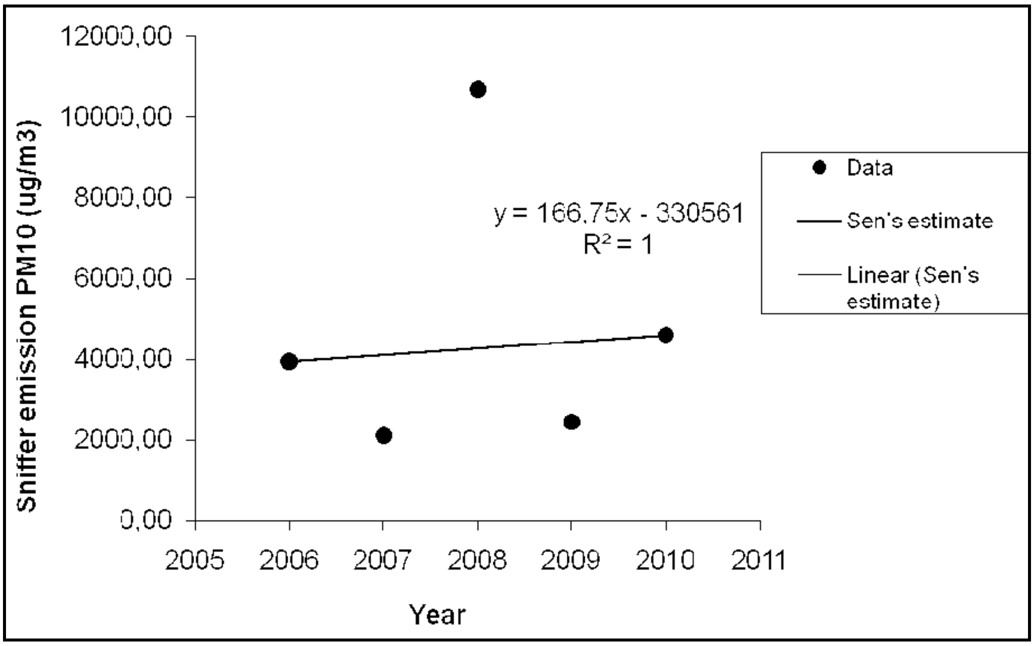

Figure 21. The trend for the concentrations of KAPU street dust emission measurements in 2006 – 2010 in Tampere, the slope is upward. The trend is calculated by using the 95th percentiles.

5.5. Evaluation of the data

Unfortunately validated air quality data was not yet available for the year 2010 for the time being. However, the non-validated data hardly goes through significant changes in the validation process, and it was justified to use the non-validated data in order to prolong the time series used in this work.

6. DISCUSSION & CONCLUSIONS

The level of PM_{10} concentration is in principle at its highest during spring, when also most of the exceedances in the daily limit value (50ug/m^3) take place. High concentrations may also occur during any other season, but usually there is an upward trend in the beginning of spring, which descends towards summer. This is also visible in the air quality data used in this thesis, regarding both Helsinki and Tampere.

The graphs based on weekly averages are very similar in shape for both cities, but the magnitude for the concentration differs between Helsinki (Mannerheimintie measuring station) and Tampere (Pirkankatu measuring station). Concentrations in Tampere are clearly lower than in Helsinki, which is obviously due to the disproportion regarding the sources of particle emissions. Particle emissions in Helsinki Metropolitan area are multiple compared to those in Tampere and its neighbors. The location of the measuring station is also significant, since it is prone to local emissions. Both measuring stations; Mannerheimintie in Helsinki and Pirkankatu in Tampere, are urban traffic stations and the detected concentrations represent the level to which people are exposed to in urban environment. However the environments of these stations differ a lot from each other; the measuring point in Mannerheimintie is along the busiest streets in Helsinki, straight in the city centre, whereas the measuring point in Tampere is somewhat outside the city centre and the amount of traffic around the measuring point is significantly lower than that in Helsinki.

