Evaluation of the Usability of Low-cost Sensors for Public Air Quality Information

Master's Thesis

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Abstract

This thesis discusses on air quality in Oslo and how it has been changed during the time from 2003 to 2013. It also goes through the existing and upcoming technologies for the collection of air quality data. The trend is changing for data collection as the use of low-cost sensors is increasing along with the concept so called big data. The research is based on the air quality data received from the official air quality monitoring stations in the city of Oslo since 2003 and data from low-cost static sensors deployed in the city of Oslo for 2015.

The main goal of this thesis is to evaluate and improve the reliability of low-cost sensors or public air quality information and to have a user-friendly visualization of pollutant data collected by the sensors so the people can have a better understanding of the air pollution in their surroundings and take actions to reduce their exposure.

We propose a linear regression model which is able to calibrate these sensors and rectify the errors and provide reliable readings to some extent. However, the values are sensitive to meteorological conditions, which stresses the need of frequent calibration, especially to account for seasonal changes. The application of field of calibration can help reduce the bias in the data. Hence it is concluded that the data from low-cost sensors cannot be used for regulatory purposes and where high data accuracy is required.

Finally, we also have researched on different air quality indices around the world and the usability of air quality data to public. We have proposed a user interface for mobile applications that can help visualize the personalized air quality index based on the health conditions of the users. However, the proposed visualization needs to go into extensive evaluation before we proceed further towards visualization. The output of the project will be useful to the people who are more sensitive towards air pollution as for instance children, asthmatics, pregnant woman, etc., but also for the general public, scientific and environmental agencies.

The thesis is completed with an exhaustive annex, presenting breakpoints for AQI, health recommendations, as well as the temporal and spatial variation of different pollutants and the statistics of the regression models used in this study.

Keywords: air pollution, air quality index, reliability of low-cost sensors, calibration

Preface

I would like to thank my supervisors, Professor Josef Noll and Nuria Castell Balaguer for their guidance, help and support throughout my thesis. Special thanks to Nuria Castell Balaguer, who guided me consistently from the very first starting till the end. I would like to thank NILU (Norwegian Institute for Air Research) for providing the data required for the research. In addition, I thank my husband, Manish Shrestha for his moral support and for being the source of motivation. Lastly, I am thankful to my family and friend for encouraging me.

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Abbreviation

AQI= Air Quality Index

NAQI= Norwegian Air Quality Index

EAQI= European Air Quality Index

PAQI = Personalized Air Quality Index

NILU= Norwegian Institute for Air Research

WHO= World Health Organization

NAAF= Norges Astma- og Allergiforbund

EEA=European Environment Agency

EPA= Environmental Protection Agency

CO= Carbon Dioxide

NO=Nitrogen Oxide

NO_2=Nitrogen Dioxide

SO_2=Sulphur Dioxide

O_3=Ozone

PM_{10}= Particulate Matter 10 micrometers or less in diameter

$PM_{2.5}$= Particulate Matter 2.5 micrometers or less in diameter

µg/m3= Microgram(s) per cubic metre

DOE= Department of Environment

US-EPA= United States Environmental Protection Agency

PSI =Pollutant Standard Index

CPCB= Central Pollution Control Board

CAA= Clean Air Asia

FMI=Finnish Meteorological Institute

NAAQS = National Ambient Air Quality Standards

COPD = Chronic Obstructive Pulmonary Disease

1 Introduction

This chapter introduces the research on the reliability of the air pollution measurement sensors and to have a user-friendly visualization of pollutant data collected by the sensors. The use of low-cost sensors has been increasing because of its portability and low-cost. But at the same time the question is rising that how trustworthy the data being provided by those low-cost sensors are compared to traditional sensors. In this research, we will go into analysis and comparison between the data from these two sensor platforms and analyze the consistency of the new low-cost sensors and different factors and variables that may deviate these sensors from providing the correct readings. The output of this research will recommend the process that is needed in order to get the relevant measurement from low-cost static sensor.

There is need of some effective way to visualize the pollutant concentration for better understanding of air pollution, which can help citizens to take proper measures or precautions to avoid polluted environment. This research points out how the use of Air Quality Indices (AQI) can help citizens to understand the relation between air pollution levels and health, but also discuss some of the challenges and limitations associated with its use. AQIs are used significantly by authorities worldwide to provide air quality information and its effects on health, so that citizens can take more precautions based on the level of air quality. This is critical for the people who are more sensitive towards air pollution as for instance children, asthmatics, pregnant woman. So, this research is based on the air quality data received from low-cost static sensors deployed in the city of Oslo and data from the official air quality monitoring stations in the city of Oslo.

Air pollution is one of the major challenges in the world. Urban areas are mostly found to be polluted due mainly to the emissions from road traffic (Ozcan, 2012). The majority of the people is attracted towards migrating into the bigger cities for a better life and opportunities. Additionally, increasing population in cities results in an increasing number of vehicles. So, if no required measures are taken, this trend may cause a radical increase in pollution in cities. It is well known that air pollution has negative impact on human health, there is need of tools that is able to make people aware about the air quality and its impact on their health, and take evasive actions to avoid its impact on human health. Though, the quality of air has been improved in Europe over the past decades, there has also been numerous places where concentrations of PM, NO_2 and O_3 are still beyond the levels for health protection (Nuria Castell, Kobernus, et al., 2014).

There have been a number of researches in this domain and with the improvement and advancement of the technology; various techniques have been developed to collect the environmental data that can help advance the current understanding about air pollution in urban areas. Among them, low-cost sensors can benefit air quality managers to understand air pollution at higher resolutions. Low-cost sensors are smaller and less expensive than reference stations, and thus can be deployed in larger numbers. So, they provide a noble prospect to complement the data from reference stations, providing data at higher resolutions. But challenges are the quality and accuracy of the data from low-cost sensors.

The use of air quality index (AQI) is one of the most common ways to signify the information related to air pollution levels in the cities. Most of the countries, or even regions in a country have developed their own AQI. This can cause confusion among people when moving between different regions or countries. However, all of them follow a same principle, with the use of a color scale or a numeric scale. For example, Canada has Air Quality Health Index where health risk is scaled from 1 to 10 or more indicating higher the number higher the risk is. Similarly, the Air Pollution Index in Malaysia is scaled from to 0 to 301+. There are several other Air Quality Indices, which have been described in upcoming chapters.

1.1 Motivation

The term *"Internet of Things"* (IoT) has evolved with the expansion of the use of internet in the world. Use of the internet has boomed with the development of new technologies. The internet is getting ubiquitous. *"The IoT vision enhances connectivity from "any-time, any-place" for "any-one" into "any-time, any-place" for "any-thing". Once these things are plugged into the network, more and more smart processes and services are possible which can support our economies, environment and health"* (Coetzee & Eksteen, 2011). The internet is the source for collecting and sharing large amounts of data in a matter of time. For example: use of sensors to collect the large amounts of pollutant data and pushing them to cloud in order to provide the statistics to the public eloquently.

Several sensors are available in the market which are capable to measure and collect the air pollutant data by mounting in several locations. The collected data are passed to the remote servers for further processing and analysis. However, this technique of having the sensors in the static point and in mobile platform can only give the raw data of the pollutants which doesn't quite make sense until and unless the meaningful information is extracted from them. As a matter of fact, how can we make more sense of these pollutant data for different group of people?

There are several ways that we can use the air pollution data. One of them could be properly visualized the data by the general users so that they can be used in the form of graphs, maps, mobile applications or websites and make proper sense in general. There is a need to improve the reliability of the sensors and to have a user-friendly visualization of pollutant data collected by the sensors so the people can have a better understanding of the air pollution in their surroundings and take actions to reduce their exposure. It is crucial for the public to be well aware and understand about the magnitude of the quality and its relation to the health hazards.

The output of the project will be not only useful to the people who are more sensitive towards air pollution as for instance children, asthmatics, pregnant woman, etc., but also for the general public, scientific and environmental agencies. For example, an asthmatic could check the information related concentration of pollutants that could worsen the case of asthmatic patients. By doing so, they can take precautions to avoid the areas which are harmful to them. For instance, notifications about health warning or precaution can be sent to the asthma patient travelling through the area having high concentration of pollutants in real-time. Another case could be a group of people who want to see the area with high concentration of certain pollutants on the map.

Sensors can be deployed in a static location or installed in mobile platform (buses, bikes, cars, etc.) to get air pollutant data in the city. For instance, the Norwegian Institute for Air Research (NILU) has been working in the projects called *"Citi-Sense-MOB"* and CITI-SENSE, where low-cost sensors are installed in mobile platform (buses and bikes), deployed in fixed locations (kindergartens and lamp posts), and carried by people (i.e. parking wards, volunteers) to measure and monitor the environmental data. Both static and mobile sensors may not be fully reliable because of temporal and spatial variation. Hence, there is a great research opportunity to improve the reliability of the sensors and also to have a user-friendly visualization of pollutant data collected by the sensors which are the main objective of this research.

1.2 Research Question

This research will try to address the following two research questions:

- Is it possible to get the reliable data from the low-cost static sensor? How to improve the reliability of air pollution measurement sensor?

- How data obtained from the sensor can be visualized in order to help people to understand levels of air pollution?

2 Background

The following section will introduce the degradation of air quality in the urban areas, the problems caused by the air pollution and its adverse effect to the public health.

2.1 Air Quality

Air pollution is growing as a major issue in the world. City areas are heavily populated as more and more people migrates into the urban area in search of a better life and opportunities. Air pollution levels are higher in the city areas compared to rural areas. Due to modernization and industrialization, air pollution is more observed producing poisonous gases in developing countries, mostly in urban areas. Cities with high population are also found with degraded air quality.

In the near future in 2050, United Nation has estimated that the urban population is expected to rise from 3.3 billion in 2007 to 6.4 billion, which is nearly to double in the world (Firdaus & Ahmad, 2011). An example of how the increase in population together with a lack of planning can worsen air pollution is the case in Istanbul. Air pollution is one of the major issues in Istanbul because of its increasing population in urban areas, unplanned or poorly planned development and in addition, uncontrolled use of fossil fuel was another reason behind unhealthy air (Ozcan, 2012).

Air pollution is being a big concern to the world for the past decades. During 1950s and 1960s in the United States, rapid increase of mobile vehicle in the cities area resulted the formation of photochemical smog, which was produced by the action of sunlight on the oxides of nitrogen and hydrocarbon (Colvile, Hutchinson, Mindell, & Warren, 2001; Fenger, 1999).

Back in December 1952, around 4000 people died within four days due to fog found in London and many people were hospitalized, suffered from bronchitis, pneumonia (Logan, 1953). This fog was called as Big Smog, which made people concern about their health. *"These tragic public events in London half a century ago spurred the realization that polluted air could not only cause an immediate increase in deaths and illness but could also result in longer-term and more subtle effects"* (Davis, 2002). London needed strict law and legislation in order to control this incident, which later introduced the Clean Air Act in 1956 (Brimblecombe, 2006).

(Fenger, 1999) have also mentioned about the increment of transportation in the urban area, due to which pollutants like nitrogen oxides, organic compounds and small particles tends to be higher. Several researches were carried out in many countries, especially in urban areas, due to heavy road traffic, which are becoming one of the major sources of poor urban air quality (Anttila, Tuovinen, & Niemi, 2011; Colvile et al., 2001; Fenger, 1999; Mavroidis & Chaloulakou, 2011; Pandey et al., 2008). Researchers are concerned about traffic related air pollution, and finding ways to improve air quality in the cities.

Although, air quality in Europe has been improved over the past decades (EEA, 2014a), some parts of Europe still have persistent problems with the concentration of some pollutants like particulate matter (PM), nitrogen dioxide (NO_2) and ground level ozone (O_3) (Nuria Castell, Kobernus, et al., 2014). Contamination of smoke, dust, small particles, carbon dioxide, nitrogen oxides, sulfur dioxide, ozone, carbon monoxide and other poisonous gases causes air pollution.

According to WHO (World Health Organization), about 3.7 million people died prematurely worldwide in 2012 due to ambient (outdoor) air pollution (WHO, 2014). According to their guidelines, the following components are the major pollutants.

- Particulate matter (PM)
- Ozone (O_3)
- Nitrogen Dioxide (NO_2) and
- Sulfur Dioxide (SO_2)

Fossil fuels are one of the main reasons behind the change in the atmospheric composition. This mainly contributes to the well-known pollutants like sulfur dioxide (SO_2), nitrogen oxide (NO), carbon monoxide (CO), volatile organic compounds and particulate matter (PM).

Primary pollutants are those which are directly emitted into the atmosphere, for e.g. CO and SO_2 whereas, secondary pollutants are formed by reaction between other pollutants and atmospheric gases, for e.g. Ozone. Some pollutants like nitrogen dioxide and some particulate matters are both primary and secondary pollutants, as they are formed directly and also after reaction with other pollutants. SO_2, NO_x, CO, Ozone, Volatile Organic Compounds, etc. are some of the examples of major gaseous pollutants. They are produced mainly from the combustion of fossil fuels and contribute to a great extent in composition of variations of the atmosphere (Katsouyanni, 2003) .

Air pollutants are transboundary in nature and the emission from one country can affect the population of another country through wind or water. Air pollutants released in one country may be diffused into the atmosphere, contributing poor air quality elsewhere too (EEA, 2014a).

Common air pollutants and their sources:

Particulate Matter:

Particulate Matter is a mixture of particles which differ in size and composition and are produced by a wide variety of natural and anthropogenic activities (Pöschl, 2005). As described by the World Health Organization, particulate matter are the mixture of solid and liquid particles of inorganic and organic substance suspended into the air. Dust, smoke, ash, soot, exhaust particle and other particles are particulate matter.

Emission from vehicle, industries, burning wood/ forest, dust from the road, soil, and construction work/ demolition, diesel exhaust, coal burning for power generation, combustion of biomass, agriculture, pollens and molds, ashes from volcano causing tiny dust particles, shipping emission are some major sources of particulate matter (Brook et al., 2004; Curtis, Rea, Smith-Willis, Fenyves, & Pan, 2006; Viana et al., 2008).

Both $PM_{2.5}$ (particulate matter less than 2.5 μm in aerodynamic diameter) and PM_{10} (particulate matter less than 10 μm in aerodynamic diameter) have an adverse effect on health considering $PM_{2.5}$ as more dangerous than other larger coarse particles and it can last in the air for more than 24 hours (Janssen et al., 2011; WHO, 2003). For instance, PM_{10} can damage the lung as it can penetrate and lodge deep inside the lung, which can cause short term mortality (Keatinge, 2002; WHO, 2014).

Nitrogen Oxides (NO_x):

Nitrogen Oxides are formed by oxidation of atmospheric nitrogen during combustion, emission from cars, buses are in the form of non-toxic nitric oxide (NO) which, when mixed with atmosphere form nitrogen dioxide (NO_2) (Fenger, 1999).

According to (EEA, 2014b), one of the reasons behind the formation of ozone and particulate matter is NO_x. Automobiles are one of the major contributors for the emission of NO_2 into the atmosphere. There are adverse effects on health from long and short-term exposure to low and high concentration of NO_2 (Nuria Castell, Kobernus, et al., 2014).

Ozone (O_3):

Ozone is the three oxygen atoms which are very important in blocking the harmful ray called ultraviolet ray coming from the sun into the earth, but if ozone is found in the troposphere then it is toxic to the human beings (Curtis et al., 2006). Ozone is the source of the hydroxyl radical (OH), which reacts rapidly with more air pollutants and trace species found in the atmosphere (Finlayson-Pitts & Pitts, 1997). According to (Curtis et al., 2006), ozone can be formed by photocopy machine, lightning, by atmospheric reactions involving volatile organic chemicals, nitrogen oxides and sunlight. It is also a transboundary pollutant (European_Union, 2008).

Sulfur Oxides (SO_2):

Sulfur dioxide is formed from burning coal, emission from vehicles and oil / gas fields and factories (Curtis et al., 2006). Controlled studies involving exercising asthmatics indicate that a proportion experience changes in pulmonary function and respiratory symptoms after periods of exposure to SO_2 as short as 10 minutes (WHO, 2006). One of the main sources for the formation of SO_2 is an electricity generation field (EEA, 2014b).

Carbon Monoxide (CO):

Carbon monoxide is one of the many ubiquitous environmental pollutant. Incomplete combustion of fossil fuel and biofuels helps to emit CO which affects human health by entering the human body through the lungs (Guerreiro, Foltescu, & de Leeuw, 2014). According to (Guerreiro et al., 2014), the CO will be found in the atmosphere for 3 months, which slowly oxidize into carbon dioxide (CO_2) and it also helps in the formation of O_3. Some other sources that emit CO are from auto-mobiles, industries, business and household processes (EEA, 2014b).

2.2 Air Quality in Oslo

Oslo is the capital city of Norway, where road traffic and combustion of wood are the major sources of air pollution. Road traffic being the major source to NO_2 (Nuria Castell, Liu, et al., 2014). Air pollution rises higher in winter rather than in summer. According to Alpopi and Colesca (2010), *"Air Quality in Oslo varies both seasonally and geographically. All parts of the city shows a high quality of air in the summer, but in winter it varies throughout the entire city"* (Alpopi & Colesca, 2010). In upcoming chapters temporal and spatial variation of air pollution will be discussed in detail.

According to Oslo Kommune, air quality is improving in Oslo, but NO_2, PM_{10} and $PM_{2.5}$ are the major problems still exist. Figure 1 shows the annual mean concentration of NO_2 including its limit value in five different cities in Norway from 2004 to 2013. The red line denotes the NO_2 limit value, i.e. 40 µg/m3, which is based on a health based standard set by the European Union shown in table 3. According to this figure, the annual average concentration of NO_2 in Oslo has been above the limit between 2003 and 2013. Levels for 2013 are higher in Oslo that in other cities. However, NO_2 is a problem in other cities, where annual NO_2 levels are still above the exceedance limit value of 40 µg/m3.

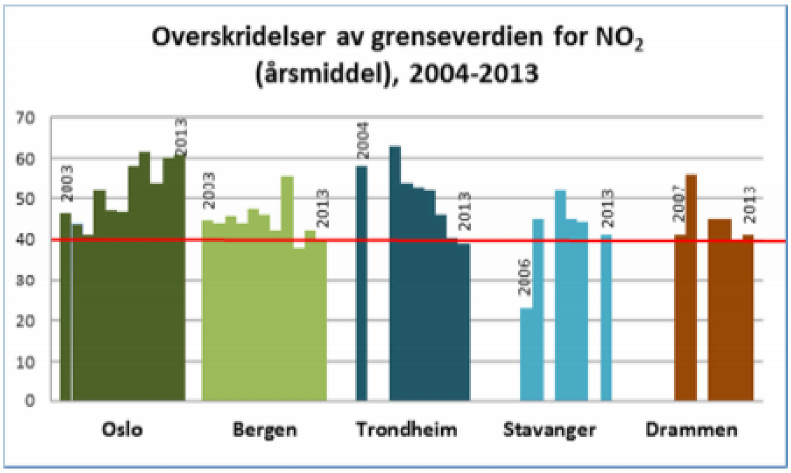

Figure 1: Exceedances of the limit value for annual mean concentration of NO_2 in five major cities in Norway.

Source: (Klima-og-miljødepartementet, 2014)

Quality of air also depends on weather condition. *"The lack of effective systems for reducing NOx emissions, has led to high ambient concentrations of NO2 in major Norwegian cities, especially during times of congestion, cold clear weather without wind and inversion"* (Hagman, Gjerstad, & Amundsen, 2011). In Norway, due to the inversion of temperature and low temperature, levels of PM_{10} and NO_2 are higher. Moreover, the level of PM_{10} is also high in spring (Berge et al., 2002).

(Hagman et al., 2011) have also mentioned their future forecast of NO_2 levels that will increase after 10 years and within 2015, it is expected that the concentration of NO_2 will rise above the limits, but if necessary actions are taken in order to improve the condition, then it is expected to slightly decrease till 2025 which can be seen in figure 2. For example: strong law and regulation act, use of electric cars, and awareness to use public transport, car pooling and soft modes instead of private cars can help to reduce harmful emissions in the near future.

The blue line in the figure below denotes the exceedance limit value for NO_2.

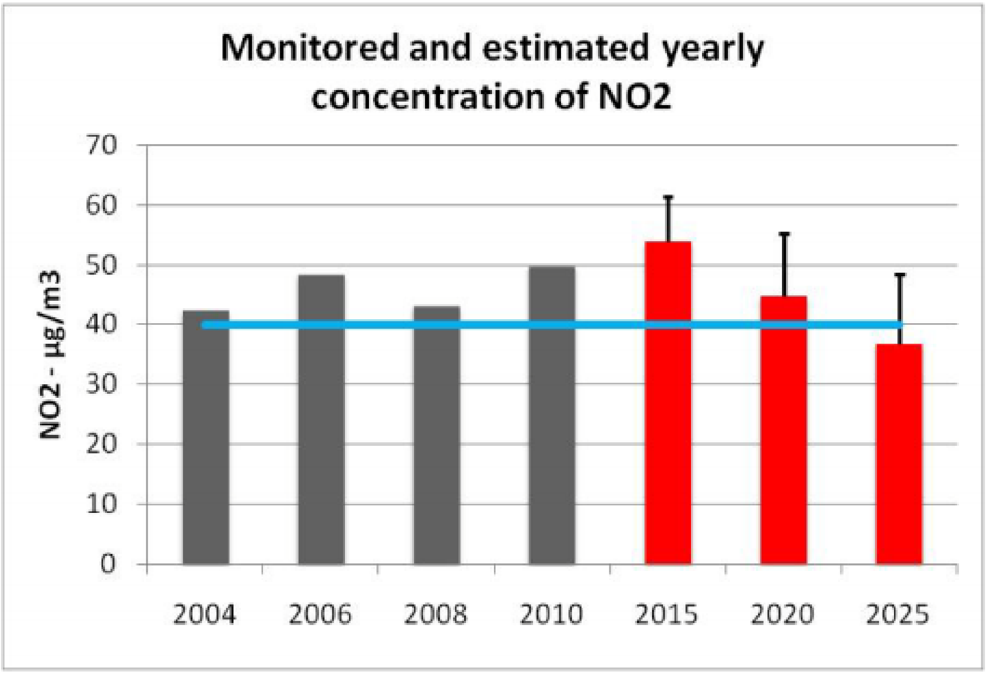

Figure 2: Annual average concentration for NO_2 in Oslo.

Source: (Hagman et al., 2011)

2.3 Air Pollution impact to the Public Health

People are rarely aware about the quality of air that they intake at different places in different time which could affect human health and can lead to premature death. People tend to ignore about the term *"How much of clean air we are inhaling in day to day life"* due to busy schedule. On the other hand, children are highly affected by air pollution as they are mostly engaged in outdoor activities (Kim, 2004).

Different air pollutants are responsible for different health problems. Air pollution can trigger serious diseases like lung cancer, pulmonary diseases, respiratory diseases like asthma, bronchitis, etc. It can affect different organs of the human being like respiratory system, urinary system, digestive system, nervous system, cardiovascular system (Kampa & Castanas, 2008) . Air pollution not only affects the respiratory system, but also affects many parts of the human body together with neurological, immunological, hematological and developmental and reproductive system where the level of respiratory and cardiovascular problems has increased, which is below US EPA and WHO standards (Curtis et al., 2006). *"Exposure to pollutants such as airborne participate matter and ozone has been associated with increases in mortality and hospital admissions due to respiratory and cardiovascular disease."* (Brunekreef & Holgate, 2002)

The effect of air pollution on human health some of which are shown in table 1:

Table 1: Effect of air pollution on human health.

Pollutant	**Health effects**
Particulate Matter	Can cause or aggravate cardiovascular and lung diseases, heart attacks and arrhythmias. Can cause cancer. May lead to atherosclerosis, adverse birth outcomes and childhood respiratory disease. The outcome can be premature death.
Nitrogen Oxides	Exposure to NO_2 is associated with increased all-cause, cardiovascular and respiratory mortality and respiratory morbidity.
Ozone	Can decrease lung function. Can aggravate asthma and other lung diseases. Can lead to premature mortality.

Sulphur Oxides	Aggravates asthma and can reduce lung function and inflame the respiratory tract. Can cause headaches, general discomfort and anxiety.
Carbon Monoxides	May lead to heart disease and damage to the nervous system; can also cause headache and fatigue.

Source: (EEA, 2014c)

For instance, children, pregnant women, old people, and people suffering from diseases are more sensitive to air pollution. Children, pregnant women and elderly people have high chance of being affected by respiratory diseases such as asthma. According to WHO, *"asthma is chronic diseases characterized by recurrent attacks of breathlessness and wheezing, which vary in severity and frequency from person to person"*. WHO estimation has mentioned that around 235 million people are suffering from Asthma. Asthma usually start early in childhood and often persist throughout life (Bousquet et al., 2004). During 1990 – 2000, a study was made in Oslo and Troms/ Finnmark which shows that children are more in number suffering from asthma from 1980- 1995 and further study was carried out in the year 2001 – 2004 in Oslo says that 11 % of children under 10 had asthma which is available in following figure (Council, 2009).

Oslo, 6-16-year olds:	**1981**	**1994**
Proportion who have or have had asthma	3.4 %	9.3 %
Proportion who have asthma now	1.6 %	5.5 %

Troms and Finnmark, 9-11-year olds:	**1985**	**1995**	**2000**
Proportion who have or have had asthma	9.3 %	13.2 %	13.8 %

Figure 3: Proportion who have or have had asthma in Oslo/ Troms and Finnmark in 1981 and 1994.

Source: (Council, 2009)

2.3.1 Health impacts on Sensitive Groups

Air pollution has greater impacts on the sensitive group of people than other groups. Sensitive groups are those people who are vulnerable and are easy to get affected even by the low level of pollutants in the air. For instance, people suffering from diseases or who are highly involved in outdoor activities for longer periods like children in playground, traffic police, people working in construction, etc. Some of the vulnerable groups are listed below who are likely to have severe health risks caused from different air pollutants.

- **Children**: Children are considered as sensitive group. As children spent most of their time in outdoor activity, they are heavily exposed to the air pollutants than other group of people and at the same time their small height is another reason that they are highly exposed to the air pollutant which are heavier than air and concentrate on breathing zone which are near ground level (Mott, Fore, Curtis, Solomon, & Hanson, 1997). Exposure to particulate matter affect the functionality of the lungs in children and can also have effect in its development. Those children who are suffering from respiratory diseases should avoid the exposure to PM (WHO, 2011)and NO_2 as well.

- **People suffering from respiratory diseases specially asthma**: People who have asthma if exposed to air pollution for long period can increase the problem for those who are suffering from bronchitis, cough and other respiratory diseases including asthma allowing the condition of asthma patient to become worse (WHO, 2004). Pollutants like NO_2, O_3, SO_2, PM_{10} and $PM_{2.5}$ aggravate asthma (Saxon & Diaz-Sanchez, 2005). Mostly children and females have this symptom and more evidence are found and discussed by (Woolcock & Peat, 1997) in term of increase in asthma.

- **People suffering from Cardiovascular Diseases**: Particulate Matter plays a crucial role in causing cardiovascular diseases (Franchini & Mannucci, 2009). Short term exposure can increase the health risk. Long term exposure may lead to death.

- **Pregnant Women and newborn babies**: Pollutants like CO, which is the main source of automobiles can cause severe health problem for pregnant women and newborn babies. Smoke from cigarettes is another source for CO and other pollutant which have negative effect causing poor infant health. Exposure to particulate matter is another pollutant that damage the fetus indirectly by provoking inflammation in the mother as the particles cannot cross the placenta (Currie, Neidell, & Schmieder, 2009).

- **Elderly People**: Elderly people may get cardiovascular and respiratory diseases if exposed to ambient air pollutants. *"The elderly are at greater risk from air pollution than other age groups due to their enhanced susceptibility and exposure to air pollutants"* (Bentayeb et al., 2012). In addition, (Bentayeb et al., 2012) has mentioned that elderly people are hospitalized as they are suffering from the asthma, chronic obstructive pulmonary disease (COPD) due to air pollution. Air pollutants caused by traffic, as for instance $PM_{2.5}$ are responsible for respiratory diseases (Halonen et al., 2009).

2.4 Impact of Air Pollution in Public Health in Oslo

Air pollution has also been listed as one of the causes of asthma, and it can also trigger asthma symptoms. NAAF has mentioned that approximately 10-12% of Norwegian children and young people and approximately 8 % of adults suffer from asthma. Study of childhood asthma at Ullevål University Hospital has found that around 4,000 children from 2 years are suffering from asthma in Oslo. This shows that around 20% of children below the age of 10 years have or had asthma. For the past 40 years, people suffering from asthma are increasing steadily (NAAF, 2007). Norway is known for the weather condition with low temperature. Temperature (less than minus 10°C) can worsen the case of asthmatic patients (NAAF, 2007).

"Although the use of asthma guidelines has reduced morbidity and mortality, the burden of asthma is still high and both the knowledge of better treatment option and their implementation need to improve" (Bousquet et al., 2004). Many researches have been funded by the EU in order to improve the condition of growing challenges of asthma. There is need to aware people by giving out information about air pollutants that can worsen the condition of people suffering from asthma.

2.5 Air Quality Guidelines / Standard

2.5.1 WHO (2005) Air Quality Guidelines

WHO proposed air quality guidelines in 2005 for major key pollutants, targeted to achieve low concentration as much as possible (WHO, 2014). The following table shows the exposure limit values for the major key pollutants which have a negative effect on the health of the people. These guidelines / standard will help to know the level of pollutant and their limits and encourage to take actions to control the pollution caused by human activities.

Table 2: WHO Air Quality Guidelines (2005).

Pollutant	Average period	Limit Values
$PM_{2.5}$	Annual	10µg/m3
	24-Hour	25µg/m3
PM_{10}	Annual	20µg/m3
	24-Hour	50µg/m3
NO_2	Annual	40µg/m3
	1-Hour	200µg/m3
SO_2	24-Hour	20µg/m3
	10 Minute	500µg/m3
O_3	8-Hour	100µg/m3

Source: (WHO, 2014)

2.5.2 European Union Health Based Standard / Limit:

In comparison with WHO air quality guidelines (table 2), European Union health based standard has slightly different limit values for the similar pollutant that WHO has taken into account. The European Union has set the health based standards/limit for other air pollutants. EU standards are summarized in table 3. It not only consists of limit value, but also includes the allowable exceedances number that can occur per year.

Table 3: EU Air Quality Standards

Pollutant	**Concentration**	**Averaging period**	**Legal nature**	**Permitted exceedences each year**
Fine particles ($PM_{2.5}$)	25 µg/m3***	1 year	Target value entered into force 1.1.2010 Limit value enters into force 1.1.2015	n/a
Sulphur dioxide (SO_2)	350 µg/m3	1 hour	Limit value entered into force 1.1.2005	24
	125 µg/m3	24 hours	Limit value entered into force 1.1.2005	3
Nitrogen dioxide (NO_2)	200 µg/m3	1 hour	Limit value entered into force 1.1.2010	18
	40 µg/m3	1 year	Limit value entered into force 1.1.2010*	n/a
PM_{10}	50 µg/m3	24 hours	Limit value entered into force 1.1.2005**	35
	40 µg/m3	1 year	Limit value entered into force 1.1.2005**	n/a
Carbon monoxide (CO)	10 mg/m3	Maximum daily 8 hour mean	Limit value entered into force 1.1.2005	n/a
Ozone(O_3)	120 µg/m3	Maximum daily 8 hour mean	Target value entered into force 1.1.2010	25 days averaged over 3 years

*Under the new Directive the member State can apply for an extension of up to five years (i.e. maximum up to 2015) in a specific zone. Request is subject to assessment by the Commission. . In such cases within the time extension period the limit value applies at the level of the limit value + maximum margin of tolerance (48 µg/m3 for annual NO_2 limit value).

**Under the new Directive the Member State was able to apply for an extension until three years after the date of entry into force of the new Directive (i.e. May 2011) in a specific zone. Request was subject to assessment by the Commission. In such cases within the time extension period the limit value applies at the level of the limit value + maximum margin of tolerance (35 days at 75µg/m3 for daily PM10 limit value, 48 µg/m3 for annual PM10 limit value).

***Standard introduced by the new *Directive*.

Under EU law a limit value is legally binding from the date it enters into force subject to any exceedances permitted by the legislation. A target value is to be attained as far as possible by the attainment date and so is less strict than a limit value.

Source: (European_Commission, 2015)

2.6 New Systems for Monitoring Air Quality

The world is craving for inventing new technology to make cities more livable. Sensor technology is one of the examples of the smart technology. Recent developments in sensor technologies made possible to monitor the air pollution .The sensors can be installed in fixed station and mobile platform like bus, car, electric bicycle and other public transport or it can be portable sensors which people can carry easily when they go outdoors.

However, sensors can experience various challenges as for instance data quality. Thus, it is important to answer the question, how accurate are the data that we are receiving from sensors? This is a question we need to answer before the data from sensor can be used to for instance alert and warn people about air pollutant concentrations.

2.6.1 Low-cost Sensor

Portability of low-cost sensor gives an advantage of gathering spatial variability along with measurement of air pollutants (Piedrahita et al., 2014). Development of low-cost sensor has given opportunities to further improve the services to introduce the clean cities to the citizen by providing more educational means of communication with citizen like air quality application, creating personalized air quality index, alert systems etc. (Nuria Castell, Kobernus, et al., 2014). *"Small commercial sensors represent a big opportunity to create sensor networks that monitor gaseous pollutants across large areas without the necessity of interpolation, which is generally inherent to conventional air quality monitoring stations"* (Núria Castell, Viana, Minguillón, Guerreiro, & Querol, 2013). Low-cost sensor technologies can complement the current tools employed to understand air pollution. This are: *monitoring stations, air quality models and satellite data*.

Monitoring stations are very expensive and require high maintenance and expert personnel to manipulate them. Due to this, there are few in a city, for instance, in Oslo there are only 11 monitoring stations. Sensor technology can be deployed in higher density offering the possibility to create maps at higher resolution. Low-cost sensors are becoming so portable that people can also carry it with them.

Air quality models require expert personnel to run them. They are computational demanding. Also it is necessary to have very accurate input data (emissions, meteorology, boundary conditions). Sensor technology can complement air quality models, for instance sensor and model results can be combined to create better air quality maps. (Lahoz & Schneider, 2014)

Satellite data provide data at global and regional scales. It is nowadays not able to provide information at resolution of meters. The chain satellite, monitoring stations, models and sensors can provide a full picture of air pollution from global to local scale. (Lahoz & Schneider, 2014)

A low-cost technology that can be used by general public demands by the citizens. A clear example is the increasing number of **DO IT YOURSELF (DIY)** projects which are helping the public to build the air quality sensors easily is increasing (Núria Castell et al., 2013). Air casting project is an example of a project that helps to monitor the air quality in urban areas (Núria Castell et al., 2013) by providing instructions on how to build your own sensor.

2.6.2 Challenges of low-cost sensor

- Even though low-cost sensor is popular with their portability, it is a challenging part to *"improve their sensitivity, stability and longevity of operation before replacement"* (Kumar et al., 2015).
- The performance of the sensor is sensitive towards meteorological conditions like temperature and relative humidity.

- In addition, it has limited accuracy and resolution (Hasenfratz, Saukh, & Thiele, 2012). Although it is low in cost, there can be lots of expenses in their maintenance and frequent replacement.

- Security and privacy (especially in personal sensors that uses also GPS data) issues are also a major concern.

2.6.3 Some of the Available Sensor Platforms

There are also companies interested in manufacturing low-cost quality sensors and have them in the market. Examples of industrial developed sensors are as follows:

DunavNet Platform:

DunavNet develop the pre-commercial platform called DunavNet Platform, which helps to measure the air pollution, meteorological parameters and location. Obtained data are sent to the database through GPRS. The DunavNet sensing platform was first integrated in electric bicycle to collect the pollutant data. (http://www.dunavnet.eu/)

UrVamm:

It is a pre-commercial platform, which has been developed by ADN and Ingenieros Asesores (Rionda et al., 2013) and are tested in other countries like Norway (Oslo) and Spain (Gijón and Valencia). This platform merges the data from air pollution, location, timestamp, instant-speed and driving conditions which is being transmitted to the database via the internet. The platform is installed in busses and other big vehicle. This platform consists of two equipment called the Cated and Nanoenvi-FMS sensors. The Cated which is located inside the bus is equipped with WiFi, 3G, Bluetooth, accelerometer, GPS and CAN-FMS sensors. The NanoEnvi system which is outside of the bus has a pump for aspiration inside the bus, a humidity sensor, a NO_2 sensor, a temperature sensor, a CO sensor, a system to attenuate humidity, and a passive filter to reduce interferences with ozone.(NILU)

GEOTECH:

It is a static outdoor sensor platform which is able to send the air pollution data collected by the sensor in the server. It consists of air quality sensors for O_3, NO_2, NO and other sensors to collect temperature, humidity, pressure, noise and particle count. Geotech AQMesh sensor which is independent low-cost multi-gas monitors, which are deployed in the places like lamp posts, balconies, fences, etc. (Stefan Reis1, 2013)

ATEKNEA

It is one of the portable sensor platforms, which measures pollutants like O_3, NO_2 and CO by using electrochemical sensors. On the other hand, it provides the information related temperature and humidity.(CITI-SENSE)

2.6.4 Crowdsource Data and People as Sensors

Crowdsource and people as sensors encourage people to participate in the collection of environmental data through smart phones, social networks and other sources. The development of portable, cheap and easy to use sensor platforms have made possible for the people to contribute gathering data about the environment. This helps to engage the people's participation through the development of mobile application or using available wearable technology utilizing mobile sensors. One of the examples taking this approach is Citi Sense-MOB (Nuria Castell, Kobernus, et al., 2014) where people participate gathering pollution data using low-cost sensors (for instance, riding a bicycle that has an integrated sensor or wearing a portable sensor). Additionally, people can also contribute by giving their own perception of the air quality in a particular moment and place using a mobile app application.

2.7 Air Quality Index (AQI)

Large volume of concentration of pollutant data is being collected from many different parts of the world to provide an updated status on the air quality. Statistical analysis of this concentration data provides simple, easily understandable and straight forward air quality status for the general public, government, scientific community, and policy makers (Bishoi, Prakash, & Jain, 2009). Complex collected data needs to be translated into understandable information to provide daily air quality status. For such tasks, AQI is developed. Therefore, there is a need of detailed analysis of data to report the correct information to the public, which is most essential part in order to establish the required policies to achieve the target level and long term objectives (European_Union, 2008).

The development of AQI should be in such a way that it is easily understandable even by the people who are not from a scientific background. It should contain the level of air pollution, including relevant information about the impact of pollution on public heath alerting them to control the symptom (Holgate, 2011). This should be like an educational chart that gives the information about how much air is getting polluted by human activities. This encourages people to control the harmful emission of pollutant caused by human activities.

An air quality index (AQI) is a tool that shows air pollutant level ranging from high to low which indicate how clean is the air (van den Elshout, Léger, & Nussio, 2008). If the level is high, then it might cause health problems for some people, especially more sensible people. If the pollution level is low, then it is considered that most of the population will not experience health problems. This kind of information helps to aware people about the polluted air in their cities and help them to avoid locations which have high pollution levels. Such development of air quality index has made easy not only to know the level of air pollution, but also to aware people to control the emission of such pollutants that has an adverse effect on public health. According to U.S. Environmental Protection Agency, *"AQI is an index for reporting daily air quality"*. It is just as forecasting the weather.

"An air quality index (AQI) is a numeric scale intended to reflect the quantity of air pollution present at a given point in time and its health significance"(Stieb et al., 2008)

Several air quality indexes have been developed, several revisions have done to existing air quality index in order to provide more precise information. (Ruggieri & Plaia, 2012) has stated that *"AQIs can be use with different aims/purposes: to communicate air quality to the general public, to assess the success/failure of pollution reduction strategies, to monitor medium and long term trends, …, and as regards these aims, even if AQIs' basic concepts are similar, they can show large differences in practical implementation."*

AQI consists of several sub-indices of individual pollutants. The indices can be different even in cities or certain areas. This can be due to local differences in the nature of air quality standards or due to use of different methodologies (Van den Elshout & Léger, 2007).

Different indices have been used in Asian and the Western World for presenting an air quality level as mentioned by Clean Air Asia.

Table 4: Different AQI with different ranges in different countries

Index	Stands for	Range	Implementing Country
AQI	Air Quality Index	0-500	US, Thailand, Abu Dhabi, Mainland China
API	Air Pollution Index	1-500	Hong Kong, Mainland China, Malaysia
AQHI	Air Quality and Health Index	1-10	Canada
CAQI	Common Air Quality Index	0-100	European Union
DAQI	Daily Air Quality Index	1-10	UK
PSI	Pollution Standard Index	0-500	Singapore
CAI	Community Air Quality Index	0-500	South Korea

Source: (CAA, 2013)

As shown in table 4, ranges of AQI can be different in different countries.

2.7.1 Existing AQI in Different Countries

Air quality indexes can be different in different countries. Some of the air quality indices that are currently being used are described below:

Air Quality Health Index – Canada

According to Environment Canada, Air Quality Health index (AQHI) is the information tool that helps to protect human health in Canada from adverse effect of air pollution. Health Canada and Environment Canada have developed this index in collaboration with the provinces and key health and environmental stakeholders.

A scale was designed from the number 1 to 10 + to make people understand the about air quality effect toward health and to make correct decisions based on the air quality health index. If the scale indicates a higher number then it indicates high risk to human health (Environment_Canada, 2014).

Figure 4: Air Quality Health Index Scale

Source: (Environment_Canada, 2014)

Four different categories of AQHI are used to indicate the health risk where 1-3 indicate as low risk, 4-6 indicate as moderate risk, 7-10 indicate as high risk and a number greater than 10 indicate very high risk (Environment_Canada, 2014).

Air Quality Index – USA

Based on (EPA, 2014), AQI is an index that shows the daily report of air pollution level that ranges between 0 and 500. In addition, it provides the level of health concern represented by different color. The main aim of this AQI is *"...to help you understand what local air quality means to your health"* (EPA, 2014).

Air Quality Index (AQI) Values	Levels of Health Concern	Colors
When the AQI is in this range:	*...air quality conditions are:*	*...as symbolized by this color:*
0 to 50	Good	Green
51 to 100	Moderate	Yellow
101 to 150	Unhealthy for Sensitive Groups	Orange
151 to 200	Unhealthy	Red
201 to 300	Very Unhealthy	Purple
301 to 500	Hazardous	Maroon

Figure 5: Air Quality Index – USA

Source: (EPA, 2014)

AQI in the USA is calculated by using following formula and standard breakpoint value as in figure 51 in Appendix A.1.

Equation 1: Formula for calculating the AQI.

$$I_p = \frac{I_{Hi} - I_{Lo}}{BP_{HI} - BP_{Lo}}(C_p - BP_{Lo}) + I_{Lo}.$$

Source: (US_EPA, 2006)

where, I_p is the index for pollutant p,

C_p is the rounded concentration of pollutant p,

BP_{Hi} is the breakpoint greater than or equal to $C_{p,}$

BP_{Lo} is the breakpoint less than or equal to $C_{p,}$

I_{Hi} is the AQI value corresponding to $BP_{Hi,}$

I_{Lo} is the AQI value corresponding to $BP_{Lo.}$

Color Indication in AQI:

AQI is made more interactive by allowing the individual to visualize the level of pollution, represented by different color based on ranges (EPA, 2014; Murena, 2004) which are explained below.

- **Good:** Good is represented by green color. This color will indicate that the air pollution level is satisfactory, but it possess little health risk.
- **Moderate:** Moderate is represented by yellow color. The level of air quality is acceptable, but there is a health risk mainly to sensitive group such as the people suffering from respiratory diseases, children etc.
- **Unhealthy for Sensitive Groups:** It is indicated by orange color where mainly sensitive group of people are high in risk.
- **Unhealthy:** Red color represents for unhealthy. Here, the level of pollution is high and can cause serious health issues to the sensitive group.

- **Very Unhealthy:** It triggers a health alert to not only for sensitive groups of people but also for normal people. This category is denoted by purple color.

- **Hazardous:** This stage denotes a serious health warning to the public as the level of air pollution is very high which is indicated by maroon color.

Air Pollutant Index – Malaysia

The main reason behind developing the air pollutant index is to provide the range of numbers indicating health risk status from good to hazardous instead of providing just the recorded concentration of each pollutant. This status is categorized according to action standards as agreed in the National Haze Action Plan (DOE, 2015). According to DOE, this index follows the Pollutant Standard Index (PSI) which is developed by United States Environmental Protection Agency (US-EPA). Altogether 5 pollutants are measured, i.e. SO_2, which is measured in 24 hours, NO_x measured in 1 hour, CO measured in 8 hours, PM_{10} measured in 24 hours and O_3 measured in 1 hour. The health risk is indicated by 5 categories in the index including the status of each category. If the number lies between 0-50 then status is good, if the number lies between 51-100 then the status is moderate, if 101-200 then status is unhealthy, if 201-300 then status is very unhealthy and if the number is greater than 301 then status is hazardous.(DOE, 2015)

API	Status
0-50	Good
51-100	Moderate
101-200	Unhealthy
201-300	Very Unhealthy
>301	Hazardous

Figure 6: Air pollution index flowchart

Source: (DOE, 2015)

The National Air Quality Index – India

The National Air Quality Index has launched in India by Central Pollution Control Board in association with all State Pollution Control Boards as air pollution was the major concern in India. Information for air quality is made available in the website of National Air Quality

Index including a map indicating the Geo-location, pollutant level (SO_2, NO_2, $PM_{2.5}$, CO, O_3), overall AQI and naming the prominent pollutant (CPCB, 2014). In order to indicate how good or bad is the air quality and its effect on human health, following categories with AQI range are described.

AQI Description	Good (0-50)	Satisfactory (51-100)	Moderately polluted(101-200)	Poor (201-300)	Very poor (301-400)	Severe (> 401)

Figure 7: Air Quality Index

Source: (CPCB, 2014)

Air Quality index – China

According to Clean Air Asia, AQI is an index that is designed for the public to know the level of air pollution in an easy and understandable way where the concentration value of pollutants are shown as a simple numerical form with health effect information and suggestion (CAA, 2013). The table below shows that mainland China follows the Air Quality Index using the ranges from 0-500. China Air Quality Index was revised in 2011 which includes six pollutants, i.e. $PM_{2.5}$, PM_{10}, SO_2, NO_2, O_3 and CO with little different AQI status.

Table 5: Air Quality Index – China.

AQI	Level
0-50	Excellent
51-100	Good
101-150	Light Polluted
151-200	Moderately Polluted
201-300	Heavily Polluted
300-500	Severely Polluted

Source: (CAA, 2013)

According to Clean Air Asia, altogether 74 cities and 25 other YRD key cities in China have started reporting in AQI by releasing concentration values of pollutants by March 2013. YRD cities are: Shanghai, Nanjing, Wuxi, Xuzhou, Changzhou, Suzhou, Nantong, Lianyungang, Huai'an, Yancheng, Yangzhou, Zhenjiang, Taizhou, Suqian, Hangzhou, Ningbo, Wenzhou, Jiaxing, Huzhou, Quzhou, Zhoushan, Taizhou, Lishui, Shaoxing, and Jinhua.

Common Air Quality Index (CAQI) – Europe

CAQI is developed by the European Union to compare the air quality within the cities of Europe in an understandable way, available on the website *http://www.airqualitynow.eu* where the indices (hourly, daily and yearly) were implemented and developed by the cities of CITEAIR (AirQualityNow, 2007). Hourly and daily indices follow the same format of calculation, whereas yearly index follows different format. The following table shows the CAQI calculation grid, which includes the updated hourly and daily values.

Table 6: Common Air Quality Index Calculation Grid.