In 2006 and 2007 in Helsinki there are clear peaks in late March (2007) and late April (2006) although high values occur throughout the period. In 2010 emissions peak around mid April, but the peak is clearly lower than for example in 2006 or 2007. It is also not visible in this graph, but PM_{10} emissions in May 2010 (week 20) are visibly higher than in preceding years. According to weather information spring 2010 was rainy; street surfaces did not stay dry for long periods of time, which may have reduced resuspension from the street surfaces, and postpone the occurrence of peak emissions.

According to the winter maintenance information collected for KAPU project, in spring 2009 in Helsinki there were substantially more dust binding registrations compared to preceding years, which may have lowered especially street dust emissions. There was substantially less information available from Tampere about the winter and spring maintenance practices, which makes it more challenging to qualitatively interpret the changes and trends in Tampere data.

Weather conditions during spring are of great importance especially in terms of the occurrence of the street dust peak emissions, but also regarding PM_{10} concentration in ambient air. During winter, weather conditions set the limits for traction control methods, how much sand or salt is used. Weather conditions, for example atmospheric inversions affect the transport and mixing of pollutants. Rain fall may have a dust binding-effect and thus lower the concentrations. Heavy rain fall washes dust away from the street environments and thus may have a significant and also long-lasting effect. The data used in this thesis was used without any pre-filtering regarding weather conditions or other external factors. The work could continue and the data further analyzed, by for example eliminating the dates when rainfall or other variable may have affected the concentration. Regarding the statistical analysis that was a part of this work, 95th percentiles were used in order to find out how the peak concentrations have developed along the years.

Several studies show that street dust contributes significantly to ambient air PM_{10} concentrations. Cutting down particle emissions from traffic has been successful, but only regarding the exhaust emissions. Since 1990's the European emission standards have introduced increasingly stringent limits defining the acceptable limits for exhaust emissions of new vehicles sold in EU member states. However the particle emissions caused by traffic and transportation remain a challenge due to non-exhaust particle emissions.

Anttila & Tuovinen (2010) who analyzed the trends of PM_{10} in 1994-2006, state, that in terms of air pollution abatement, the results of the 95th percentiles trend analysis is less favorable than that of the monthly means, and that their results suggest that the measures taken to reduce the yearly street dust problem have not in general been successful. When analyzing the 95th percentiles from 2006 to 2010 with the same MAKENSES template that Anttila & Tuovinen used in their study, a downward trend can be detected for both cities. For Helsinki, this downward trend is clear and also statistically significant. In Tampere case, the slope is not steep, the emissions have stayed more or less in a same level (what comes to 95th percentiles). One of the explanations could be that according to maintenance records, Helsinki has put more emphasis on introducing new and effective methods in combating the dust problem. Sanding as a traction control method has been less frequently used, whereas dust binding has been more frequently used. It also has to bear in mind that the initial airborne particle emissions in Tampere are significantly lower than in Helsinki. The difference in initial street dust emissions is not as significant though

One important thing to note is that the time series used for this study is very short, only five years. Five years of measurement data is not much, and in order to achieve more reliable or extensive information longer time series together with extensive and regular measurements should be considered. However, information gained from this study can as such bring added value for the cities in their air quality protection work.

One possibility would also to use different time frames to study specific periods during years or during springtime. However this is not necessarily meaningful regarding the big seasonal and meteorological differences between years. The occurrence of peak concentrations fluctuates between years, which can be seen by looking the trends of weekly averages presented in this work.

What comes to comparing the air quality data with the data from the KAPU project, it looks like the consistency with the data is axiomatic only occasionally. This however is generalization from a qualitative analysis solely based on looking the weekly average figures, and the interpretation can be considered quite rough. KAPU measurements have been carried out on an irregular basis, and the number of measurements in Tampere has only been from 2 to 4, and in Helsinki 9 to14 times during springtime dust period. Similarly as with the air quality data, longer time series together with more regular and extensive measurements, as well as more extensive maintenance registrations, would produce better baseline for the interpretation of the results.