Index Class	Grid	ROADSIDE INDEX						BACKGROUND INDEX							
		Mandatory pollutant			**Auxiliary pollutant**			**Mandatory pollutant**				**Auxiliary pollutant**			
		NO_2	**PM_{10}**		**$PM_{2.5}$**		**CO**	**NO_2**	**PM_{10}**		**O_3**	**$PM_{2.5}$**		**CO**	**SO_2**
			1 hour	**24 hours**	**1 hour**	**24 hours**			**1 hour**	**24 hours**		**1 hour**	**24 hours**		
Very High	>100	>400	>180	>100	>110	>60	>20000	>400	>180	>100	>240	>110	>60	>20000	>500
High	100	400	180	100	110	60	20000	400	180	100	240	110	60	20000	500
	75	200	90	50	55	30	10000	200	90	50	180	55	30	10000	350
Medium	75	200	90	50	55	30	10000	200	90	50	180	55	30	10000	350
	50	100	50	30	30	20	7500	100	50	30	120	30	20	7500	100
Low	50	100	50	30	30	20	7500	100	50	30	120	30	20	7500	100
	25	50	25	15	15	10	5000	50	25	15	60	15	10	5000	50
Very Low	25	50	25	15	15	10	5000	50	25	15	60	15	10	5000	50
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

NO_2, O_3, SO_2: hourly value / maximum hourly value in µg/m3

PM_{10}, $PM_{2.5}$: hourly value / maximum hourly value or adjusted daily average in µg/m3

CO: 8 hours moving average / maximum 8 hours moving average in µg/m3

Source: (AirQualityNow, 2007)

According to (AirQualityNow, 2007), to make the values more comparable, stations are divided into two categories i.e. Background Index and Roadside Index. *"Background, representing general situation of the given agglomeration (based on urban background monitoring site). Roadside, being representative of city streets with a lot of traffic, (based on roadside monitoring stations)"* (AirQualityNow, 2007). By collecting hourly and daily data in two different sections, it is easier to understand and compare current and past data of air pollution located in different cities within the Europe. According to (AirQualityNow, 2007), yearly index provides the annual air quality information of the cities based on European standard.

Based on (AirQualityNow, 2007), if the index value is greater than 1, then limit values did not meet with one or more than one pollutant. Similarly, if the index value is less than 1, then values are under the limit. These annually recorded value helps to know more detail about the health impact of long term exposure to the air pollution based on distance to the target set by the European Union annual norm (AirQualityNow, 2007).

	NO2	PM10 Year Average	PM10 exceedences daily average	Ozone # days 8-hour averages > 120µg/m³	SO2	Benzene	Overall Index
Target value (µg/m³)	40	40	31	25	20	5	
Target index	1.0	1.0	1.0	1.0	1.0	1.0	

Figure 8: Common annual air quality index calculation grid.

Source: (AirQualityNow, 2007)

Air Quality Index - Norway (NAQI)

Luftkvalitet.info **(http://www.**luftkvalitet.info) provides the air quality information , which is developed and managed by the Norwegian Institute for Air Research (NILU) on behalf of the Environment Agency (Luftkvalitet.info). Luftkvalitet.info has presented the air quality indicator including the health effect alert and limitation number ranges for pollutants that can harm human health. Recently new AQI is updated at **http://www.**luftkvalitet.info where it contains ranges for daily PM_{10} and $PM_{2.5}$ including with hourly PM_{10}, $PM_{2.5}$, NO_2, SO_2 and O_3. There is a slight change in the ranges for each pollutant. Now, it has a new color indicator where *very high* level is represented by purple, *high* with orange, *moderate* with yellow and *low* with green.

This website aims to provide not only the current air quality level, but also alerts for next 48 hours. This index mainly includes pollutants like PM_{10}, $PM_{2.5}$ and NO_2 including SO_2, which has been creating a negative effect on public health in Norway (Luftkvalitet.info, 2015) . Table 7 is the old AQI whereas table 8 is new AQI.

Table 7: Air Quality Indicator with warning to Health effect.

Air Quality Indicator	**Health effects related to air pollution**	**PM_{10}**	**$PM_{2.5}$**	**NO_2**	**SO_2**	**O_3**
		u g / m3				
Very High	Very big health risk	> 200	> 100	> 200	> 350	> 240
High	Health risks occur in certain areas.	100-200	50-100	150-200	250-350	180-240
Moderate	Moderate health risk	50-100	25-50	100-150	150-250	100-180
Low	Small health risks	<50	<25	<100	<150	<100

Source: (Luftkvalitet.info)

Table 8: Updated Air Quality Index.

Pollution Level with Notification Classes	**Health risk**	**PM_{10} Daily**	**$PM_{2.5}$ Daily**	**PM_{10} Hourly**	**$PM_{2.5}$ Hourly**	**NO_2**	**SO_2**	**O_3**
		u g / m3						
Very High	Serious	> 150	> 75	> 400	> 150	> 400	> 500	> 240
High	Significantly	50-150	25-75	80-400	40-150	200-400	350-500	180-240
Moderate	Moderate health risk	30-50	15-25	50-80	25-40	100-200	100-350	100-180
Low	Small	<30	<15	<50	<25	<100	<100	<100

Source: (Luftkvalitet.info, 2015)

Luftkvalitet.info also provides the health recommendation for each pollution level, which is listed in Appendix A.3: table 15.

2.7.2 Criticism in using the Air Quality Index

AQI is developed to generate air quality report and to encourage people to avoid adverse health effects from air pollution. Many existing air quality indices have been criticized and revised to develop new and appropriate AQI for the country. According to (Stieb et al., 2008) *"Most AQIs currently in use around the world are calculated by comparing each pollutant in the index to its standard, and reporting the index as the number corresponding to the pollutant that is highest relative to its standard."* This AQI has also been criticized as it fails to relate air pollution data with health issues which is mentioned by (Stieb et al., 2008). Similarly, Pollution Standards Index (PSI) which is computed by EPA was revised several times.

Establishment of different guidelines for the human health related to air pollution has different exposure limits for short term and long term exposure. According to (Ruggieri & Plaia, 2012), *" Different criteria for short-term and long-term exposure are established, but these can lead to a contradiction since, whereas criteria for short term exposure are usually met, the limit values for long term exposure are often exceeded."* It is often true that even if hourly or daily average data are within the limits, yearly average data may not be within the limit.

On the other hand, developing new AQI is the reason behind the improvement of AQI so that people can plan their daily routine and outdoor activities based on this index more easily. AQI aware people from adverse health risk that could cause from air pollution and this index makes people able to take necessary precaution at the time of high air pollution level (Wai et al., 2012). *"The relations between air quality and health are many, they interact in still poorly understood ways and their exact nature is hard to quantify"* (Elshout, 2012).

3 Methodology

The methodology followed in this research is based on engineering method. *"The engineering method, as applied to computing research, would involve examining existing research findings or problem areas from the point of view of seeking improvements or replacements to those findings, then building or developing artifacts in order to test their value."* (Glass, 1995)

It is commonly used method in the field of computing research. But it is quite rare to have researchers who repeat until no further improvements are possible as suggested by engineering method. So, the author suggests that it would be wiser to involve satisfying result rather than obtaining the result that cannot be further improved. This method consist of four major steps, listed as below:

a) **The information phase:** This is an initial step that includes the study of literature and surveys. During this phase, several literature was studied to gather the information related air pollution, its impact to health. Different existing AQIs, existing project, ongoing researches and various sensor platforms were studied.

b) **The propositional phase:** This phase is composed of proposing and / or formulating hypothesis method, algorithms, methods and solutions (Glass, 1995). In this phase, several existing air quality indices that are available in Europe and other countries were examined and the importance of creating a user-friendly visualization of pollutant data collected by the sensors using air quality index was discussed. The proposition was made to evaluate the reliability of low-cost sensor platform compared with static sensor platform.

c) **The analytical phase:** This phase is the main phase of this research which includes "*analyzing and exploring a proposition, leading to a demonstration and/or formulation of a principle or theory*. To achieve the goal of this research, our first analysis process started with data collection. Pollutants (NO_2, PM_{10}, $PM_{2.5}$ including CO and O_3) data for the period from 2003 to 2013 was provided by NILU. These data were collected from static sensor network in eight different stations within Oslo.

For the statistical analysis of pollutant data, open air package data analysis tool was used together with RStudio. Average concentration for each pollutants for 10 years were calculated hourly, daily and annually which were later evaluated with exceedance limit proposed by the European Union. The idea behind this analysis was to know the trend of air pollution level, and at the same time to know the period in which air pollution rises the exceedance level in different locations. More detailed explanation is covered in chapter 4. In addition, spatial and temporal variation were analyzed which is covered in chapter 4 section 4.5.

There is an increasing trend of using low-cost sensors due to its affordability and portability. But can low-cost sensor networks complement the existing static sensor? To find the answer, low-cost sensors have been deployed in order to test and compare the data obtained from both low and static air monitoring networks.

To address research questions of my thesis, quantitative analysis was done by mounting low-cost static sensor at different location in the year 2015 and comparing the data obtained from both low and static air monitoring networks. The main aim of this research is to evaluate and compare the results obtained from two different types of sensors (static and low-cost) and test for reliability of low-cost sensors.

d) **The evaluative phase:** This phase involves *"evaluating a proposition or analytic finding by means of experimentation (controlled) or observation (uncontrolled, such as a case study or protocol analysis), perhaps leading to a substantiated model, principle, or theory."* (Glass, 1995)

After analytical phase, linear model analysis was conducted on the data collected from both types of sensors and they were compared to the reliability test of low-cost sensors. The result is covered in chapter 4 section 4.6. To address the second research question, prototype for mobile application was proposed specially for sensitive groups of people, including the personalized AQI visualization which have been recommended during the research. This part is covered in section 4.7.2.

4 Analysis and Discussion

4.1 Analysis of Air Pollution in Oslo

The pollution level varies from place to place due to the variation found in geographical and climatic condition. Therefore, it is crucial to allocate the location where the measurement is taken. For example, it can be near traffic area, industry area or the area which are behind the road station named as city background station as mentioned in common air quality index (Elshout, 2012).

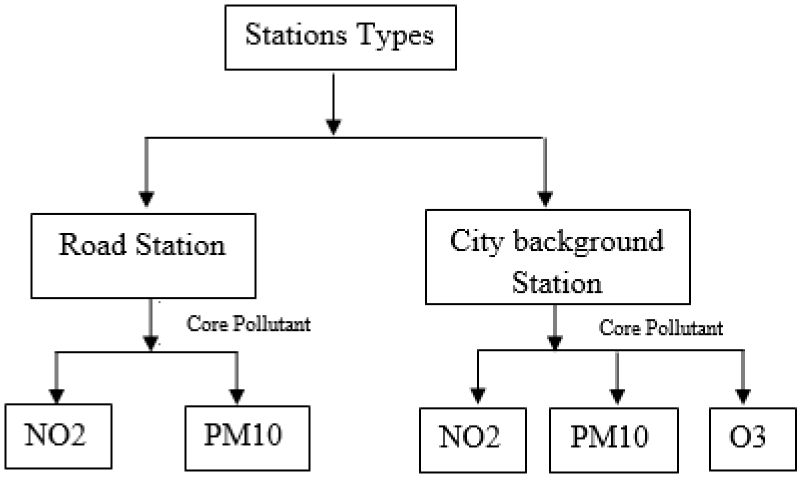

Figure 9: Stations Types

Road station (traffic area) is one of the crucial places which cannot be neglected to choose as an air pollution measurement site. Similarly, the city background station is another site where it is important to measure. For instance, concentration of ozone can rises up due to a photochemical reaction during high temperature, and also background stations can be used to evaluate the pollution transported from other regions. Areas like densely populated areas, industrial areas are major points where air pollution plays an important role and it is important to monitor (van den Elshout, Léger, & Heich, 2014).

4.2 Distribution of Static Sensor in Reference Stations

NILU has provided the hourly data from the year 2003 to 2013, collected from the reference stations (eight different locations) in Oslo - Alnabru, Bærum, Bygdøy, Grønland, Smestad, Kirkevein, Hjortnes and Sofienbergparken. The figure below shows the position of the stations taken from google map and the table 9 show more details on each station. This data are being processed in Rstudio in order to filter and rearrange the data in the required format to make a statistical analysis.

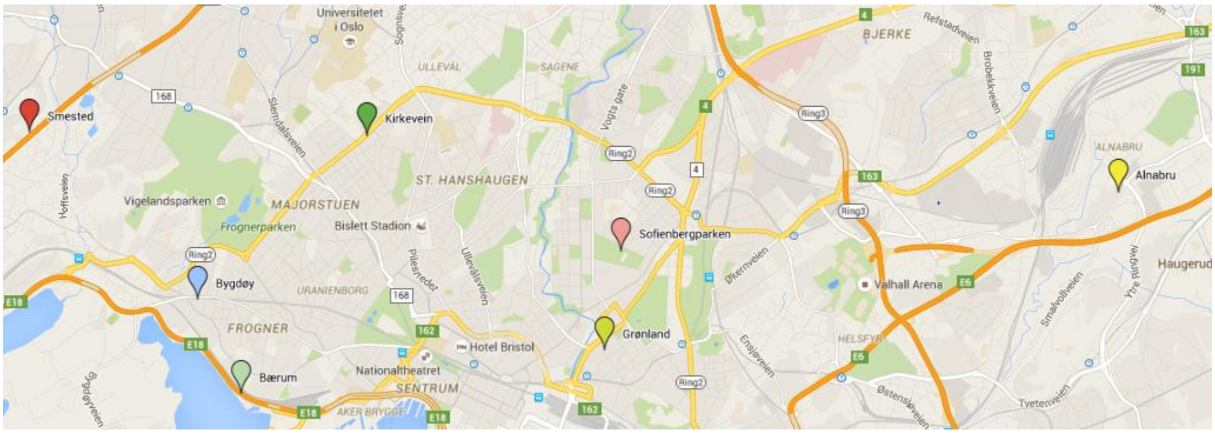

Figure 10: Eight reference stations in Oslo

Table 9 : List of Air Quality Monitoring Stations

City	**Station**	**Zone**	**Height above sea level**	**Station type**	**Compounds (online meas.)**
Oslo	**Alnabru**	32V	95 m	Near Road station	PM_{10}, $PM_{2.5}$, NO, NO_2, NO_x
Oslo	**Bygdøy Alle**	32V	17 m	Near Road station	PM_{10}, $PM_{2.5}$, NO, NO_2, NO_x
Oslo	**Grønland**	32V	15-41 m	City background station	NO_2, O_3, SO_2

Oslo	**Sofienbergparken**	32V	24 m	City background station	PM_{10}, $PM_{2.5}$
Oslo SVO	**Bærum**	32V		City background station	O_3
Oslo SVO	**Hjortnes**	32V		Near Road station	PM_{10}, $PM_{2.5}$, NO, NO_2, NO_x
Oslo SVO	**Kirkeveien**	32V	61 m	Near Road station	PM_{10}, $PM_{2.5}$, NO, NO_2, NO_x, CO
Oslo SVO	**Smestad**	32V	60 m	Near Road station	PM_{10}, $PM_{2.5}$, NO, NO_2, NO_x

Source: Norwegian Institute for Air Research (NILU)

4.3 Quantitative Analysis of Air Pollution in Oslo

Obtained data were summarized to different temporal resolutions, including daily, monthly and yearly resolution. These summarized time series were plotted to get the patterns of different pollutant concentration. For each station, yearly, monthly, daily and hourly time plots were created. Similarly, for each year and each station, the time variation graph was plotted which include hourly, monthly and weekdays plot. Furthermore, the exceedance level of each pollutant was also computed for daily and yearly resolution on the basis of standard exceedance level recommended by the European Union as mentioned in table 3. In order to calculate the exceedance levels of the air pollutants for my research, the limit values established by the European Union have been used.

The location of air quality stations in different places in the city has made it possible to measure, monitor the pollutant levels across the city and the distribution pattern of different pollutant into the stations.

Mainly NO_2, PM_{10} and $PM_{2.5}$ are the main pollutants that are most affecting air quality in Norway. So, the major focus is given to these pollutants for this research. Following figure 11, 13 and 15 shows the annual average concentration of NO_2 and PM.

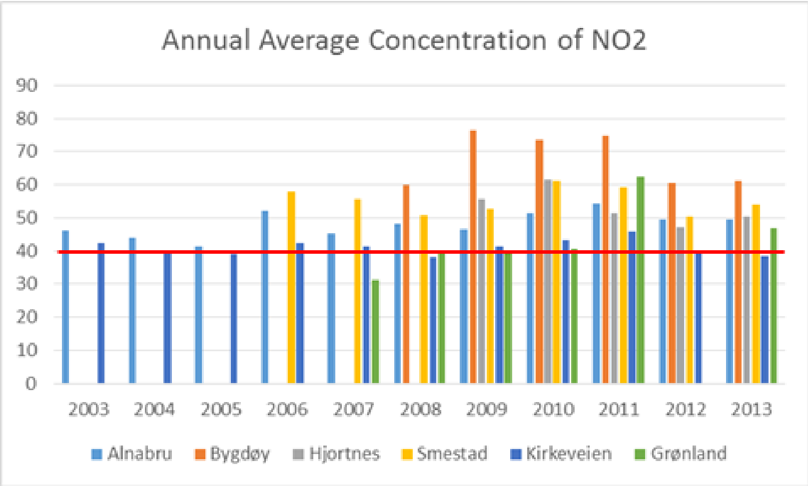

Figure 11: Annual average concentration of NO_2.

Red dashed represent the exceedance limit for NO_2 i.e., 40µg/m3.

Figure 11 illustrates how the annual average concentration of NO_2 collected from six different locations in Oslo, generally exceed the limit of 40µg/m3 required by the EU Directive 2008/50/EC. It seems the annual average concentration of NO_2 in Bygdøy has gradually decreased from 2011 to 2013, but still found to be above the limit. Whereas, the annual average concentration of NO_2 in all six stations in 2011 has exceeded the limit, where Bygdøy having the highest annual NO_2 concentration. While filtering the data of NO_2, there were some errors in measurement of data for the Grønland station during 2012. So, Grønland has not been considered for the year 2012.

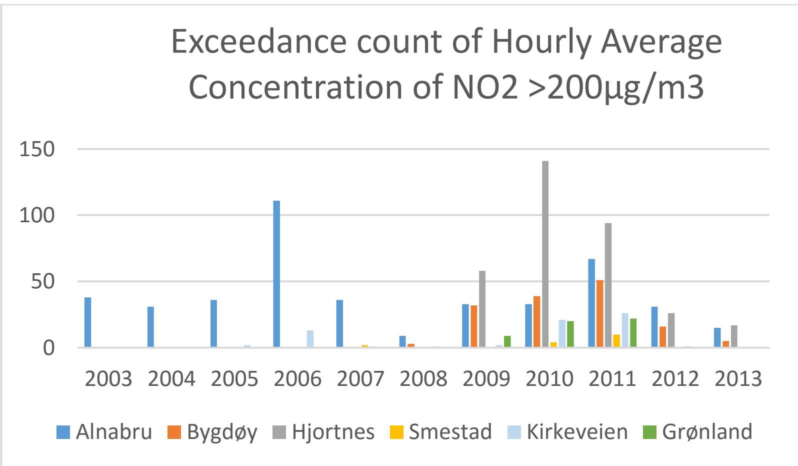

Figure 12: Exceedance count of Hourly Average for NO_2 >200 µg/m3

As mentioned in EU legislation, the hourly exceedance limit for NO_2 is 200µg/m3, where it is allowed to exceed up to 18 times. Exceedance count of hourly average concentration of NO_2

was calculated. The above figure shows the number of times the hourly average of NO_2 had exceeded per year starting from 2003 to 2013. Hjortnes was the highest in the number of days where the hourly average concentration of NO_2 exceeded the standard limit. But during the year 2011, 2012 and 2013, the exceedances count for Alnabru, Bygdøy and Hjortnes gradually decreases.

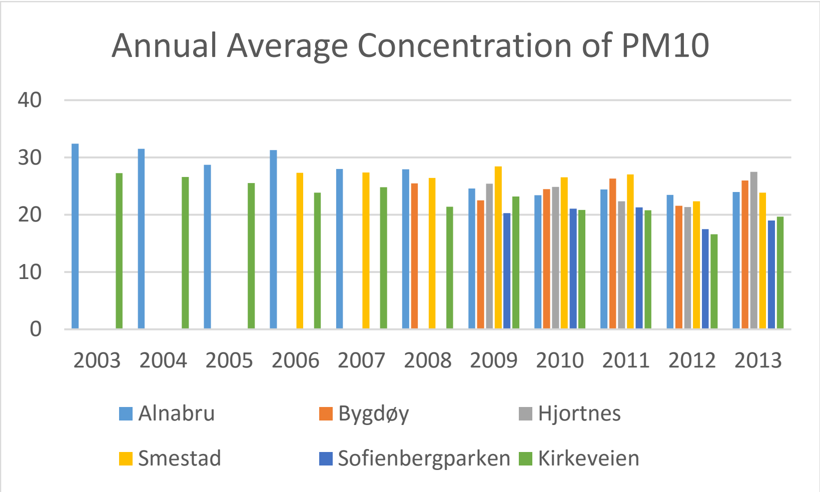

Figure 13: Annual Average Concentration of PM_{10} under the exceedance limit 40µg/m3

Similarly, figure 13 shows the annual average concentration for PM_{10} in six different locations in Oslo. The exceedance limit for PM_{10} is 40µg/m3 (table 3), the annual average concentration of PM_{10} has never exceeded the limit in the given locations. But, this does not mean that public health has not been adversely affected. It is always better to achieve lower concentration of pollutants. Based on EU's limit value, the annual average concentration for PM_{10} has not been exceeded, but considering table 2, WHO has other exposure limits for health protection which are more restrictive. It shows that the annual exposure limit for PM_{10} as 20µg/m3, which is lower than the EU's limit. So, based on WHO exposure limit, above figure shows that the annual average concentration of PM_{10} is above the limit stated by WHO for some stations and years.

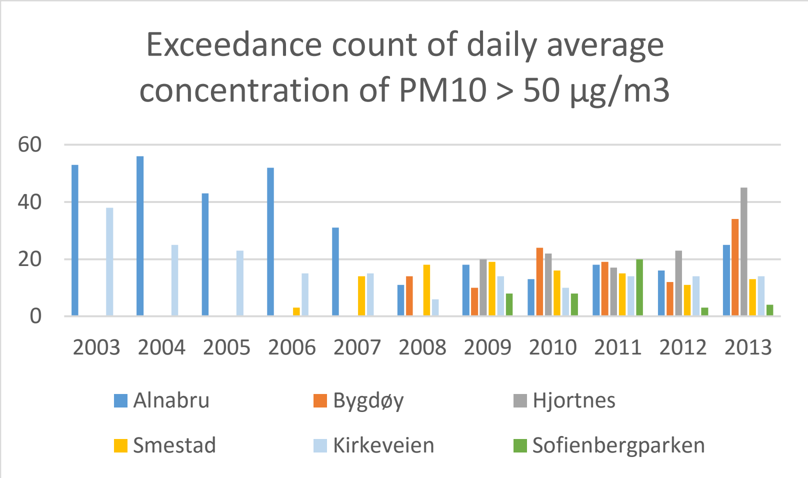

Figure 14: Number of days the daily average concentration of PM_{10} exceeds the limit value, i.e 50 µg/m3.

Furthermore, figure 14 shows the count of days with a daily average concentration of PM_{10} which was above the limit value i.e. 50 µg/m3. According to this figure, in the year 2004, Alnabru exceeded the limit almost 56 times, which is higher than the targeted number of days. But as the time goes by, the number of exceedances gradually decreases. Similarly, in 2013, Hjortnes exceeded the limit of 35 times per year proposed in the EU legislation. Observing the year 2007 to 2012, none of the stations exceeded more than 35 times, which indicates that it is below the limits proposed in the EU legislation.

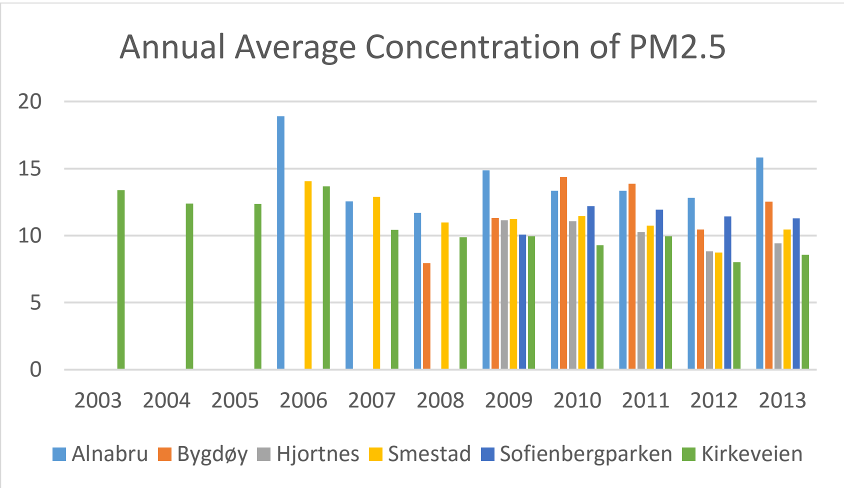

Figure 15: Annual Average Concentration of $PM_{2.5}$

The annual average concentration of $PM_{2.5}$ is shown in above figure. The annual exceedance limit value for $PM_{2.5}$ is 25µg/m3 (table 3). This figure shows that the annual average concentration of $PM_{2.5}$ was under the limit as purposed by EU legislation. Whereas, table 2 (WHO guidelines) says different limit value for $PM_{2.5}$ i.e. 10 µg/m3. Following the WHO limit, some of the stations in Oslo will be exceeding $PM_{2.5}$ concentrations for health protection.

4.4 Temporal and Spatial Variation of Air Pollution in Oslo

Oslo, the capital and the largest city in Norway is located at the northern end of Oslo Fjord which is surrounded by topographical pot formation (Kukkonen et al., 2005). The level of air pollution differs between countries due to their meteorological and topographical variation, atmospheric chemical reaction and sources of emission (Kukkonen et al., 2005). In addition, it also depends on the distribution of population and pollution sources (Morawska, Vishvakarman, Mengersen, & Thomas, 2002).

The cold temperature at ground level, which is mostly in the winter season or at night forms temperature inversion. *“Meteorology has a profound effect on air pollution. When stationary high pressure systems settle over Western Europe in winter, wind speeds fall and temperature inversions form”* (Brimblecombe, 2006).

During winter, polluted air is trapped in ground level because warm inversion air above the cold temperature do not let the polluted air rise up into the atmosphere. Winter season is all about cold temperature and long night compared to day. So, the longer the cold temperature at ground level, higher the pollution level, which adversely affect the health with a short period of time (FMI). Burning of woods is excessively high during winter to escape from cold temperature. *“The wood-burning episodes characteristically occur in cold, calm and stable winter conditions, in which the ground is covered with ice and snow, and the traffic- induced suspension of road dust is therefore of minor importance.” (Kukkonen et al., 2005).* Moreover, emission from mobile vehicle (exhaust), short industry chimney also contributes to air pollution episodes during winter time.

4.4.1 Analysis of Temporal Variation and Spatial Variation in Oslo

To know the distribution pattern of NO_x, NO_2, NO, PM_{10} and $PM_{2.5}$, air pollution were evaluated spatially and temporally from eight reference stations in Oslo, where air pollution data from 2003 to 2013 was taken into consideration, except for some stations where the data collection started only from 2006 and 2008. Following plots are presented only for the year 2013.

In order to know the temporal variation in Oslo, time variation function was used which gives four different plots of pollutants at once - day of the week variation, mean hour of day variation and a combined hour of the day – day of the week plot and a monthly including with 95% confidence interval in the mean.

The temporal variation of NO_2, PM_{10} and $PM_{2.5}$ in Alnabru for 2013 are displayed in figure 16 and figure 17 respectively. Figure 16 shows different temporal trends in concentration of NO_2 in Alnabru. The highest peak is found at around 7:00 and another peak being at around 19:00 which is much lower than the peak in the morning. The values are lower during the night and at the noon which may be due to less traffic on the road. Similarly, concentration of NO is higher than NO_2. However, the day of the week plot shows that measured NO_2 are low during weekend compared to weekdays.

Variation can also be seen seasonally in monthly plot in following figures which clearly depict that concentrations of these pollutants in winter season (Norway -December, January, and February) have higher concentrations than other season. Nitrogen dioxide is experienced during winter and summer (Kukkonen et al., 2005). Following figure shows that the concentration level of NO_2 are relatively lower in summer season (June, July, and August) than winter, spring season (March, April, and May), and autumn season (September, October, and November). This may be due to temperature inversion where air quality is highly polluted as the temperature gets lower.

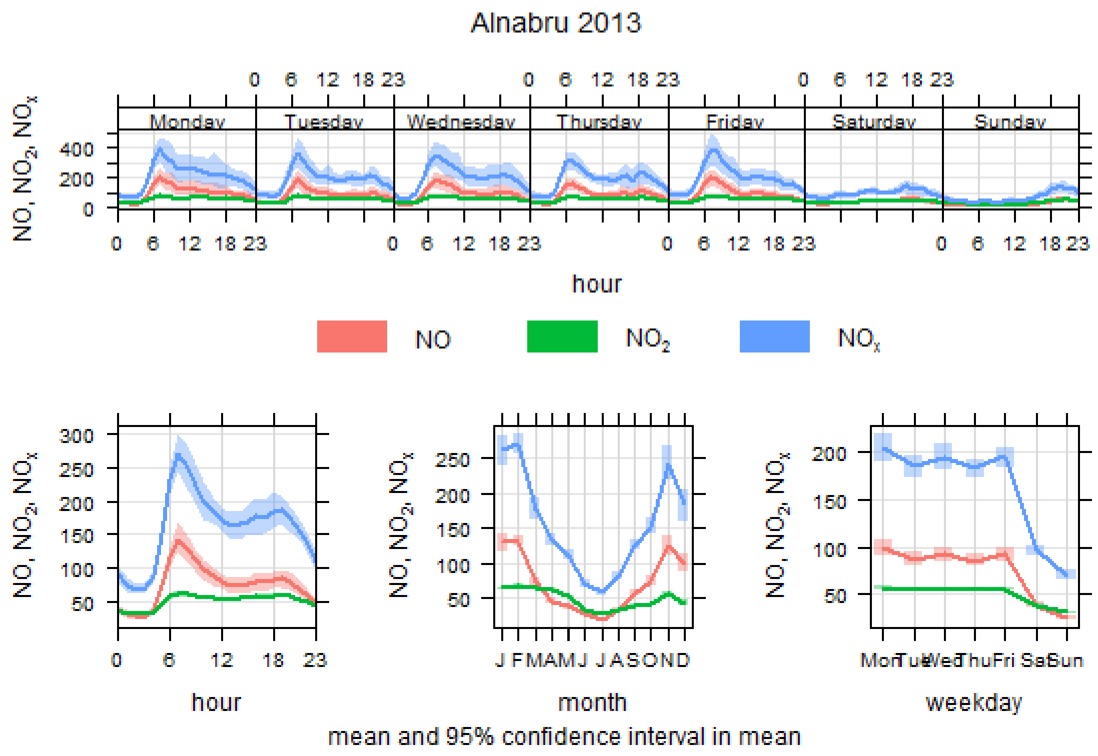

Figure 16: Temporal Variation of NO, NO_2 and NO_x found in Alnabru in 2013

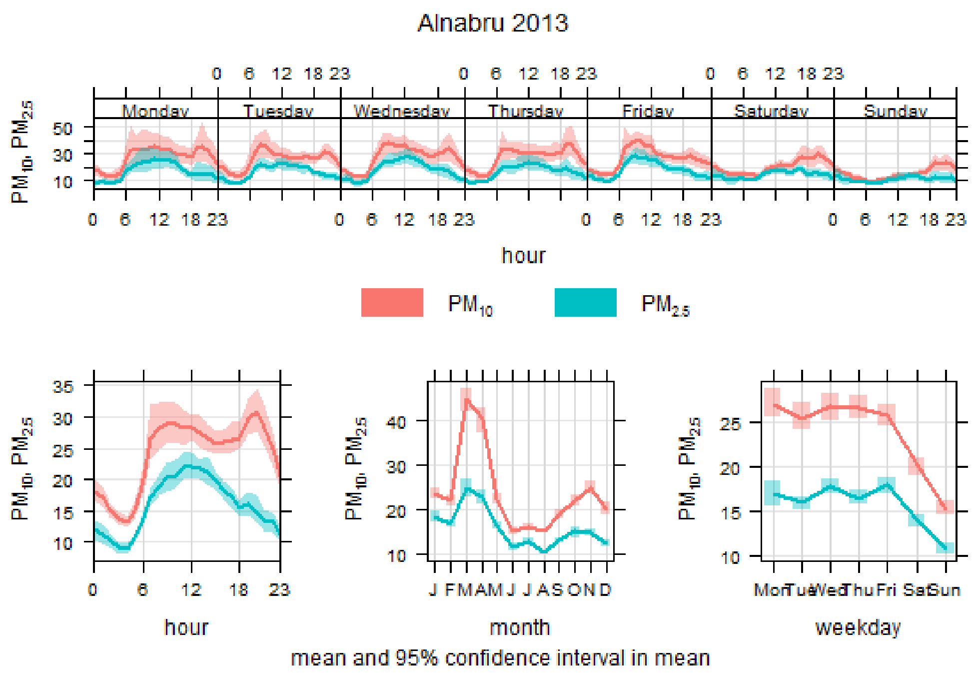

Figure 17: Temporal variation of PM_{10} and $PM_{2.5}$ in Alnabru in 2013.

Similarly, if we look into PM_{10} and $PM_{2.5}$ variation in bottom left plot of figure 17, the highest concentration of PM_{10} were found at around 20:00 and around 7:00 in Alnabru in 2013. Furthermore, looking into the seasonal variation in the monthly plot, it shows that during spring, the level of PM_{10} peaks, but gradually decreased during the summer and starts to increase gradually from the autumn. It seems that from the month of December to February, the level of PM_{10} is seen lower, but not lower than the summer season. Similar results is observed by (Omstedt, Bringfelt, & Johansson, 2005) in their studies where PM_{10} levels rise into peak during start of spring and late winter in Nordic countries where studded tires are in used. This is because during the winter, the roads are wet due to snow and low temperature. As a result the suspension of dust particle decreases and during spring, solar radiation and high temperature helps to increase the evaporation rates due to which roads are found dry, and as a result dust particles are found in high amount. This decreases dust layer in spring season. (Omstedt et al., 2005)

It is observed that during weekdays, PM_{10} and $PM_{2.5}$ levels are found higher than weekend, which can be seen in the bottom right corner of the figure. This may be because of rush and busy hours during the weekdays.

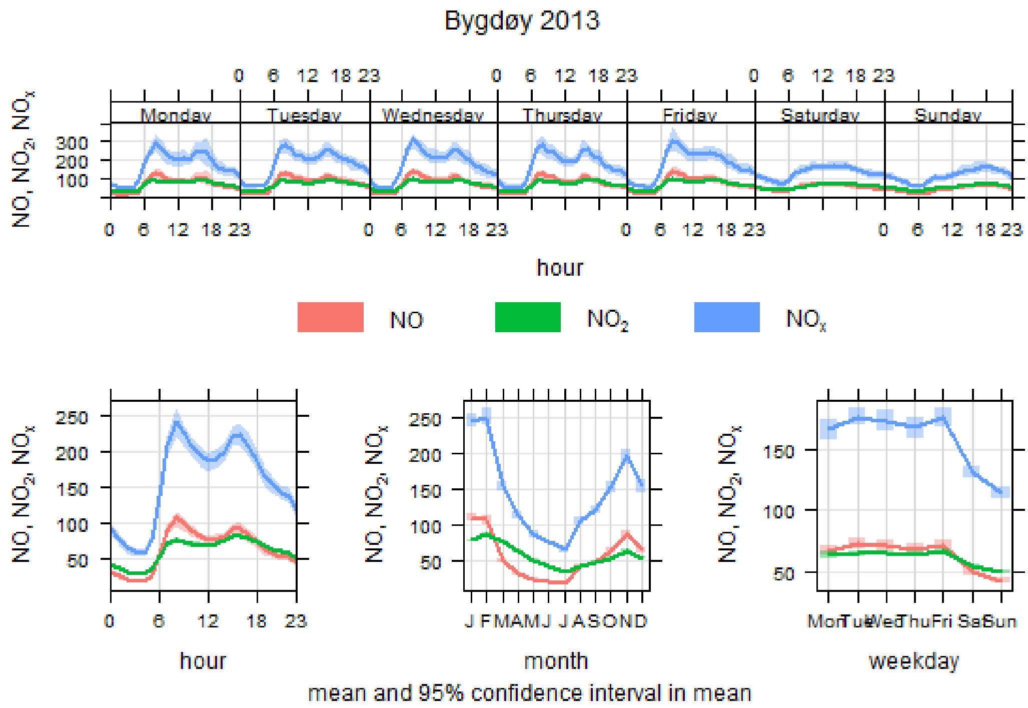

Figure 18: Temporal Variation of NO, NO_2 and NO_x found in Bygdøy in 2013

Similarly, figure 18, 20 and 22 show the temporal variation of NO, NO_2, and NO_x in Bygdøy, Kirkevein and Smested for the year 2013, whereas figure 19, 21, and 23 shows the temporal variation of PM_{10} and $PM_{2.5}$ in Bygdøy, Kirkevein and Smested for the year 2013.

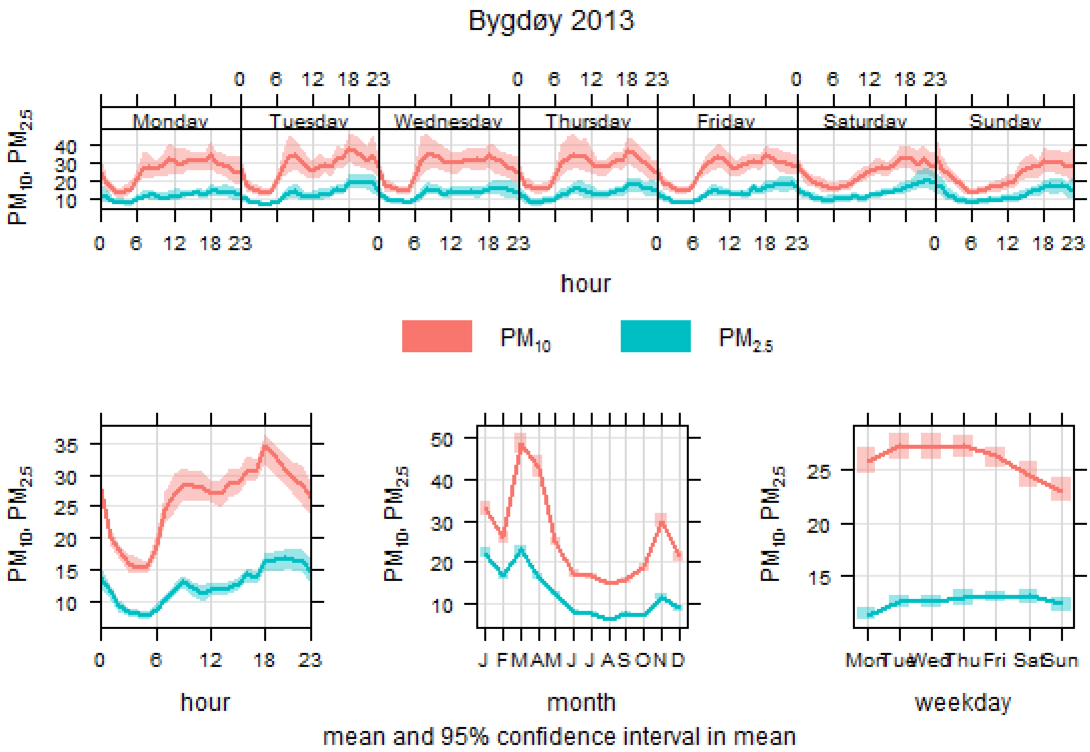

Figure 19: Temporal variation of PM_{10} and $PM_{2.5}$ in Bygdøy in 2013

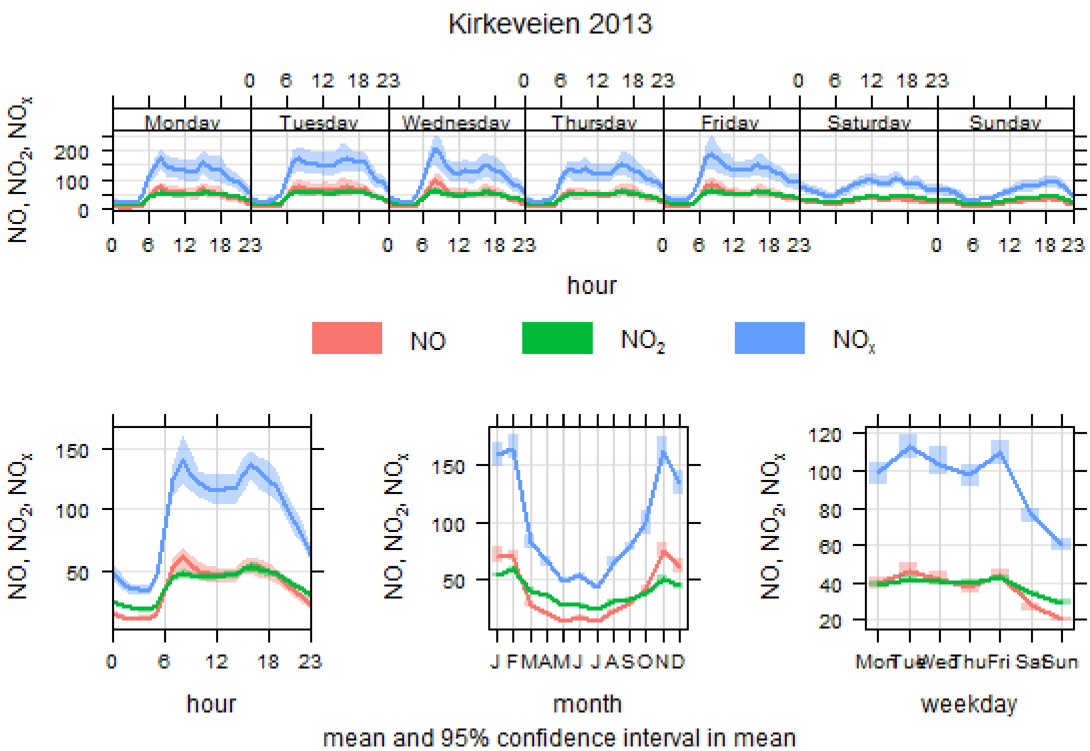

Figure 20: Temporal Variation of NO, NO_2 and NO_x found in Kirkeveien in 2013

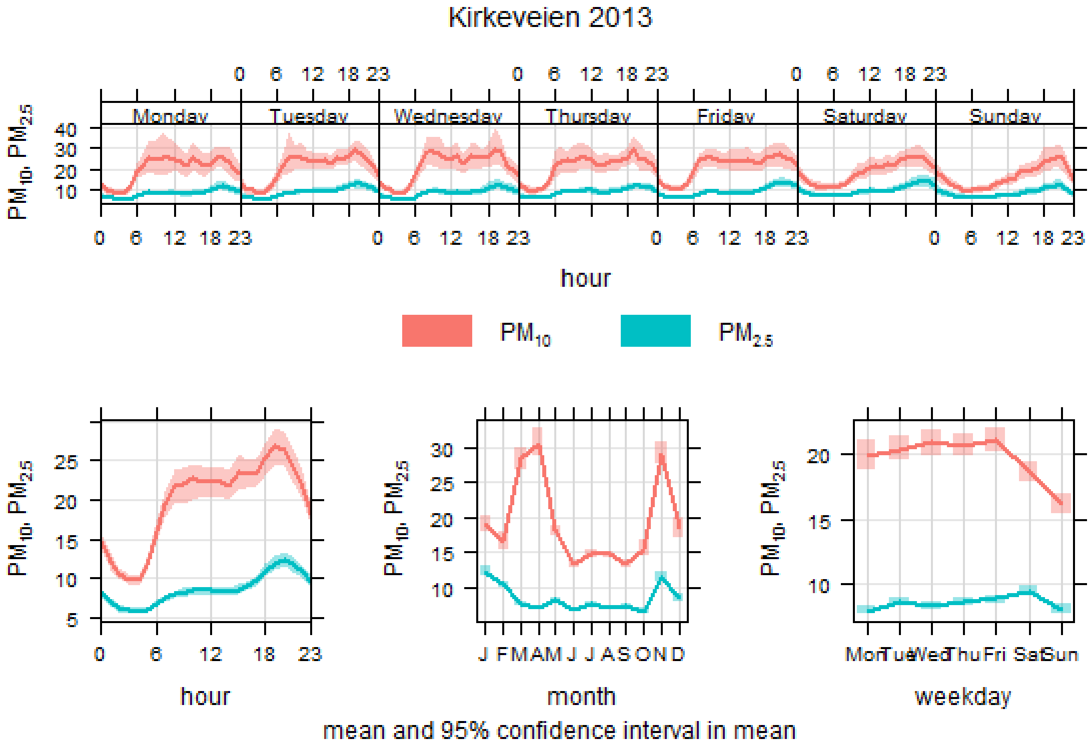

Figure 21: Temporal variation of PM_{10} and $PM_{2.5}$ in Kirkeveien in 2013

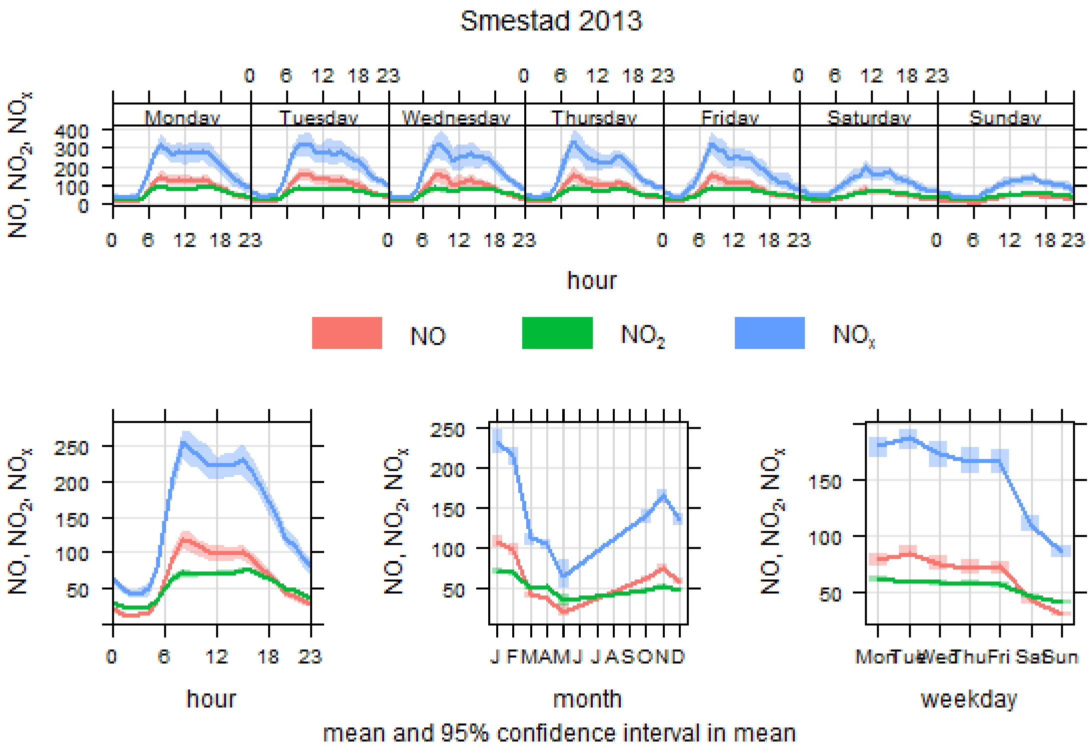

Figure 22: Temporal Variation of NO, NO_2 and NO_x found in Smested in 2013

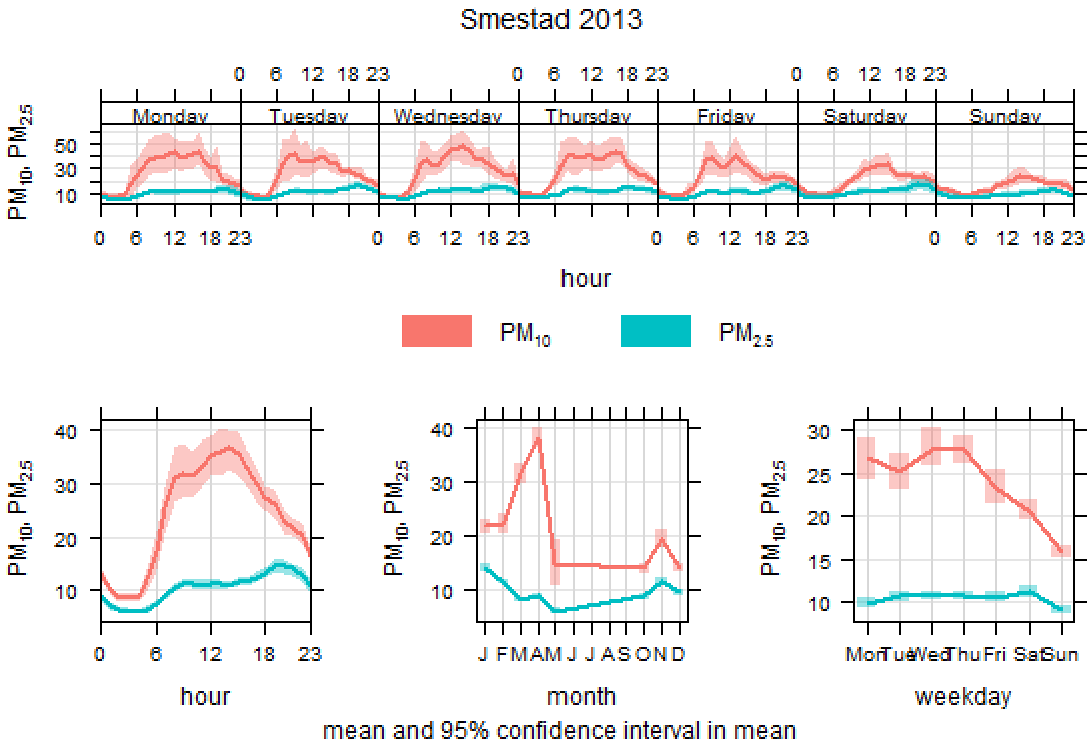

Figure 23: Temporal variation of PM_{10} and $PM_{2.5}$ in Smested in 2013

In all the stations, NO_2 is higher during weekdays compared to weekends. At the bottom-left corner, plot in each figure, hourly plot for 24 hour shows that around 7:00 a.m. or 8:00 a.m. concentration of NO_2 tends to rise to peak and another peak in the afternoon (15:00 – 16:00). This shows the rush hour in Oslo. Moreover, if we look into a monthly plot for these pollutants then, it shows that generally concentration of NO_2 rises up in winter (December, January and Feburary) and later gradually decreases during the summer (June, July and August).