The trend for the 95th percentiles of the KAPU data (2006 – 2010) was also studied. 95th percentile was calculated for each year, for all the measurement results during one year. In other words maximum concentrations regardless of the timing were used. This was used to exclude external factors such as rainfall that are otherwise affecting the concentrations. A downward trend was detected only for Helsinki. The downward trend is clear, similar to that of the air quality data, and according to MAKENSES statistics, it is also statistically significant. In Tampere case, the trend for 95th percentile is actually upward. One explanatory factor could be, the same as with the air quality data, that according to maintenance records, Helsinki has put more emphasis on introducing new and effective methods in combating the street dust problem.

As stated earlier, in case more profound trend analysis or comparison between the air quality data and street dust emissions was to be achieved, more regular and continuous monitoring of the street dust emissions would be needed. What comes to year 2011, KAPU measurements proceed in Helsinki Metropolitan area, but the city of Tampere is not participating the project for the time being.

Compared to other European cities, or even other large Scandinavian cities, it looks like Finnish cities did not suffer from severe threats regarding air pollution. Our biggest challenge is the pollutants associated with traffic; nitrogen dioxide and particulate matter. Closer look on the daily concentrations of PM_{10} sized particles in big Finnish cities reveal that especially during springtime the levels are alarming. Especially because safe limit value, under which no adverse health effects would occur, has not been detected.

The range of health effects is broad, but most often the effects are related to respiratory symptoms and cardiovascular diseases. What makes it even trickier is that particles of this magnitude can basically be found everywhere, and thus all population is affected. However often it is the most vulnerable groups of people; children, elderly and sick people, who suffer the most. The health aspect alone is important enough to deal with the matter with most severity.

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APPENDICES

ENVIRONMENTAL PROTECTION ACT Chapter 15 APPENDIX 1:1(2)

From The Environmental Protection Act:
Chapter 15 - Miscellaneous provisions
Section 102

Protection of air quality

(1) Municipalities shall use all means at their disposal to prepare for action to prevent any exceedances of limit values for air quality laid down by Government decree in the municipality. Any exceedances limit values shall be announced publicly and the population shall be warned. Government decrees on air quality shall contain provisions on cases where preparation is essential and on the detailed content of warnings.

(2) In the case of a exceedence of a limit value laid down in a Government decree, the municipality shall take appropriate action or issue orders to restrict traffic and decrease emissions. Provisions concerning reduction of emissions arising from activities subject to permit and any unexpected occurrence of significant air pollution will be issued separately.

(3) Municipalities must provide members of the public with information about the preparation of air quality plans and programmes and give them an opportunity to express their views about the draft plans and programmes at a sufficiently early stage. The opportunity must be given by posting information about the matter on the municipal notice board or in a newspaper in general circulation in the area, and also in electronic form. Information on the approved plan or programme and its justification and on how consideration has been given to the views expressed must be provided in the same manner as for for the draft plan or programme.