(Kukkonen et al., 2005) have mentioned that pollutants like particulate matter are experienced in winter and spring season in many cities. If we look into the figure 19, 21, and 23, concentration of PM_{10} and $PM_{2.5}$ tends to be lower during the winter season compared to spring season. But the concentration of PM_{10} tends to rise from March and gradually decrease until summer in Alnabru, Bygdøy, Kirkevien, and Smested in 2013. In Oslo, the resuspension of PM is an important source of PM_{10} (and also $PM_{2.5}$) after the snow is melted in the months of March and April, when studded tires are still in use.

Similar pattern can be seen in the hourly plot in bottom left corner of the figure, where the concentration of PM_{10} and $PM_{2.5}$ starts to increase at around 6:00 a.m. which gradually increases during day time and tends to rise to the peak at around 6:00 p.m. or 7:00 p.m.

Eventually, there is slight different in the station Smested in hourly plot, where the concentration of PM_{10} increases at around 6:00 a.m. and gradually increases and goes to the peak at 2:00 p.m. which then ultimately decreases. In addition, PM_{10} and $PM_{2.5}$ concentration are found to be lower on weekends than on weekdays.

4.5 Analysis of data from low-cost sensors

The sensor platforms were received later than initially planned in the CITI-SENSE project. Some of the planned work in the thesis as for instance the evaluation of data from low-cost sensors once deployed in kindergartens in Oslo could not be included as the sensor platform have not been installed in the city location until November 2015.

The analysis presented is based on the data from the co-location of the sensor platforms with referencing monitoring stations in Oslo.

4.5.1 Comparison between the Kirkeveien Station and the Pods

This section includes the analysis of data obtained from low-cost sensor technology. Altogether there are 24 pods which are installed at Kirkeveien station. Data gathered from these pods were then compared with air quality monitoring site i.e Kirkeveien in order to evaluate the difference between data obtained from low-cost sensor and fixed monitoring site.

The pods were installed at Kirkeveien from 13.04.2015. Similarly, some sensors were distributed to other monitoring sites including Aakebergveien, Alnabru and Manglerud from 29.06.2015 till 22.09.2015.

Analysis was divided into three sections:

- First, data were analyzed by taking the hourly average mean from 13.04.2015 to 24.06.2015 received from 24 pods and later compared with Kirkeveien data.

- Secondly, data from only 10 pods which are co-located at Kirkeveien for a longer time (period between 13.04.2015 and 22.09.2015) is analyzed to evaluate monthly variations in the behavior of the pods.

- At last, the data from 29/06/2015 to 22/09/2015 of the pods located at Manglerud, Akebergveien, Alnabru were analyzed with the data from those stations.

These data were measured in ppb (parts per billion) unit, whereas data received from an air quality monitoring station is in µg/m³ (micro gram per cubic meter) unit. For the comparison, the gas (NO, NO_2, O_3, CO) was converted into the same units. Therefore, *µg/m³* unit was later converted into unit *ppb* using the following formula:

ppb = (µg/m³) *(273.15+ °C)/(12.187*M))

where °C is the temperature in Celsius and M is the molecular mass of the gas.

Data for the temperature for the same period was obtained from Eklima (*eklima.met.no*) for the station of Blindern, Oslo. M denotes molecular weight of gaseous pollutant. Molecular weight of **CO:** 28.0101, **NO:** 30.0061, **NO_2:** 46.0055, and **O_3:** 47.9982.

Particulate matter is measured in µg/m³ in both, the pods and the Kirkeveien station and so therefore it is not necessary to be converted for this analysis.

4.5.2 Linear model Analysis

Since this analysis is about comparing two different type sensor measuring the same pollutants so, linear model analysis was conducted. Regression analysis and correlation evaluation were also done using linear model. Coefficient of determination or percentage of variance (R^2) was calculated to determine how well the model fits the data.

$$R^2 = 1 - \frac{\sum(\hat{y}_i - y_i)^2}{\sum(y_i - \bar{y})^2} = 1 - \frac{\text{RSS}}{\text{Total SS(corrected for mean)}}$$

$0 \leq R^2 \leq 1$

where, y is the dependent variable, i.e data from Kirkeveien and $\bar{y}$ is mean of the dependent variable. The value of R^2 close to 1 indicates the better fit (Faraway, 2002). The table 10 shows the slope and offset for the pods analyzed.

Table 10: Correlation of 24 pods for different pollutants (CO, NO, NO_2, O_3, PM_{10}, $PM_{2.5}$)

Pod	**Monthly comparison from 13.04.2015 to 24.06.2015**	**Corrrelation (r2) for CO**	**Corrrelation (r2) for NO**	**Corrrelation (r2) for NO_2**	**Corrrelation (r2) for O_3**	**Corrrelation (r2) for PM_{10}**	**Corrrelation (r2) for $PM_{2.5}$**
	April	0.6	0.93	0.62	0.79	0.55	0.48
	May	0.21	0.91	0.35	0.52	0.12	0.27
688150	June	0.24	0.89	0.13	0.5	0.36	0.16
	April	0.68	0.85	0.42	0.28	0.42	0.33
	May	0.21	0.9	0.25	0.32	0.06	0.17
712150	June	0.23	0.89	0.068	0.099	0.19	0.066
	April	0.71	0.93	0.33	0.33	0.4	0.32
	May	0.36	0.87	0.16	0.27	0.067	0.26
715150	June	0.23	0.83	0.003	0.23	0.19	0.073
	April	0.67	0.82	0.44	0.6	0.12	0.32
	May	0.26	0.66	0.26	0.55	0.042	0.23
718150	June	0.14	0.82	0.03	0.47	0.093	0.087
	April	0.69	0.94	0.46	0.092	0.46	0.43
	May	0.32	0.92	0.26	0.17	0.087	0.28
733150	June	0.21	0.91	0.022	0.31	0.22	0.066
	April	0.66	0.97	0.43	0.67	0.26	0.32
	May	0.28	0.91	0.2	0.58	0.051	0.26
737150	June	0.17	0.9	0.031	0.48	0.16	0.082
	April	0.72	0.97	0.31	0.64	0.42	0.42
	May	0.34	0.92	0.17	0.48	0.079	0.31
743150	June	0.27	0.91	0.0097	0.48	0.17	0.074
	April	0.45	0.88	0.47	0.11	0.37	0.25
	May	0.32	0.86	0.35	0.04	0.05	0.12
744150	June	0.2	0.81	0.3	0.011	0.16	0.036
	April	0.7	0.81	0.36	0.67	0.36	0.36
	May	0.32	0.83	0.25	0.63	0.064	0.28
746150	June	0.22	0.81	0.012	0.49	0.16	0.064
	April	0.71	0.93	0.41	0.71	0.42	0.34
	May	0.36	0.8	0.22	0.63	0.058	0.2
750150	June	0.26	0.73	0.024	0.51	0.17	0.077
	April	0.7	0.88	0.49	0.61	0.43	0.28
	May	0.34	0.85	0.29	0.53	0.08	0.23
751150	June	0.23	0.6	0.097	0.33	0.19	0.078
	April	0.68	0.96	0.36	0.17	0.39	0.36
	May	0.32	0.92	0.1	0.27	0.06	0.27
756150	June	0.22	0.9	0.026	0.32	0.21	0.073
764150	April	0.71	0.97	0.28	0.0059	0.42	0.34

	May	0.34	0.94	0.05	0.034	0.065	0.28
	June	0.23	0.92	0.15	0.039	0.18	0.064
	April	0.41	0.51	0.37	0.23	0.45	0.3
	May	0.3	0.43	0.28	0.19	0.072	0.22
785150	June	0.17	0.63	0.26	0.12	0.22	0.074
	April	0.66	0.82	0.32	0.073	0.36	0.33
	May	0.32	0.7	0.0042	0.14	0.066	0.3
828150	June	0.19	0.54	0.14	0.31	0.17	0.084
	April	0.74	0.7	0.69	0.43	0.41	0.36
	May	0.41	0.73	0.58	0.24	0.063	0.27
846150	June	0.28	0.57	0.51	0.16	0.2	0.069
	April	0.67	0.82	0.4	0.33	0.49	0.43
	May	0.3	0.67	0.3	0.36	0.088	0.29
849150	June	0.17	0.52	0.21	0.25	0.2	0.063
	April	0.73	0.63	0.47	0.22	0.46	0.41
	May	0.36	0.6	0.41	0.29	0.064	0.27
850150	June	0.29	0.38	0.3	0.28	0.22	0.05
	April	0.36	0.29	0.43	0.34	0.47	0.31
	May	0.29	0.56	0.35	0.29	0.069	0.21
855150	June	0.14	0.37	0.23	0.24	0.0027	0.073
	April	0.66	0.66	0.48	0.38	0.45	0.3
	May	0.31	0.49	0.38	0.29	0.0024	0.24
856150	June	0.19	0.33	0.27	0.25	0.19	0.072
	April	0.65	0.82	0.47	0.57	0.1	0.29
	May	0.32	0.64	0.27	0.5	0.044	0.27
861150	June	0.17	0.54	0.12	0.42	0.13	0.078
	April	0.48	0.73	0.55	0.4	0.46	0.33
	May	0.36	0.66	0.4	0.31	0.054	0.12
862150	June	0.28	0.59	0.24	0.21	0.23	0.058
	April	0.68	0.83	0.37	0.41	0.36	0.29
	May	0.3	0.65	0.18	0.31	0.056	0.25
863150	June	0.19	0.55	0.013	0.16	0.17	0.057
	April	0.71	0.83	0.42	0.054	0.51	0.36
	May	0.37	0.66	0.033	0.095	0.084	0.27
864150	June	0.27	0.52	0.043	0.19	0.28	0.047

From above table shows the variation of correlation from the period 13.04.2015 to 24.06.2015 for the pollutants (CO, NO, NO_2, O_3, PM_{10}, $PM_{2.5}$). The correlation variation for CO varies between 0.14 and 0.74. It seems that during April the value of correlation in all 24 pods are higher which is more than 0.5 and decreases is in May and June. There may be some factor that causes the pattern. A similar pattern is found for NO_2 where the correlation varies between 0.003 and 0.69 for NO_2 but 22 out of 24 pod have lower than 0.5 correlation.

Similarly, the correlation varies between 0.29 and 0.97 for NO where the maximum value is almost found during April having the correlation above 0.5 whereas in case of O_3, 17 out of 24 pods have the correlation lower than 0.5. Similarly, in case of PM_{10} and $PM_{2.5}$, maximum value of correlation are lower than 0.5 but found mostly during April.

In the following figures, examples of the scatterplots is shown for only one pod (identified by serial number 864150). The figures show clearly that NO has the strongest correlation, while O_3 has the lowest correlation, and no pattern is observed in the data from this sensor.

From the figure 24, it shows that CO has a correlation below 0.5 and the sensor is capable to detect peaks in the concentration. The values of NO in figure 25 depicts that the values strongly correlated as the correlation between the values from the pod and monitoring sites is 0.74 which is quite close to 1. Ozone values are weakly correlated as the scatter plot shows no pattern and the correlation coefficient is quite low (0.11) in figure 26. This means that, if we consider the pod to give correct values, then the static sensors for measuring O_3 is not reliable at all and cannot be calibrated. Similarly, figure 27 shows weakly correlated with highly dispersed values for $PM_{2.5}$ and the value of R2 is quite low which signifies that linear model does not fit for $PM_{2.5}$ and the figure 28 depicts the correlation for PM_{10} is 0.46 which is close to 0.5, but PM_{10} has better performance than $PM_{2.5}$. For instance, monthly scatter plot for the pod 864150 are available in the appendix C.1 for the period of 3 months for 5 different pollutants.

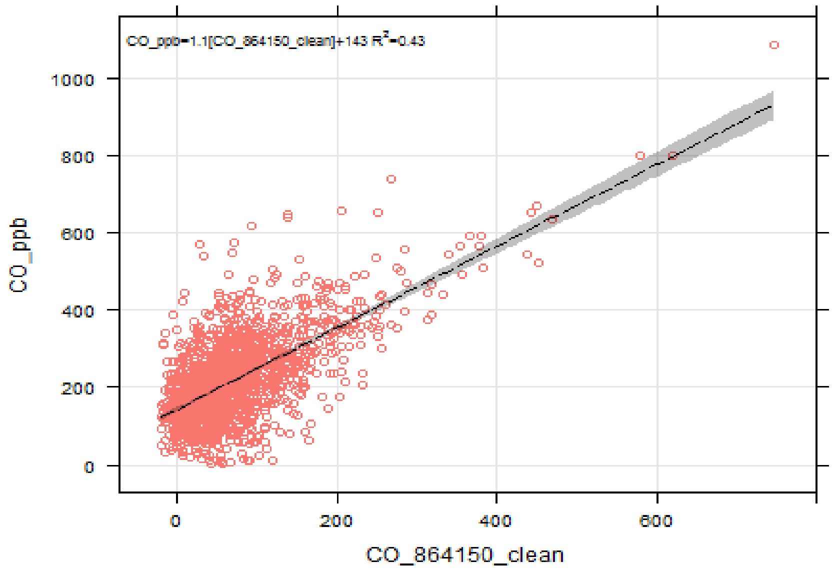

Figure 24: Scatter Plot for CO from pod and Kirkeveien.

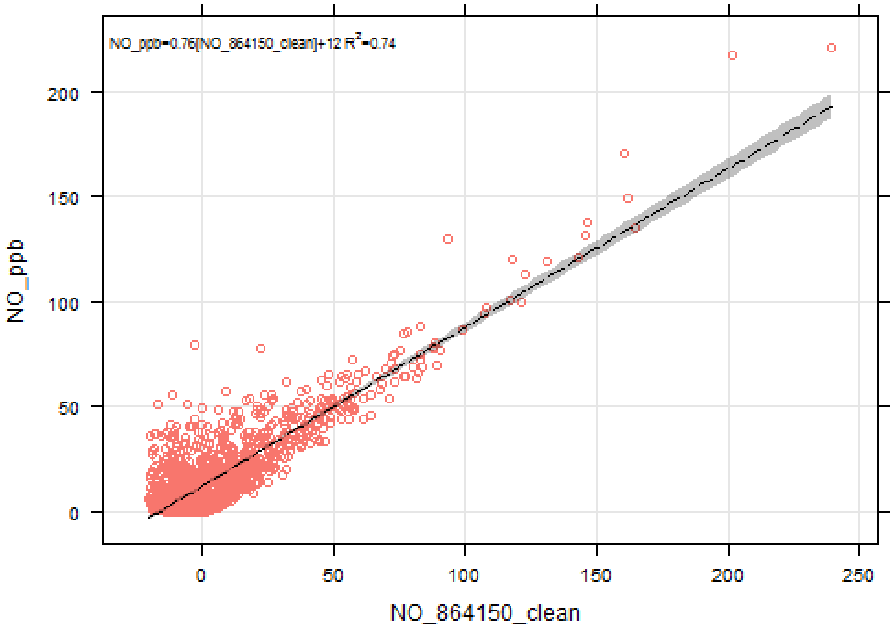

Figure 25: Scatter Plot of NO from pod and Kirkeveien

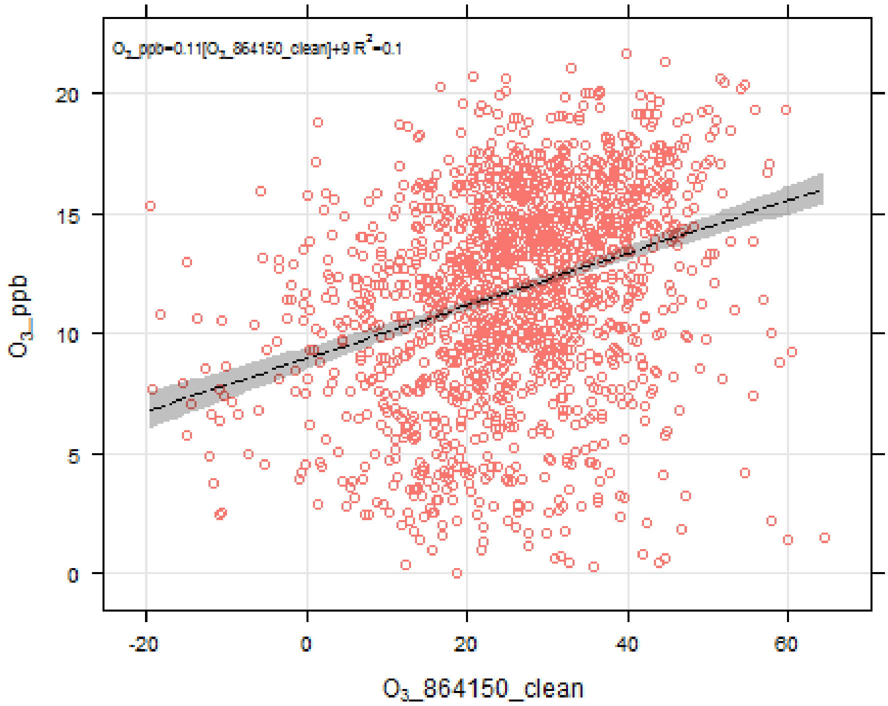

Figure 26: Scatter Plot of O_3 from pods and Kirkeveien

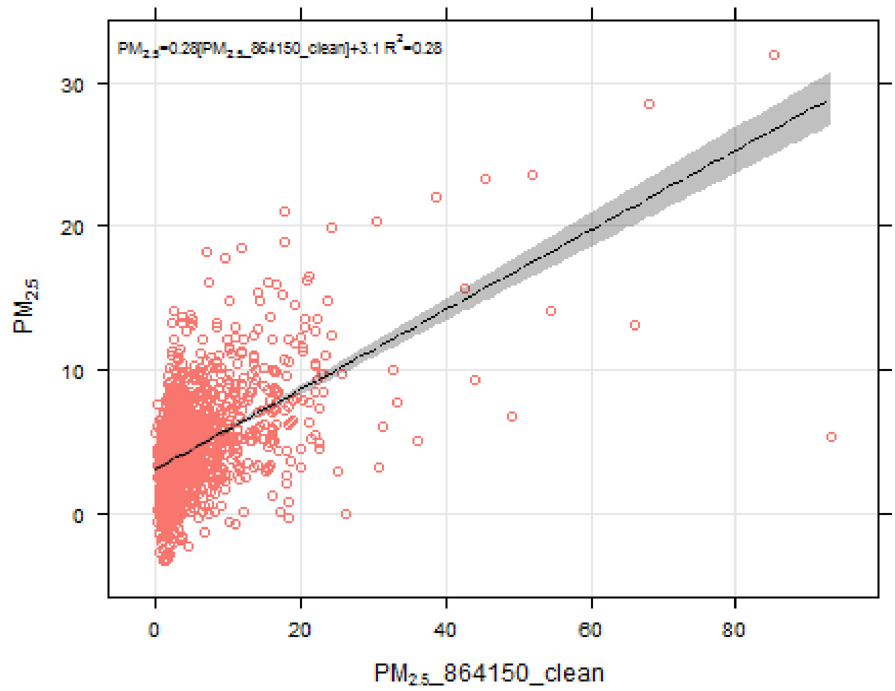

Figure 27: Scatter Plot of $PM_{2.5}$ from pods and Kirekeveien

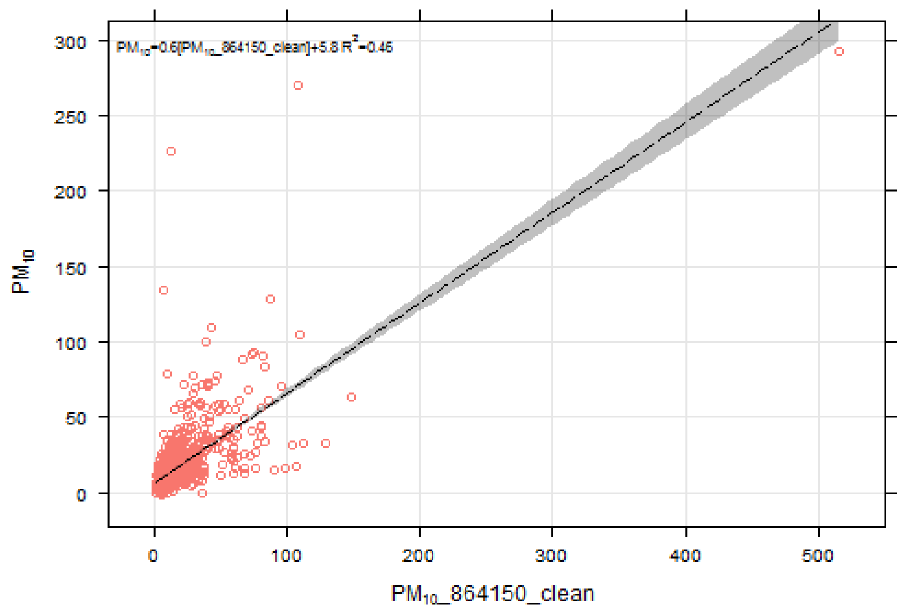

Figure 28: Scatter Plot of PM_{10} from pods and Kirkeveien

4.5.3 Temporal behavior of the pods

In order to evaluate the temporal behavior of the pods, the linear model and correlation was calculated in a monthly basis. For the 24 pods data was available between April and June. However, for 10 out of the 24 pods data was available from April to September. For instance, following figure relates how the correlation, gradient and intercept varies from month to month for 10 pods.

If we look into gradient from the month April to June from the following figure 29 to 34, we can see that there are variations, but it keeps around the same values for the different gases. The larger differences occur during the summer months. For the intercept from the figure 35 to 40, it is also observed a similar behavior, with differences between summer and spring months, this is shown more clearly for CO and $PM_{2.5}$. Similarly, in cases in correlations from figure 41 to 46 also shows a monthly variation, possibly linked with the fact that the sensors suffer from interferences to temperature and relative humidity.

Linear field calibration is necessary to ensure that the sensors are aligned with the data from the reference instrumentation. Results here show that in order to ensure the best performance of the sensors, field calibration should be performed on a regular basis. From the results, variations in gradient, interference and correlation seem to be linked with variations in the meteorological conditions, thus it will be recommendable to have at least a calibration every season.

- **Gradient from April to September for pod 1 to 10**

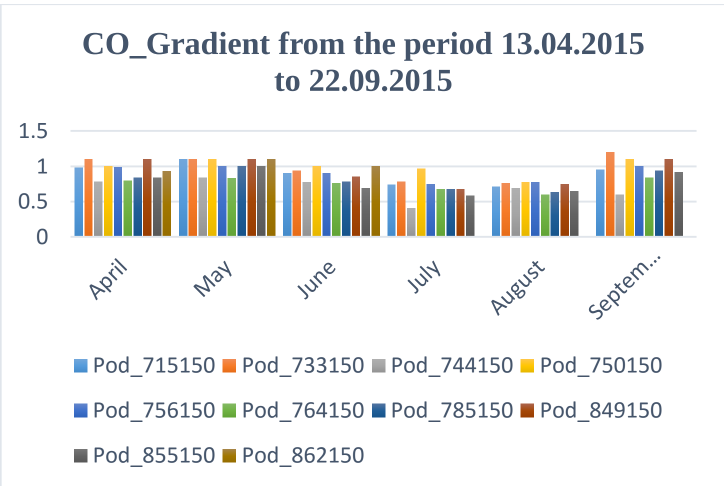

Figure 29: Gradient of CO from April to September for pod 1 to 10

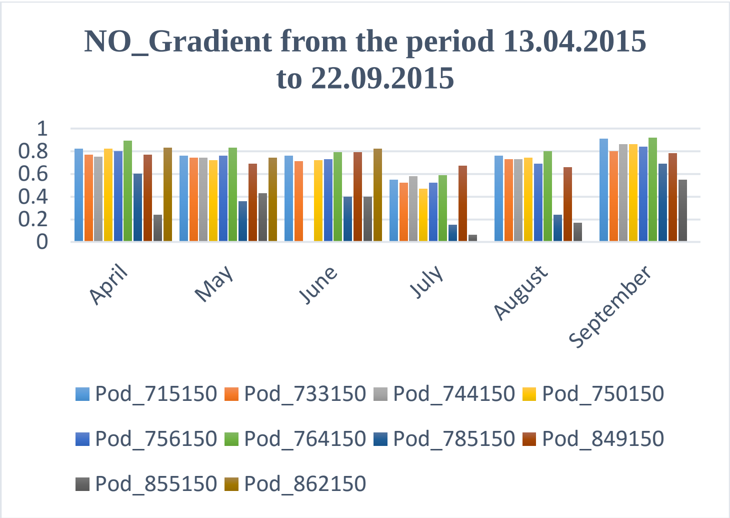

Figure 30: Gradient of NO from April to September for pod 1 to 10

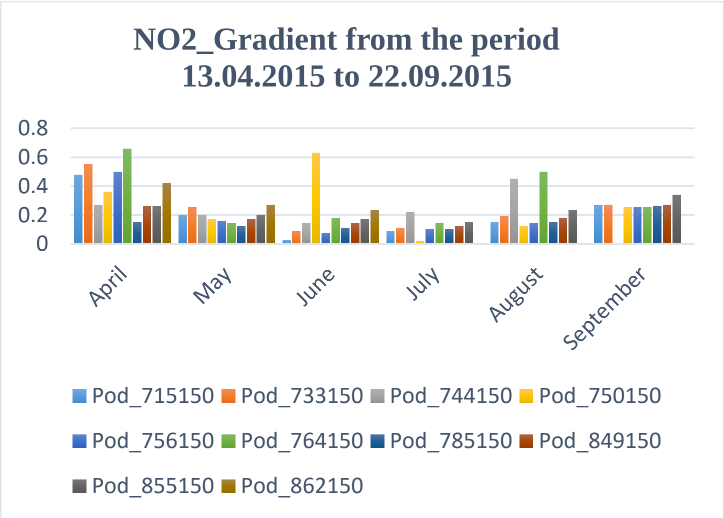

Figure 31: Gradient of NO_2 from April to September for pod 1 to 10

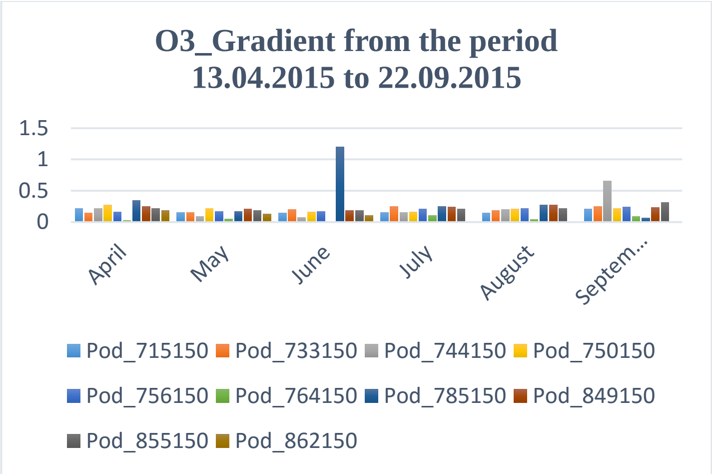

Figure 32: Gradient of O_3 from April to September for pod 1 to 10

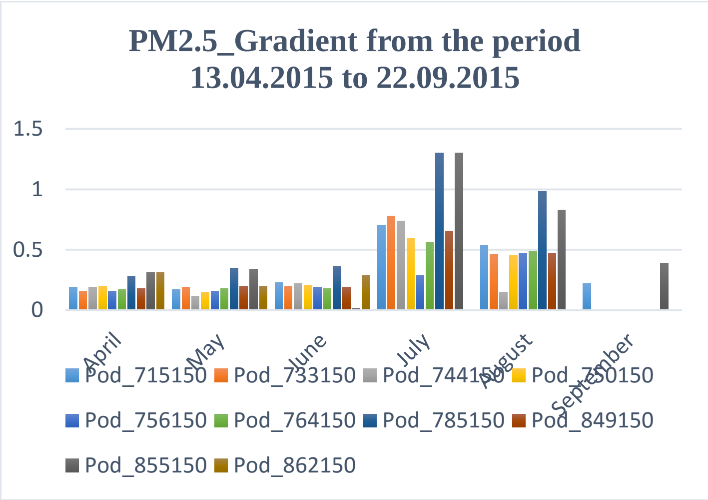

Figure 33: Gradient of $PM_{2.5}$ from April to September for pod 1 to 10

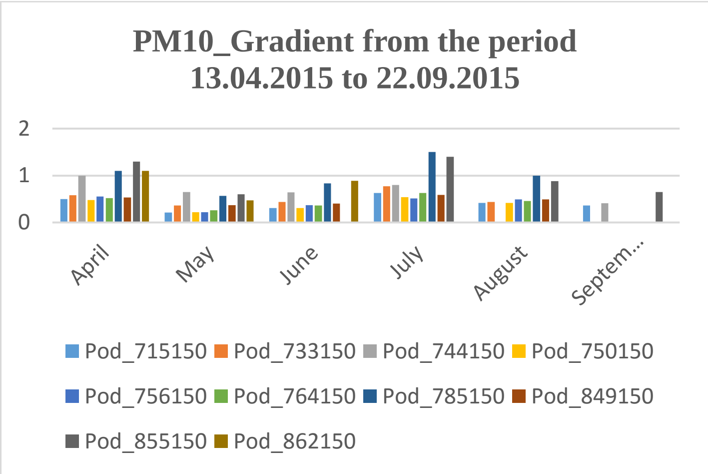

Figure 34: Gradient of PM_{10} from April to September for pod 1 to 10

- **Intercept from April to September for pod 1 to 10**

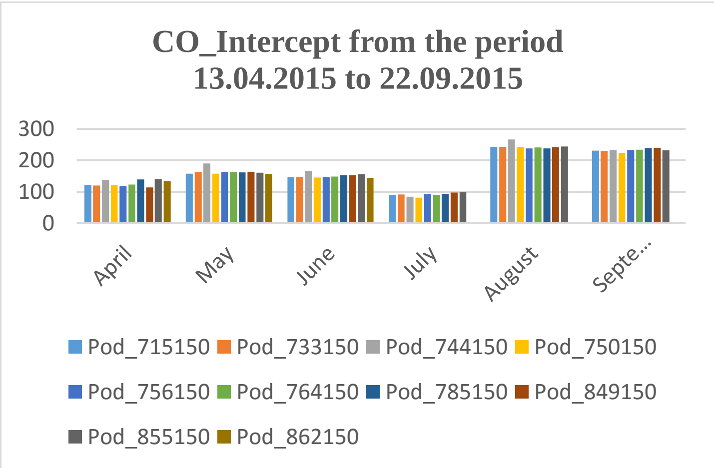

Figure 35: Intercept of CO from April to September for pod 1 to 10

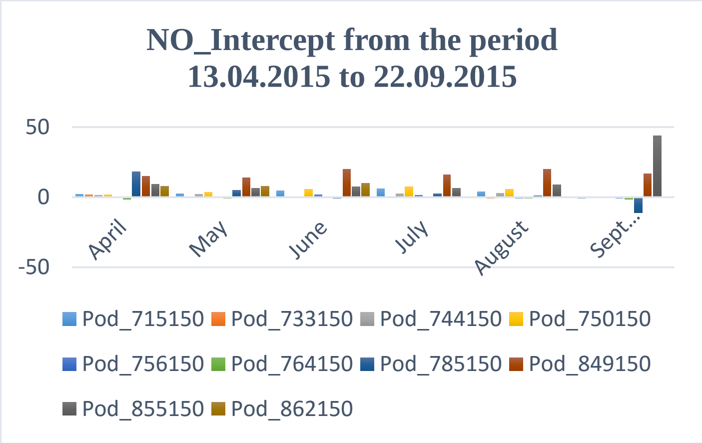

Figure 36: Intercept of NO from April to September for pod 1 to 10

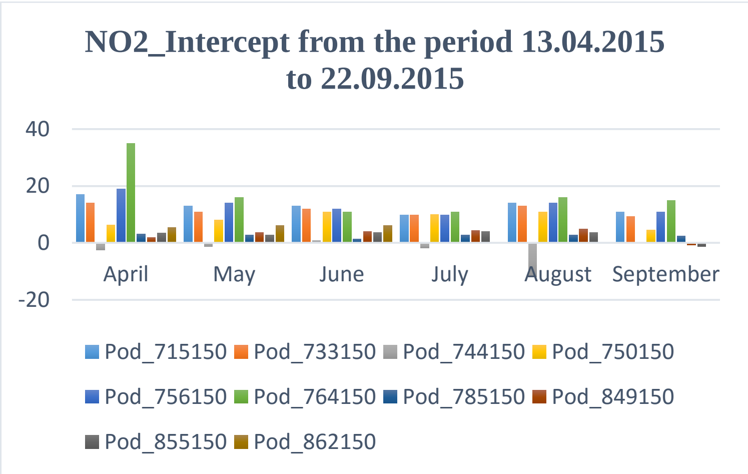

Figure 37: Intercept of NO_2 from April to September for pod 1 to 10

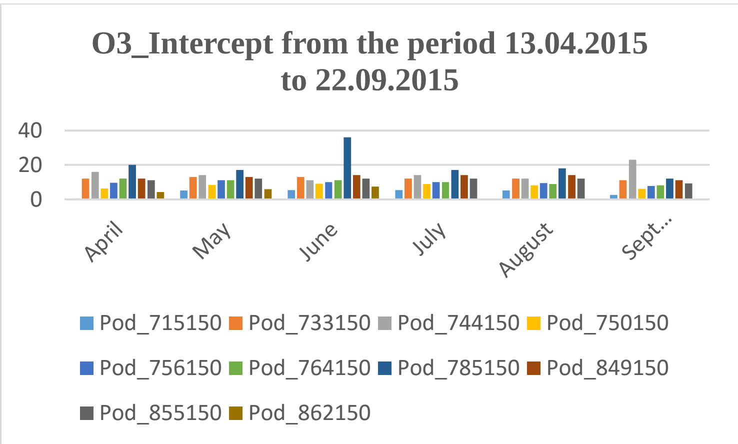

Figure 38: Intercept of O_3 from April to September for pod 1 to 10

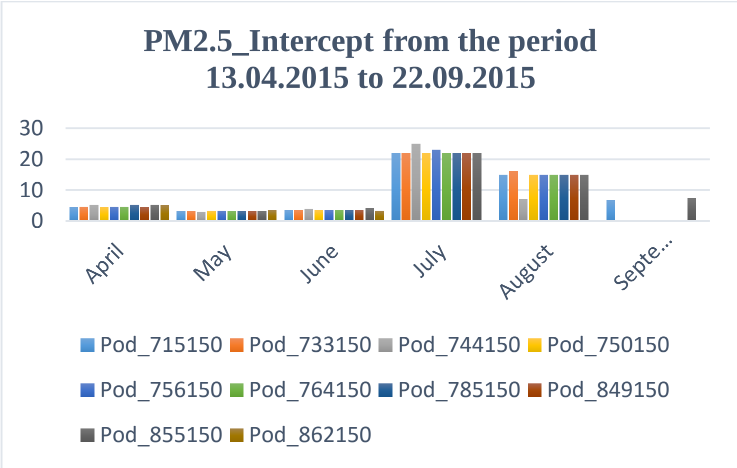

Figure 39: Intercept of $PM_{2.5}$ from April to September for pod 1 to 10

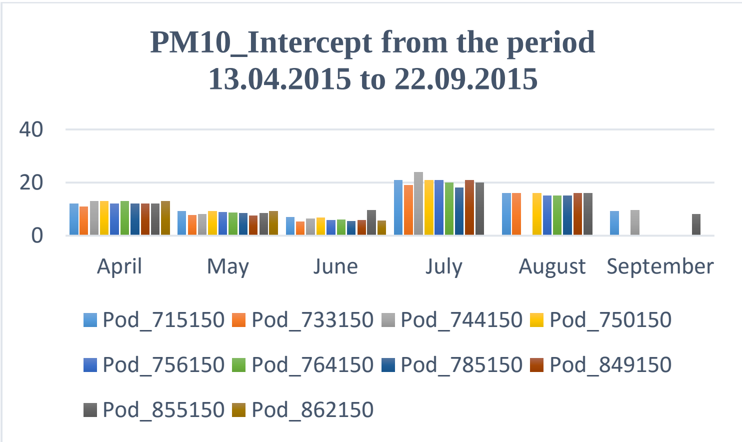

Figure 40: Intercept of PM_{10} from April to September for pod 1 to 1

➢ Correlation from April to September for pod 1 to 10

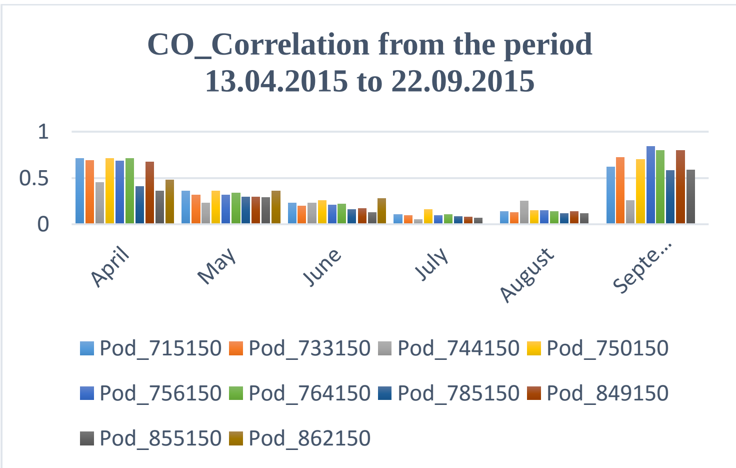

Figure 41: Correlation of CO from April to September for pod 1 to 10

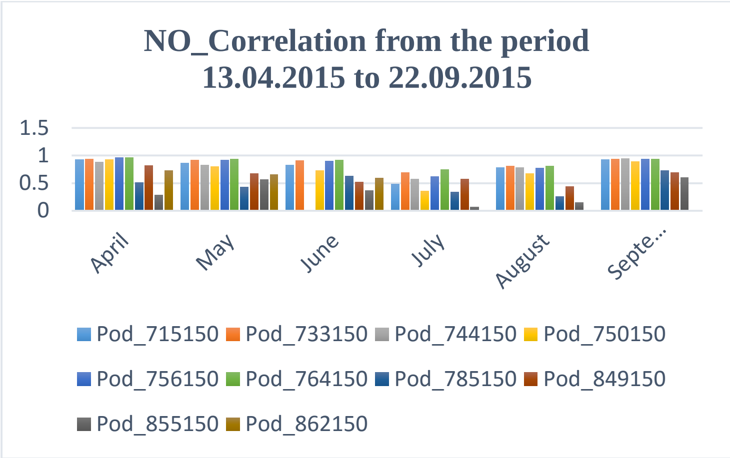

Figure 42: Correlation of NO from April to September for pod 1 to 10

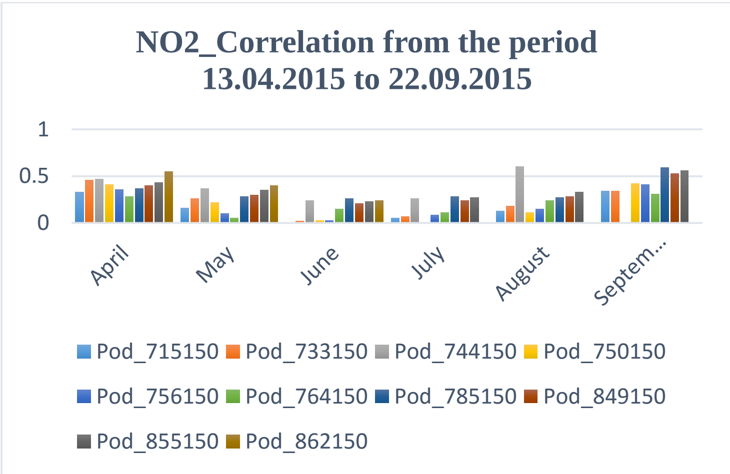

Figure 43: Correlation of NO_2 from April to September for pod 1 to 10

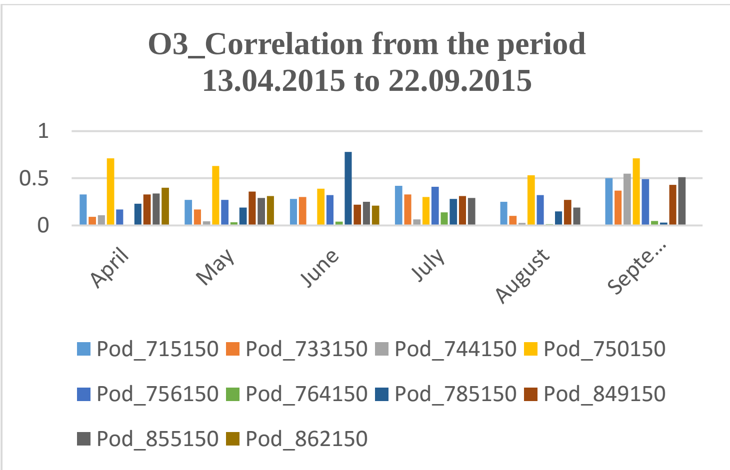

Figure 44: Correlation of O_3 from April to September for pod 1 to 10

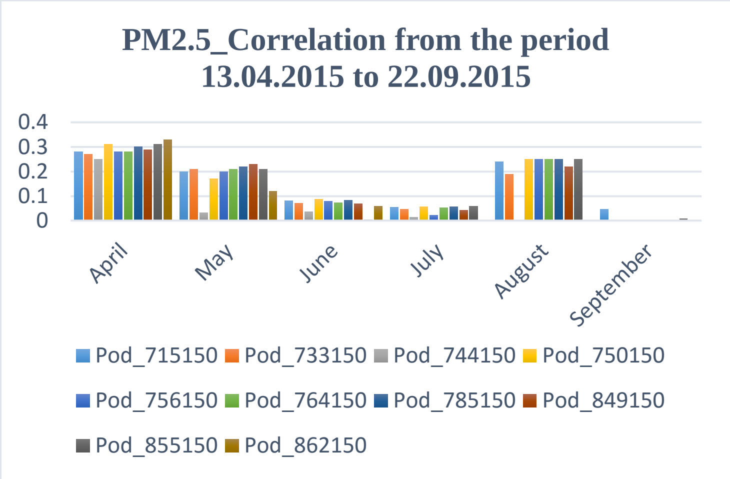

Figure 45: Correlation of $PM_{2.5}$ from April to September for pod 1 to 10

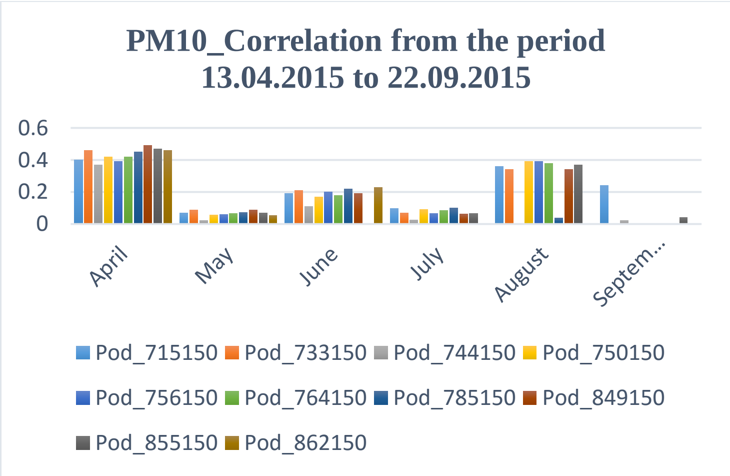

Figure 46: Correlation of PM_{10} from April to September for pod 1 to 10

4.5.4 Field calibrations and Statistics using modStats

One of the challenges of low-cost static sensors is to get the accurate reading from them in order to improve the quality of data received. To overcome this issue, there is need of frequent sensor calibration. (Hasenfratz et al., 2012) also point out the need of frequent calibration, for which he purposed three calibration algorithm based on a traditional approach namely *forward calibration, backward calibration and instant calibration*. On the other hand, there is many other alternatives for calibration. For instance, linear regression is one of the statistical method which is used often (Burke, 2001).

The use of linear regression analysis helped to predict the values and find the relationship between the data. Thus obtained results from the linear regression were used to calibrate the pods based on the field results. Concentrations from the pods are displaced regarding the field concentrations. For instance, the values for the CO from the pods showed an intercept around 150 ppb.

Furthermore, for the calibrations, “modStats” function is used to evaluate the model statistically in Rstudio. *“The modStats function provides key model evaluation statistics for comparing models against measurements and models against other models.” (Carslaw & Ropkins, 2012)* This function have different statistics that can be used in order to evaluate the model which are explained below in the table.

Table 11: List of model performance evaluation statistics with their formula

Oi representst the ith observed value and Mi represents the ith modelled value for the total of n observations.