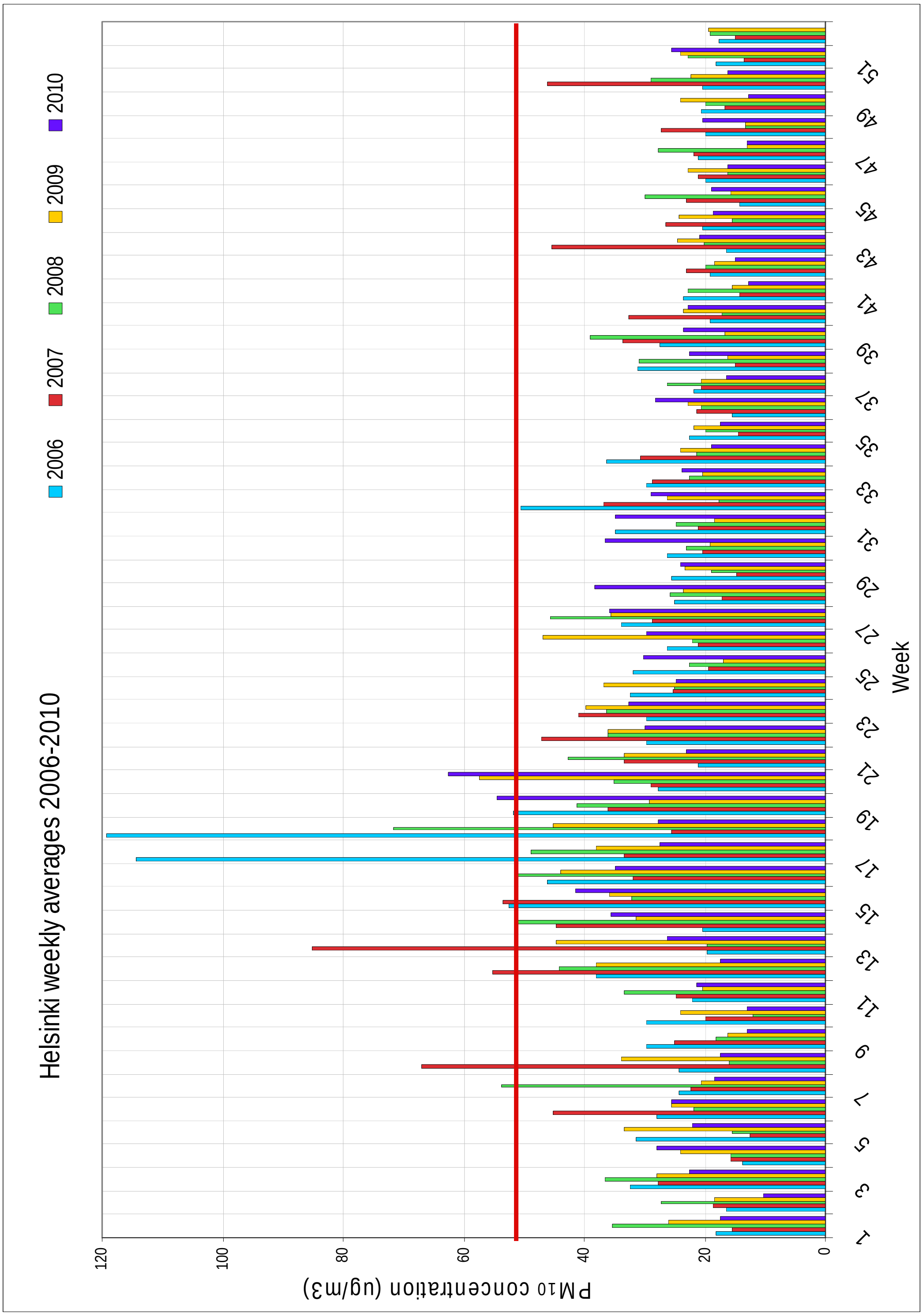
(http://www.finlex.fi/fi/laki/kaannokset/2000/en20000086.pdf:
NB: Unofficial translation; legally binding texts are those in Finnish and Swedish
Ministry of the Environment, Finland

ENVIRONMENTAL PROTECTION ACT
(86/2000; amendments up to 137/2006 included)
February 4, 2000

APPENDIX 2: 1(4)

WEEKLY AND DAILY AVERAGES OF AIR QUALITY MONITORING DATA FROM HELSINKI AND TAMPERE AS FIGURES

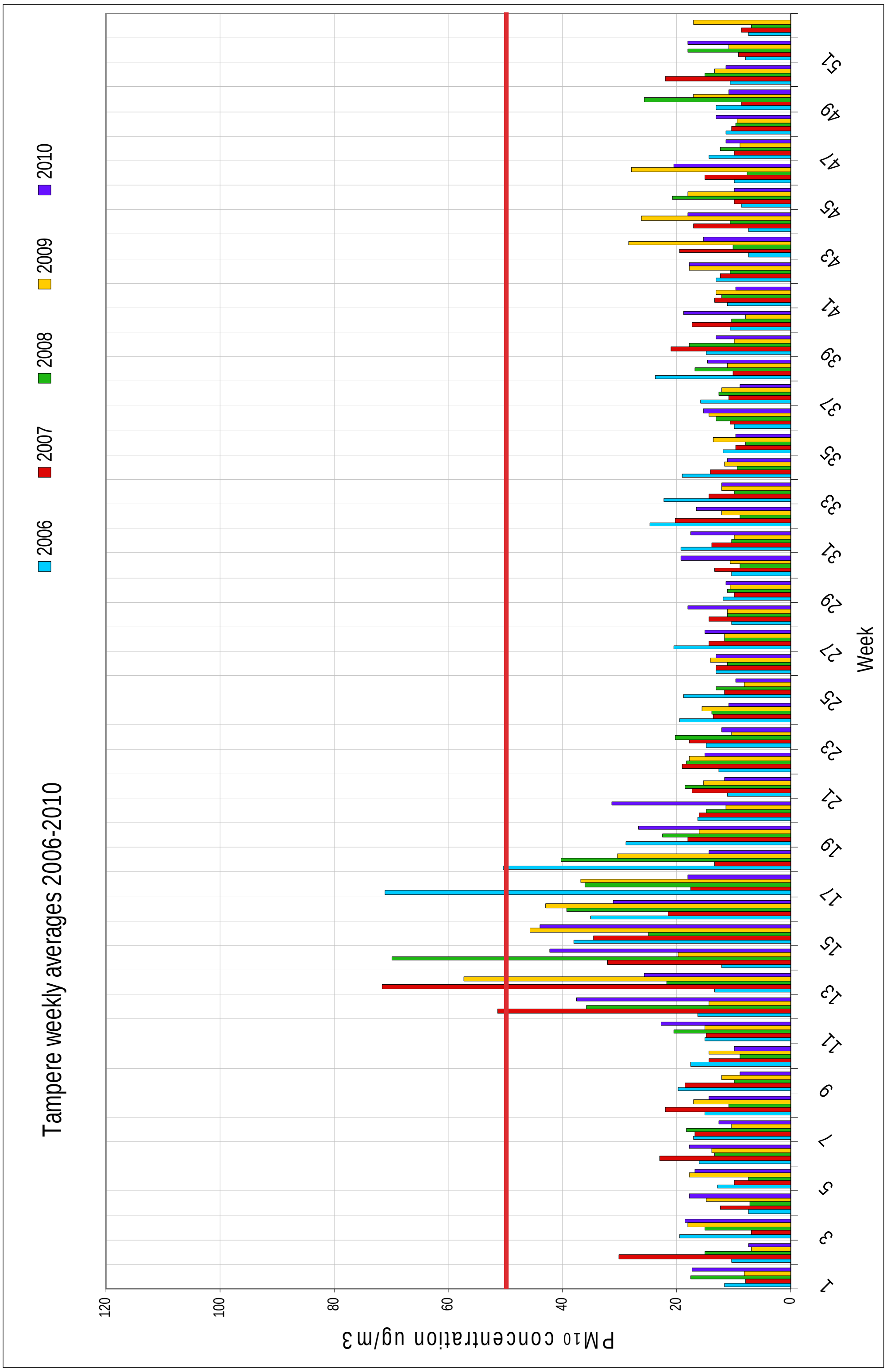
Weekly averages of PM_{10} concentrations in Mannerheimintie measuring station in Helsinki. Red line indicates the limit value for daily PM_{10} average concentration.



APPENDIX 2: 2(4)