Statistic	Meaning	Formula
Fraction of predictions within a factor or two (FAC2)	FAC2 is the fraction of modelled values within a factor of two of observed values.	$0.5 \leq \frac{M_i}{O_i} \leq 2.0$
Mean bias (MB)	MB provides a good indication of the mean over or under estimate of predictions.	$M = \frac{1}{n}\sum_{i=1}^{N} M_i - O_i$

Mean Gross Error (MGE)	MGE provides a good indication of the mean error regardless of whether it is an over or under estimate	$MGE = \frac{1}{n}\sum_{i=1}^{N} \lvert M_i - O_i \rvert$
Normalised mean bias (NMB)	NMB is useful for comparing pollutants that cover different concentration scales and the mean bias is normalised by dividing by the observed concentration	$NMB = \frac{\sum_{i=1}^{n} M_i - O_i}{\sum_{i=1}^{n} O_i}$
Normalised mean gross error (NMGE)	NMGE further ignores whether a prediction is an over or under estimate.	$NMGE = \frac{\sum_{i=1}^{n} \lvert M_i - O_i \rvert}{\sum_{i=1}^{n} O_i}$
Root mean squared error (RMSE)	RMSE is a commonly used statistic that provides a good overall measure of how close modelled values are to predicted values	$RSME = \left(\frac{\sum_{i=1}^{N}(M_i - O_i)^2}{n}\right)^{1/2}$
Correlation coefficient (r)	r is a measure of the strength of the linear relationship between two variables. When r = 1, it indicate that between two variables there is perfect linear relationship with positive slope. When r = -1, it indicates that between two variables there is also a perfect linear relationship with negative slope.	$r = \frac{1}{(n-1)}\sum_{i=1}^{n}\left(\frac{M_i - \overline{M}}{\sigma_M}\right)\left(\frac{O_i - \overline{O}}{\sigma_O}\right)$
Coefficient of Efficiency (COE)	COE is simple formulation to measure the model performance. When COE = 1, it is perfect model. When COE = 0, then it indicate that this model is no more able to predict the observed values than does the	$COE = 1.0 - \frac{\sum_{i=1}^{n} \lvert M_i - O_i \rvert}{\sum_{i=1}^{n} \lvert O_i - \overline{O} \rvert}$

	observed mean. When COE = -1, then the model is less effective than the observed mean in predicting the variation in the observations.	

Source: (Carslaw & Ropkins, 2012)

After the linear model (or field calibration) is applied to correct the original values, we get the table below showing the errors. For instance, following table shows the results for 24 pods for the pollutant CO for the period 13.04.2015 to 24.06.2015.

Table 12: Statistics for 24-pods for CO from 13.04.2015 to 24.06.2015

Pods	**FAC2**	**MB**	**MGE**	**NMB**	**NMGE**	**RMSE**	**R**	**COE**
688150	0.911435942	-2.37E-13	69.01761193	-1.02E-15	0.295747	91.55378	0.583037	0.183797
712150	0.910745234	-2.03E-13	68.3956002	-8.73E-16	0.293724	89.49408	0.602115	0.187007
715150	0.882935352	8.77E-14	63.38414474	4.05E-16	0.293236	84.32698	0.636727	0.235297
718150	0.871629543	-1.32E-13	67.91957855	-6.14E-16	0.315401	89.61824	0.567962	0.176479
733150	0.881455399	-1.23E-13	64.58245981	-5.69E-16	0.299412	85.72913	0.61578	0.21653
737150	0.86877563	-9.89E-14	67.21759003	-4.58E-16	0.311758	88.74808	0.579715	0.18587
743150	0.883855981	-2.24E-13	62.64353053	-1.04E-15	0.289998	83.62855	0.643794	0.243934
744150	0.876882777	-2.15E-13	66.39346332	-9.98E-16	0.307553	88.04827	0.522133	0.16883
746150	0.877336449	-1.82E-13	64.27610526	-8.46E-16	0.298193	85.3694	0.621174	0.222451
750150	0.883855981	-2.87E-13	62.54802998	-1.33E-15	0.289198	83.57509	0.644718	0.24574
751120	0.879883382	1.71E-13	64.43853903	7.91E-16	0.298742	85.092	0.623578	0.21973
756150	0.87915937	-1.40E-13	65.0612985	-6.52E-16	0.301958	86.39619	0.611465	0.21267
764150	0.880631949	-1.62E-13	63.93882885	-7.49E-16	0.296201	84.73744	0.628422	0.226596
785150	0.868852459	4.66E-14	67.68163821	2.16E-16	0.314011	89.47336	0.495895	0.151586
828150	0.878504673	-7.67E-14	66.26364855	-3.55E-16	0.306812	88.07441	0.593909	0.201074
846150	0.899477048	-1.99E-13	61.19516437	-9.16E-16	0.282409	81.03282	0.670892	0.261686
849150	0.87251462	2.95E-13	67.1015759	1.37E-15	0.310855	88.5285	0.584933	0.188966
850150	0.88959907	-2.09E-13	61.72574924	-9.67E-16	0.28576	82.34635	0.657733	0.255359
855150	0.867850099	2.43E-13	69.15525327	1.13E-15	0.320988	91.13826	0.467836	0.133823
856150	0.878504673	-1.21E-13	66.6040838	-5.60E-16	0.307848	87.89631	0.595565	0.197081
861150	0.871779859	3.80E-13	66.72515282	1.76E-15	0.308806	88.44724	0.589565	0.19563

862150	0.880655738	-1.71E-13	63.82092428	-7.90E-16	0.295235	84.73666	0.579867	0.208146
863150	0.874926943	-1.49E-13	66.02663379	-6.93E-16	0.306121	87.43199	0.596324	0.200749
864150	0.890951276	-2.46E-13	61.95291551	-1.14E-15	0.286428	82.6124	0.654895	0.252958

4.5.5 Summary

Results from table 12 shows that for the same sensor there is a variation in the performance. From the analysis, it shows that there is requirement of field calibration. The gradient and intercept found after comparing the data from the sensors with the data from reference instrument are different from the objective values of 1 and 0 respectively. For the sensors analyzed, best results are obtained from the NO sensor, and worse results are for NO_2, O_3 and $PM_{2.5}$. On the other hand, results of PM_{10} and CO show promising results.

4.5.6 Recommendation towards low-cost sensor

Data obtained from the fixed site monitoring station is more reliable and accurate than data from low-cost sensor platforms. At the same time, monitoring stations are not as flexible as low-cost platforms. Monitoring stations are not as portable as low-cost platforms; moreover the high cost while setting and the need of maintenance cannot be neglected. Low-cost sensor came into the market as an alternative solution. But the challenges while using low-cost sensor are not hidden as well.

Based on the analysis, the gradient and intercept are sensitive to variations in the meteorological conditions, which will stress the need of frequent calibration, especially to account for seasonal changes. The application of field calibration can help to reduce the bias in the data.

At this stage of development of low-cost sensors they can be used in research projects, and to help to create awareness about air pollution among the population (always, warning the people about the limitations in data accuracy of this type of platforms). The data from low-cost sensors cannot be used for regulatory purposes or any other purposes where high data accuracy is required.

4.6 Computation of AQI by comparing NAQI and CAQI

There is no any unified way to visualize the air quality, there can be a different way of visualizing the air quality as described previously in section 2.9. For this section, CAQI and NAQI taken into consideration for the computation of AQI.

4.6.1 Similarities and differences of AQI

The main focus of this subsection is on similarity and differences during the analysis of the concentration of the pollutant data. For ongoing research, CAQI and NAQI were tested and computed by comparing the results obtained from Norwegian AQI and CAQI. By doing so, a number of times of agreements and disagreements between CAQI and NAQI are pursued.

CAQI has five indicators whereas NAQI has only four air quality indicators which can be seen in table 6 and 7. During this thesis, new NAQI was introduced with some changes in ranges and new color indication. But for the computation old NAQI was referred, i.e. table 7. Both NAQI and CAQI were evaluated and compared for three pollutants (NO_2, PM_{10} and $PM_{2.5}$) on hourly basis for eight reference stations.

Before computing, two cases are separated for agreement and disagreement condition.

Disagreements:

NAQI says Low - CAQI says Very low / medium / high / very high

NAQI medium - CAQI Very low / Low/ High/ Very high

NAQI high - CAQI Very low/Low/Very high

NAQI very high - CAQI very low/ low/ medium/ high

Agreements:

NAQI Low - CAQI Low

Medium - Medium

High - High

Very high - Very high

After careful analysis, it is found that NAQI mostly disagree with CAQI when the level of NO_2, PM_{10} and $PM_{2.5}$ is low and very low. This is because CAQI consist one extra category that indicate very low. But, if we consider low and very low indicator as low, then the number of disagreements are quite low. A similar pattern is seen in the data taken into consideration (i.e. from 2003 to 2013).Table below shows the number of disagreements for the year 2013.

Table 13: Total Number of Disagreement found between NAQI and CAQI for NO_2, PM_{10} and $PM_{2.5}$ in 2013

Reference Stations	**NAQI**	**CAQI**	**NO_2**	**Reference Stations**	**NAQI**	**CAQI**	**PM_{10}**	**Reference Stations**	**NAQI**	**CAQI**	**$PM_{2.5}$**
Alnabru	Very High	High	15	**Alnabru**	High	Very High	4	**Alnabru**	Very High	High	2
	Low	**Very Low**	**4513**		**Low**	**Very Low**	**6007**		**Low**	**Very Low**	**4218**
	High	Medium	51		Medium	High	48		High	Medium	49
									Medium	Low	373
Bygdøy	Very High	High	5	**Bygdøy**	High	Very High	6	**Bygdøy**	Very High	High	7
	Low	**Very Low**	**2916**		**Low**	**Very Low**	**5456**		**Low**	**Very Low**	**6233**
	High	Medium	76		Medium	High	59		High	Medium	34
									Medium	low	283
Hjortnes	Very High	High	17	**Hjortnes**	High	Very High	19	**Hjortnes**	Very High	High	0
	Low	**Very Low**	**4939**		**Low**	**Very Low**	**5928**		**Low**	**Very Low**	**7471**
	High	Medium	170		Medium	High	88		High	Medium	3
									Medium	low	120
Kirkevein	Very High	High	0	**Kirkevein**	High	Very High	1	**Kirkevein**	Very High	High	0
	Low	**Very Low**	**5971**		**Low**	**Very Low**	**6341**		**Low**	**Very Low**	**7311**
	High	Medium	26		Medium	High	35		High	Medium	7
									Medium	Low	87
Smested	Very High	High	0	**Smested**	High	Very High	7	**Smested**	Very High	High	0
	Low	**Very Low**	**2306**		**Low**	**Very Low**	**3140**		**Low**	**Very Low**	**3666**
	High	Medium	21		Medium	High	39		High	Medium	3
									Medium	Low	93
Grønland	Very High	High	0	**Sofienbergparken**	High	Very High	1	**Sofienbergparken**	Very High	High	0
	Low	Very Low	321		Low	Very Low	6716		Low	Very Low	6529
	High	Medium	0		Medium	High	15		High	Medium	15
									Medium	Low	243

4.6.2 Visualization of Data

There can be many visualization techniques which can convert the raw data into meaningful information. The main aim of this chart is to make an informative chart to the public. For instance: If a user is a child and provides the input to the system:

"Child has health problem asthma" and child is going to "*St.Hanshaugen*".

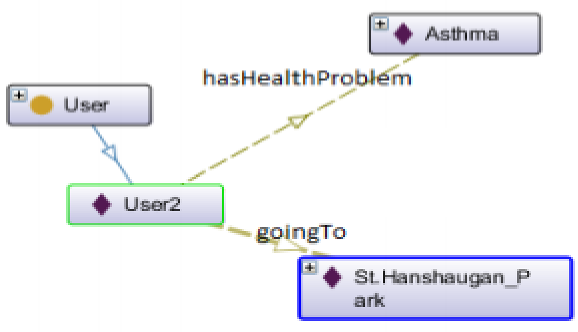

Figure 47: Scenario created using ontology using Protégé 4.3

After the input, the system should be able to map the level of each pollutant which can trigger asthma patience to a worse condition from the current to desired destination "*St.Hanshaugen*". After mapping, customized message pops up with result and recommendation.

- **Visualization of pollutant data based on NAQI**

In the scenario where a low-cost sensor is located, for example, in the playground of a school, the teachers and children will be advised from the air pollution levels at their location. This information can help them for example to plan outdoor activities. This is, if the pollution levels are high, it might be better to postpone the activities until they are at safe levels. Similarly, table 1 shows the health related issues related to PM.

For instance, figure 48 shows a prototype which shows the concentration of PM_{10} on 13th April 2015 for 24 hours. It shows the three scales of pollution level, namely Good, Moderate, High and Very High. They are represented by the colors as recommended by NAQI where the level ranges between 0 to 200 and more. The chart shows the concentration value of PM_{10} which were computed using the linear model for the pod 715150.

There is also the possibility to visualize a global air quality index (computed, for example as the worst case). A global index, instead of a pollutant by pollutant index can be quite useful for the public to get a general idea about how polluted the air is and take the precautions required.

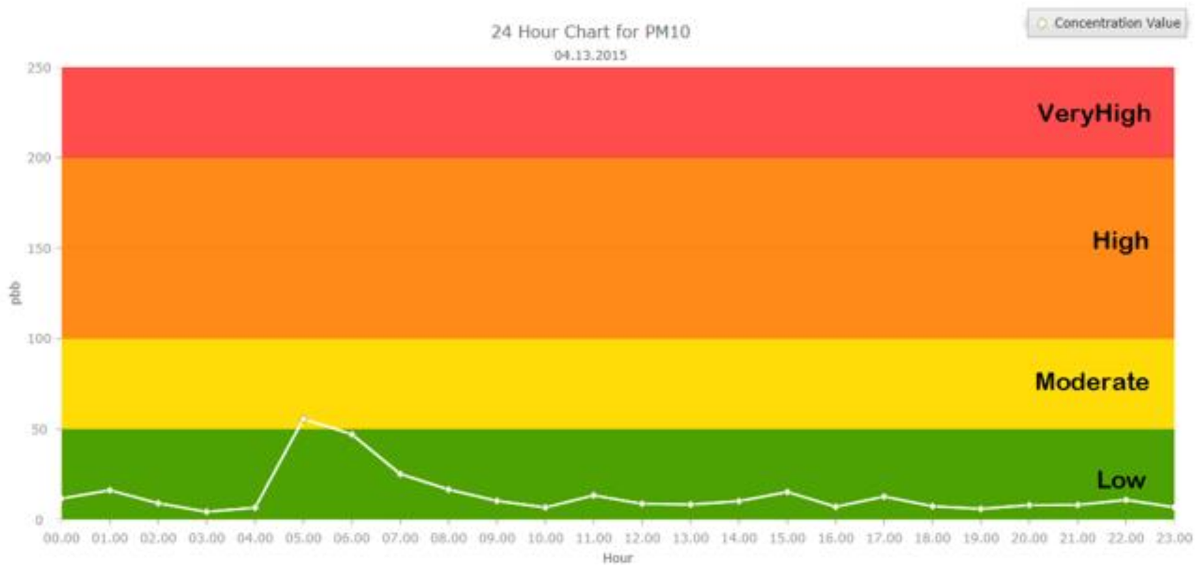

Figure 48: Visualizing concentration of PM_{10} hourly with predicted values.

It tries to follow the pattern of NAQI with same color identification which are changes according to NAQI ranges.

➢ Prototype for Mobile Application

We have prepared a prototype for a mobile application called *Air Check* which can help citizens visualize the PAQI. Using this application, users can provide their personal health information and as a result, the person can get an alert message if he/she is vulnerable to the effects of air pollution based on the provided information. This can help the users to make instant decision to reschedule their outdoor activities.

Input Data for the Air Check

- Input can be from reference monitoring stations
- It can also be from low-cost sensors that people have installed in their home, in public spaces or in other places of interest (example: kindergartens, schools, hospitals etc.).
- If enough sensors are deployed in a city, these data can be used to generate a high resolution air quality map. This can also be an input data for the mobile app. By knowing the position of the person from the GPS on the phone, he or she can get personalized information about the air quality in their surroundings (i.e. closet sensors or point data extracted from the air quality map).

Following screenshots shows how the user can interact with their mobile application and stay alert with the level of air quality. Below in figure 49 is the configuration screen where the user can provide the input in the application about health related problems he/she has, for example- asthma, bronchitis, common cold and other diseases that they are suffering which can harm if expose to high level of pollution. Then the tolerance level is set automatically which is shown at the bottom of the screen. For the advanced users, the default tolerance level can be overridden and set manually too.

Figure 50 shows the snapshot of a screen of *Air Check* which includes 24 hours chart for PM_{10} taken from the figure 48. This information is also quite useful for the users to visualize when the air pollution is lower or higher during the day.

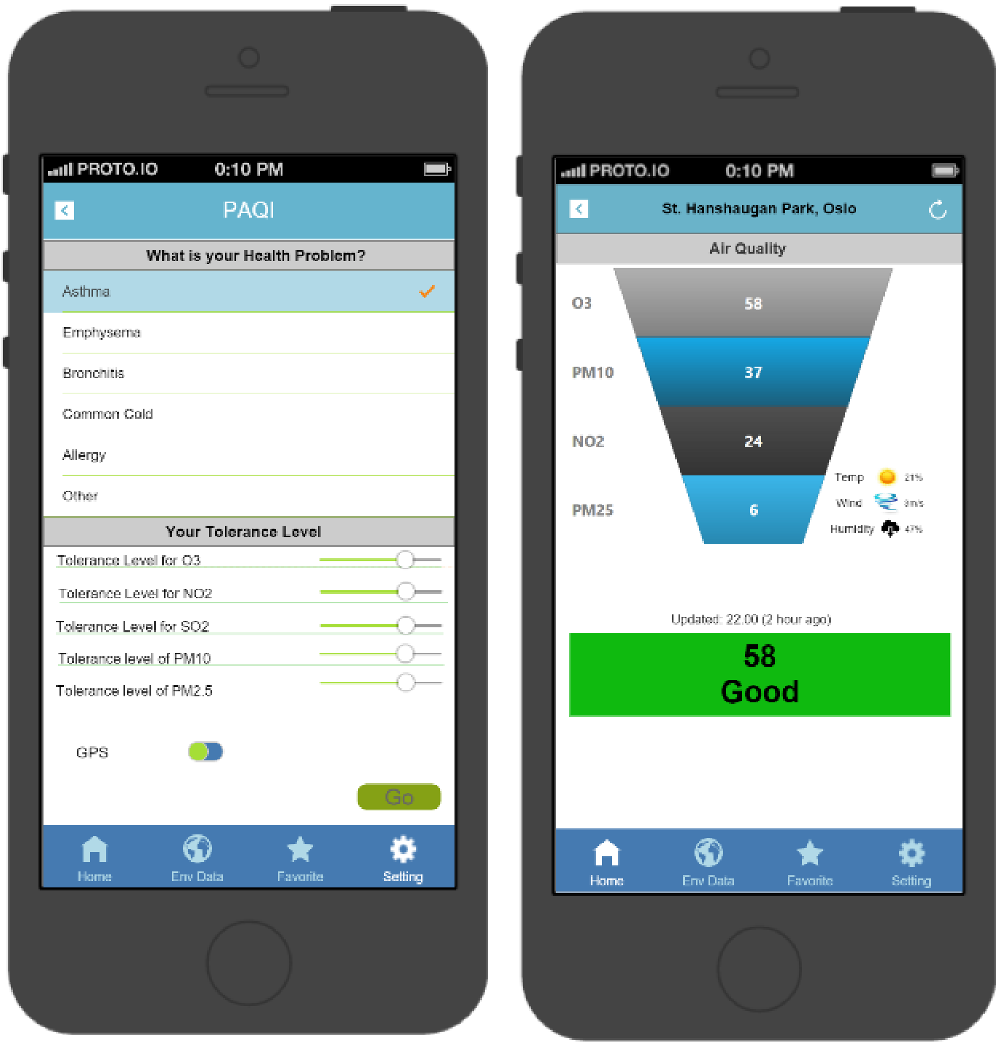

Figure 49: Prototype for mobile application configuration screen

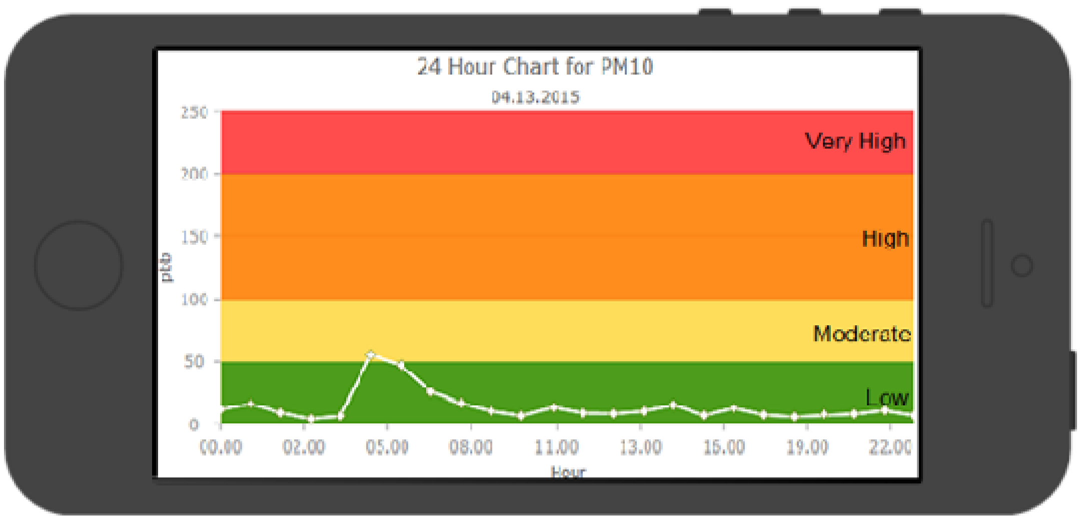

Figure 50: Line chart showing the level of pollutants

5 Conclusion and Future Work

The growing popularity of the use of low-cost sensor in most of the field has made easier to get the data instantly but low-cost sensors still face many challenges. During the analysis of this thesis, low-cost static sensors were co-located in air quality monitoring stations in Oslo in order to compare the data gathered by the low-cost sensors with the data gathered by reference instruments and check its reliability.

From the analysis of low-cost sensors and sensor from air monitoring stations, it is clear that data gathered from low-cost sensors is not completely reliable. In order to improve the reliability of the data, frequent calibration or seasonal calibration is necessary. But calibration is another big challenge on using a low-cost sensor. Later in the research, simple linear regression model was used in the calibration process and model was evaluated using modStats function. In addition, the prototype for user-friendly visualization technique was purposed for better understanding of air pollutant data together with NAQI.

Visualization technique is another big challenges and wide topic for the further study. For example: AQI is a good tool for visualizing data. Although current AQI gives some information related to health effects caused by air pollution, not everybody reacts the same way to air pollution. It depends on their vulnerability/ immunity power. This points out the need of appropriate health advices and recommendations index, specifically to the sensitive group of people as they can get effected even if the pollution level is good or moderate depending on the individual immunity power. According to (Makri & Stilianakis, 2008), *“Better understanding of vulnerability could also be used to provide needed information about specific populations to patient support organizations and health professionals”.*

This research is a step forward in finding the appropriate visualization tool for sensitive group which can include the separate alert system to guide them to lower their exposure. Currently available AQI are general measurement tools including with indication of health issue. But the sensitive group can get the full benefit if they can get the customized message based on their health conditions. That means, they should be able to provide their health problems as input from which they can get the advices and recommendations based on the data they entered. In this way, we can grab the attention from public and aware them about the relationship between health and air pollution effect.

Due to limited time, purposed prototype has not evaluated and presented to end-user groups for feedback. So, the next step would be to evaluate the prototypes proposed. To do so, quantitative analysis can be done by involving the mobile user group who has general background knowledge about air pollution and its factors including a layman. The user group should also include sensitive and non-sensitive groups to air pollution.

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Appendix A

A.1 Standard Breakpoint for the AQI

This Breakpoint...						...equal this AQI		...and this category
O_3 (ppm) 8-hour	O_3 (ppm) 1-hour1	PM_{10} (μg/m^3)	$PM_{2.5}$ (μg/m^3)	CO (ppm)	SO_2 (ppm)	NO_2 (ppm)	AQI	
0.000 - 0.064	-	0 - 54	0.0 - 15.4	0.0 - 4.4	0.000 - 0.034	(2)	0 - 50	Good
0.065 - 0.084	-	55 - 154	15.5 -40.4	4.5 - 9.4	0.035 - 0.144	(2)	51 - 100	Moderate
0.085 - 0.104	0.125 - 0.164	155 - 254	40.5 - 65.4	9.5 - 12.4	0.145 - 0.224	(2)	101 - 150	Unhealthy for Sensitive Groups
0.105 - 0.124	0.165 - 0.204	255 - 354	65.5 - 150.4	12.5 - 15.4	0.225 - 0.304	(2)	151 - 200	Unhealthy
0.125 - 0.374 (0.155 - 0.404)[4]	0.205 - 0.404	355 - 424	150.5 - 250.4	15.5 - 30.4	0.305 - 0.604	0.65 - 1.24	201 - 300	Very unhealthy
(3)	0.405 - 0.504	425 - 504	250.5 - 350.4	30.5 - 40.4	0.605 - 0.804	1.25 - 1.64	301 - 400	Hazardous
(3)	0.505 - 0.604	505 - 604	350.5 - 500.4	40.5 - 50.4	0.805 - 1.004	1.65 - 2.04	401 - 500	Hazardous

[1] Areas are required to report the AQI based on 8-hour ozone values. However, there are areas where an AQI based on 1-hour ozone values would be more protective. In these cases the index for both the 8-hour and the 1-hour ozone values may be calculated and the maximum AQI reported.