WEEKLY AND DAILY AVERAGES OF AIR QUALITY MONITORING DATA FROM HELSINKI AND TAMPERE AS FIGURES

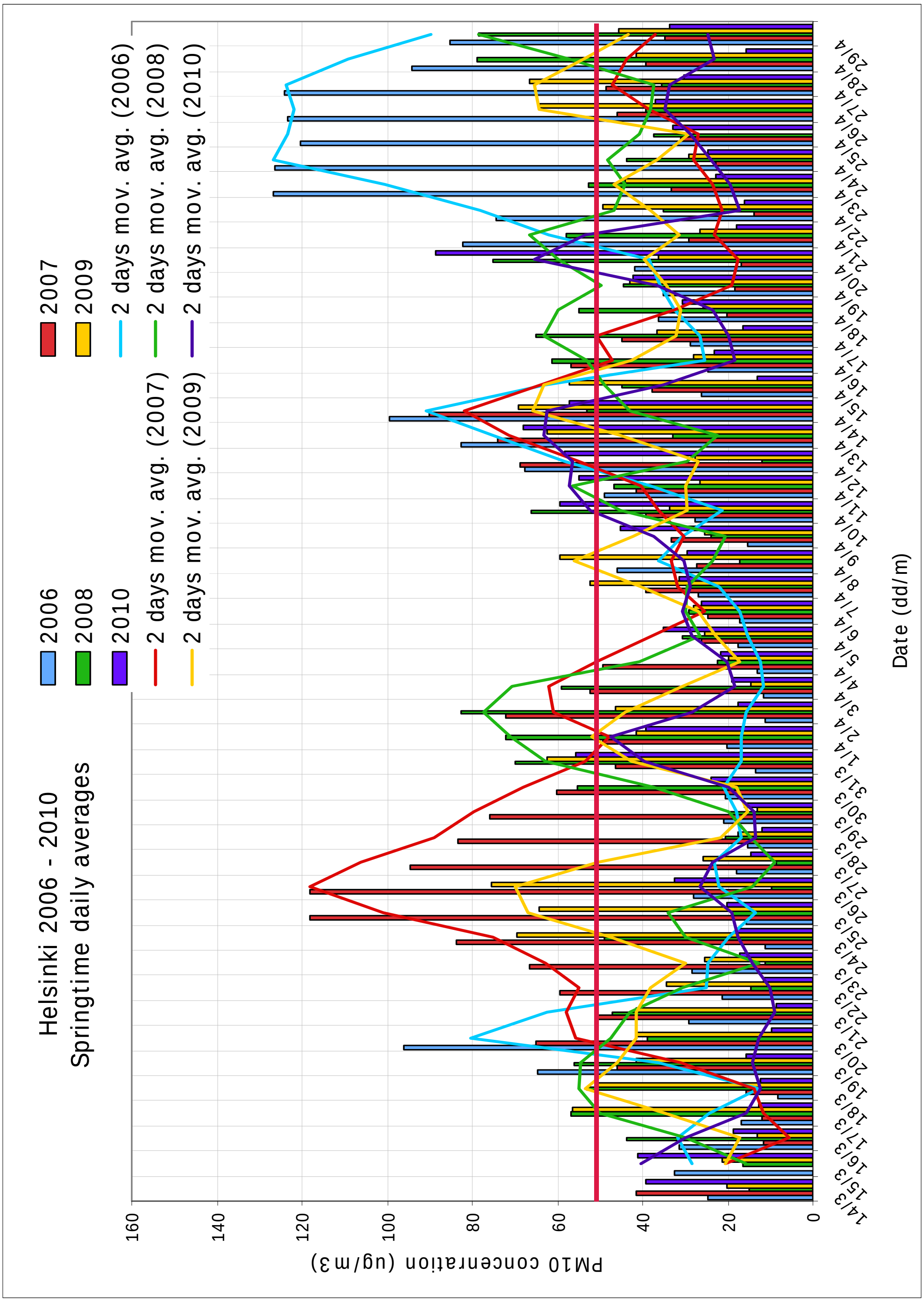
Weekly averages of PM_{10} concentrations in Pirkankatu measuring station in Tampere. Red line indicates the limit value for daily PM_{10} average concentration.



APPENDIX 2: 3(4)

WEEKLY AND DAILY AVERAGES OF AIR QUALITY MONITORING DATA FROM HELSINKI AND TAMPERE AS FIGURES

Daily concentrations and moving average of springtime PM_{10} concentrations in Helsinki (Mannerheimintie) from the March 15. until April 30. in 2006 – 2010.



APPENDIX 2: 4(4)

WEEKLY AND DAILY AVERAGES OF AIR QUALITY MONITORING DATA FROM HELSINKI AND TAMPERE AS FIGURES

Daily concentrations and moving average of springtime PM_{10} concentrations in Tampere (Pirkankatu) from the March 15. until April 30. in 2006 – 2010.