[2] NO_2 has no short-term NAAQS and can generate an AQI only above a value of 200.

[3] 8-hour O_3 values do not define higher AQI values (≥ 301). AQI values of 301 or higher are calculated with 1-hour O_3 concentrations.

[4] The numbers in parentheses are associated 1-hour values to be used in this overlapping category only.

Figure 51: Standard Breakpoint for the AQI. Source:(US_EPA, 2006)

A.2 Summary of pollutants data

These pollutant data were collected from air monitoring stations (Alnabru, Bygdøy, Hjortnes, Kirkeveien, Smestad, Grøndland, SofienbergParken, Bærum)

Table 14: Summary of pollutants data collected from air monitoring stations.

Alnabru 2013				
NO	**NO_2**	**NO_x**	**PM_{10}**	**$PM_{2.5}$**
Min. : 0.00	Min. : 1.11	Min. : 0.16	Min. : 0.00	Min. : 0.00
1st Qu.: 10.30	1st Qu.: 25.70	1st Qu.: 42.90	1st Qu.: 11.00	1st Qu.: 7.00
Median : 33.16	Median : 44.58	Median : 95.96	Median : 18.00	Median : 12.00
Mean : 74.32	Mean : 49.39	Mean : 160.85	Mean : 23.95	Mean : 15.83
3rd Qu.: 89.41	3rd Qu.: 67.20	3rd Qu.: 200.06	3rd Qu.: 28.00	3rd Qu.: 21.00
Max. :1393.79	Max. :298.22	Max. :2427.92	Max. :350.00	Max. :205.00
NA's :1045	NA's :883	NA's :895	NA's :264	NA's :1936

Bygdøy 2013				
NO	**NO_2**	**NO_x**	**PM_{10}**	**$PM_{2.5}$**
Min. : 0.87	Min. : 2.65	Min. : 5.39	Min. : 0.00	Min. : 0.00
1st Qu.: 18.15	1st Qu.: 36.50	1st Qu.: 66.46	1st Qu.: 12.00	1st Qu.: 5.00
Median : 41.55	Median : 57.43	Median : 122.73	Median : 20.00	Median : 9.00
Mean : 63.21	Mean : 61.10	Mean : 157.69	Mean : 25.95	Mean : 12.53
3rd Qu.: 87.35	3rd Qu.: 81.42	3rd Qu.: 211.94	3rd Qu.: 32.00	3rd Qu.: 16.00
Max. :626.34	Max. :318.84	Max. :1273.68	Max. :327.00	Max. :125.00
NA's :1617	NA's :1617	NA's :1617	NA's :249	NA's :378

Hjortnes 2013				
NO	**NO_2**	**NO_x**	**PM_{10}**	**$PM_{2.5}$**
Min. : 0.000	Min. : 0.24	Min. : 0.00	Min. : 0.00	Min. : 0.000
1st Qu.: 6.135	1st Qu.: 18.52	1st Qu.: 27.23	1st Qu.: 9.99	1st Qu.: 5.440
Median : 29.395	Median : 41.10	Median : 83.98	Median : 16.26	Median : 7.920
Mean : 64.777	Mean : 50.28	Mean : 146.11	Mean : 27.50	Mean : 9.427
3rd Qu.: 90.688	3rd Qu.: 72.97	3rd Qu.: 206.72	3rd Qu.: 30.47	3rd Qu.:11.780
Max. :707.840	Max. :249.01	Max. :1300.09	Max. :312.62	Max. :64.180
NA's :602	NA's :325	NA's :333	NA's :143	NA's :134

Kirkeveien 2013					
NO	**NO_2**	**NO_x**	**PM_{10}**	**$PM_{2.5}$**	**CO**
Min. : 0.00	Min. : 0.00	Min. : 0.03	Min. : 0.00	Min. : 0.000	Min. :0.0000
1st Qu.: 5.89	1st Qu.: 17.07	1st Qu.: 26.84	1st Qu.: 9.18	1st Qu.: 4.860	1st Qu.:0.1800
Median : 16.56	Median : 31.71	Median : 56.84	Median : 14.86	Median :	Median

				7.250	:0.3000
Mean : 36.80	Mean : 38.24	Mean : 94.16	Mean : 19.64	Mean : 8.573	Mean :0.3661
3rd Qu.: 41.20	3rd Qu.: 52.15	3rd Qu.:114.83	3rd Qu.: 23.37	3rd Qu.:10.360	3rd Qu.:0.4400
Max. :518.86	Max. :178.36	Max. :956.22	Max. :242.30	Max. :68.490	Max. :2.9800
NA's :613	NA's :597	NA's :579	NA's :615	NA's :648	NA's :2207

Smestad 2013				
NO	**NO_2**	**NO_x**	**PM_{10}**	**$PM_{2.5}$**
Min. : 0.00	Min. : 0.25	Min. : 0.19	Min. : 0.49	Min. : 0.39
1st Qu.: 13.85	1st Qu.: 28.12	1st Qu.: 49.83	1st Qu.: 9.04	1st Qu.: 5.53
Median : 38.50	Median : 49.51	Median :107.53	Median : 16.13	Median : 8.54
Mean : 64.75	Mean : 53.96	Mean :152.27	Mean : 23.88	Mean :10.44
3rd Qu.: 94.19	3rd Qu.: 75.22	3rd Qu.:218.22	3rd Qu.: 28.82	3rd Qu.:13.40
Max. :424.60	Max. :195.45	Max. :791.50	Max. :269.09	Max. :74.05
NA's :4233	NA's :4201	NA's :4203	NA's :4191	NA's :4195

SofienbergParken 2013		**Grøndland 2013**	**Bærum 2013**
PM_{10}	**$PM_{2.5}$**	**NO_2**	**O_3**
Min. : 0.00	Min. : 0.00	Min. : 0.00	Min. : 0.00
1st Qu.: 9.00	1st Qu.: 5.00	1st Qu.: 17.50	1st Qu.: 21.39
Median : 15.00	Median : 9.00	Median : 41.10	Median : 49.08
Mean : 18.97	Mean : 11.29	Mean : 46.68	Mean : 47.18
3rd Qu.: 25.00	3rd Qu.: 15.00	3rd Qu.: 70.25	3rd Qu.: 70.26
Max. :540.00	Max. :153.00	Max. :138.00	Max. :115.43
NA's :37	NA's :306	NA's :8171	NA's :340

More summary of pollutant data since 2003 can be found in
https://www.dropbox.com/sh/hvz17fa529oo9c5/AAB4TkN94qr68i2MfJfKKouMa?dl=0

A.3 New Health recommendation provided by Luftkvalitet.info

Table 15: Health effect and Health Advice for PM_{10}, $PM_{2.5}$ and NO_2.

Source: (Luftkvalitet.info, 2015)

Level	PM_{10} Daily	$PM_{2.5}$ Daily	PM_{10} Hourly*	$PM_{2.5}$ Hourly*	NO_2	Health Effect	Health Advice
Low	< 30	< 15	<50	< 25	< 100	**Low or no health risk**	Outdoor activity is recommended
Moderate	30-50	15-25	50-80	25-40	100-200	**Moderate health risk** Health effects can occur in some asthmatics and people with others respiratory diseases, as well as severe heart disease	Outdoor activities can be recommended for the vast majority, but some consider their activity in areas of high traffic or high other emissions
High	50-150	25-75	80-400	40-150	200-400	**Significant health risk** Health effects can occur in asthmatics and persons with other respiratory diseases, as well as severe heart disease	Children with respiratory disease (asthma, bronchitis) and adults with severe cardiac vascular or respiratory illnesses should reduce outdoor activities and do not reside in the most polluted areas
Very High	> 150	> 75	> 400	> 150	> 400	**Serious Health Risks** Sensitive groups of the population can get health effects. Respiratory Irritations and discomfort can occur in healthy people	People with heart or vascular respiratory disease should reduce outdoor activities and do not reside in the most polluted areas

Appendix B

B.1 Temporal and Spatial variation analysis

This appendix shows the temporal and spatial variation in various parts of Oslo (Bærum, Hjortnes, Sofienbergparken) for the year 2013.

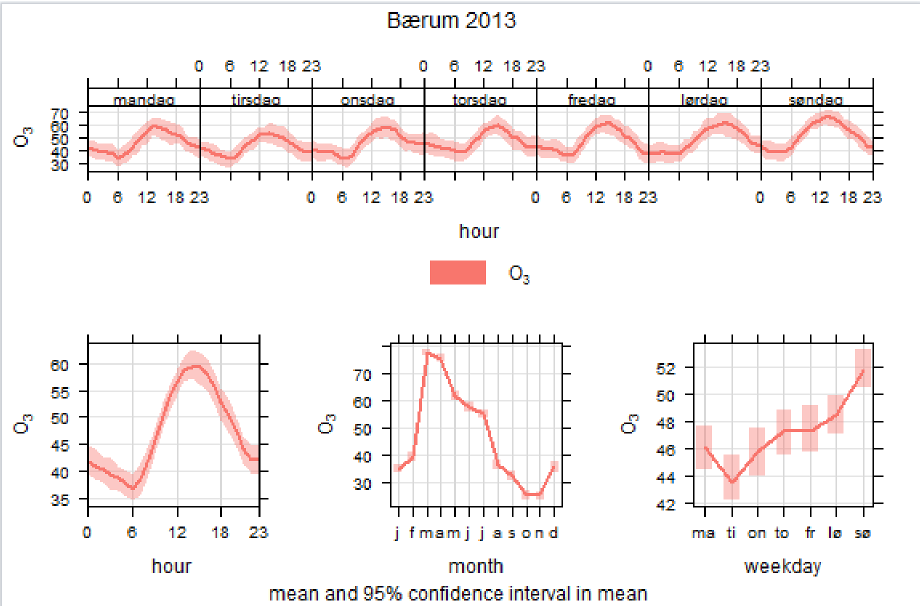

Figure 52: Temporal variation of O_3 in Bærum in 2013

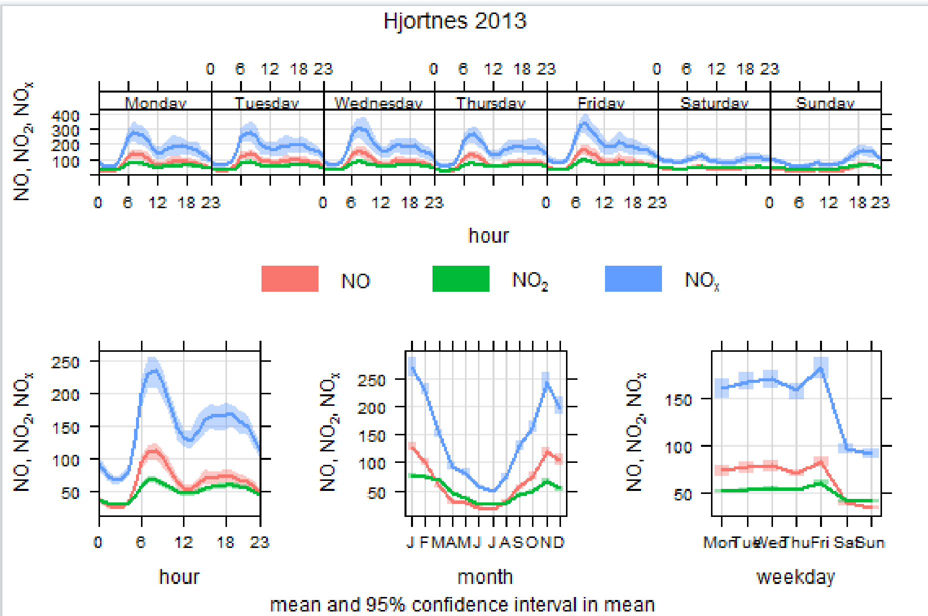

Figure 53: Temporal variation of NO, NO_2 and NO_x in Hjortnes in 2013

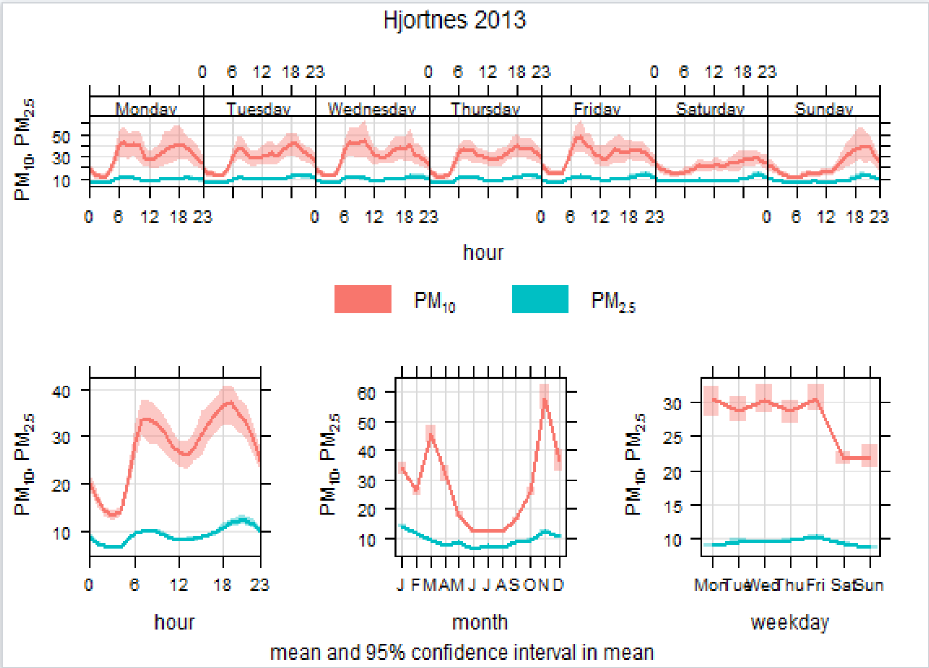

Figure 54: Temporal variation of PM_{10} and $PM_{2.5}$ in Hjortnes in 2013

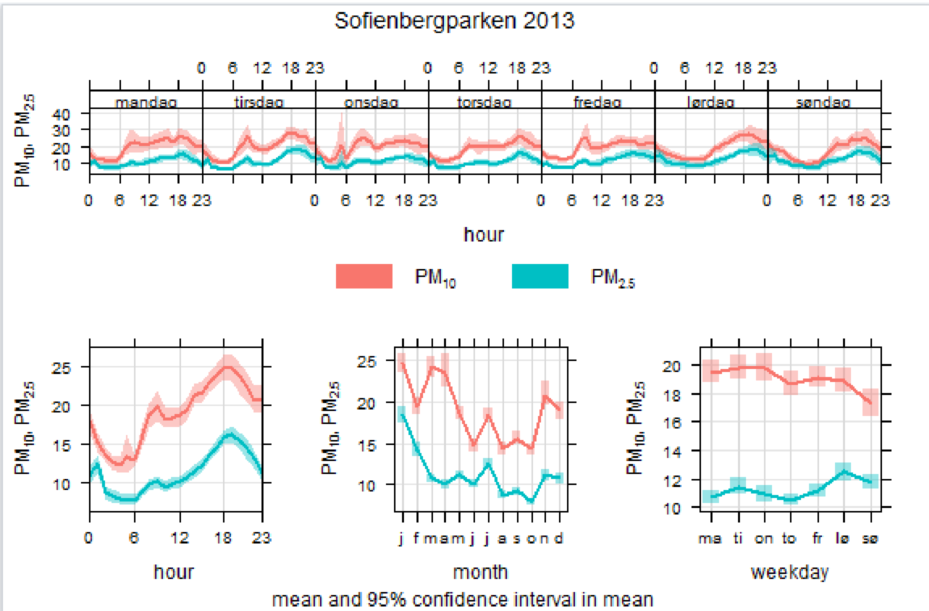

Figure 55: Temporal variation of PM_{10} and $PM_{2.5}$ in Sofienbergparken in 2013

More temporal and spatial variation from the year 2003 to 2013 analyzed in this research which can be seen in following link: https://www.dropbox.com/sh/pgh2mn11lsk5sll/AABxS1wTIg-D47_2WAkGj1n-a?dl=0

Appendix C

C.1 Monthly scatter plot of different pollutants

This appendix shows the monthly scatter plots of different pollutants collected from low-cost static sensors.

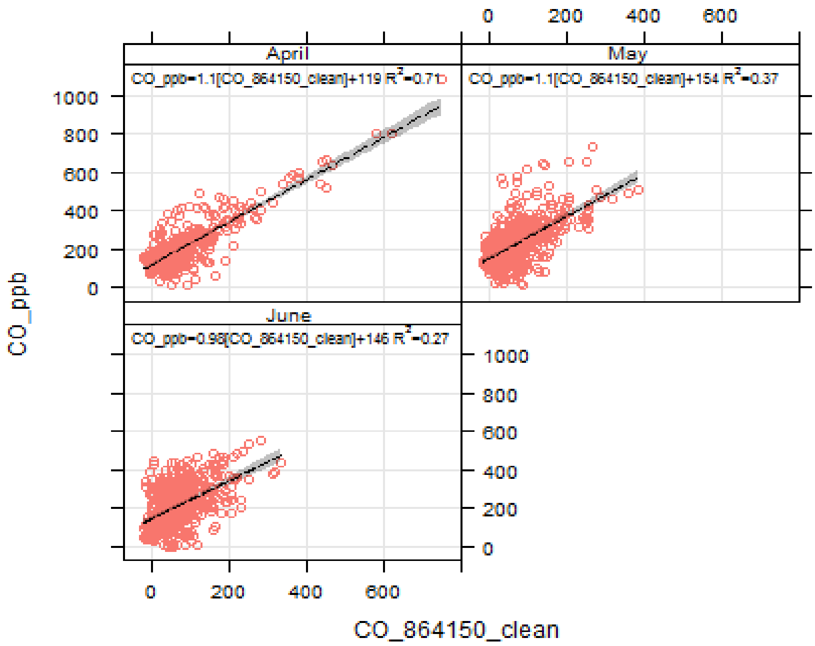

Figure 56: Monthly Scatter Plot of CO from pods and Kirkeveien

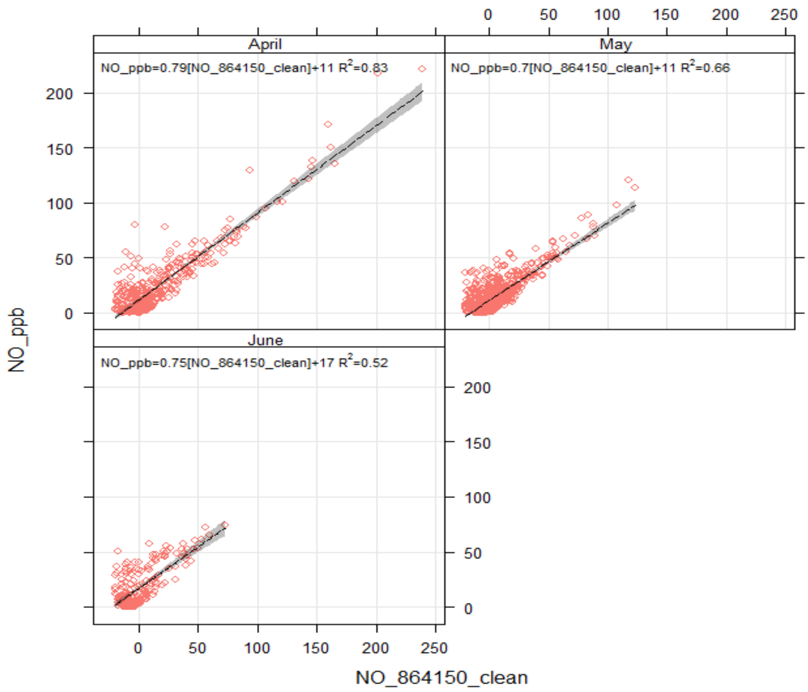

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Figure 57: Monthly Scatter Plot of NO from pods and Kirkeveien

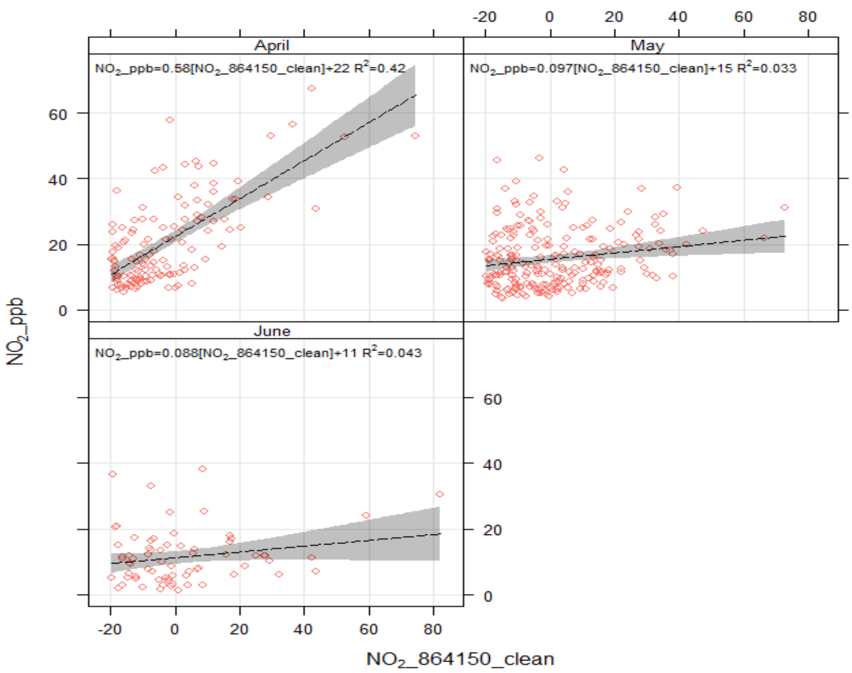

Figure 58: Monthly Scatter Plot of NO_2 from pods and Kirekeveien

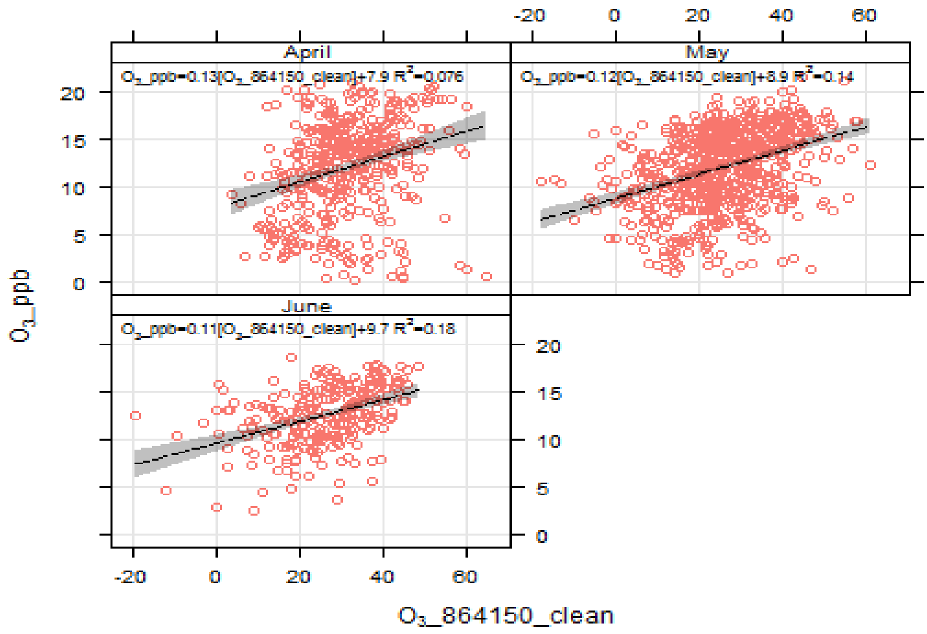

Figure 59: Monthly Scatter Plot of O_3 from pods and Kirkeveien

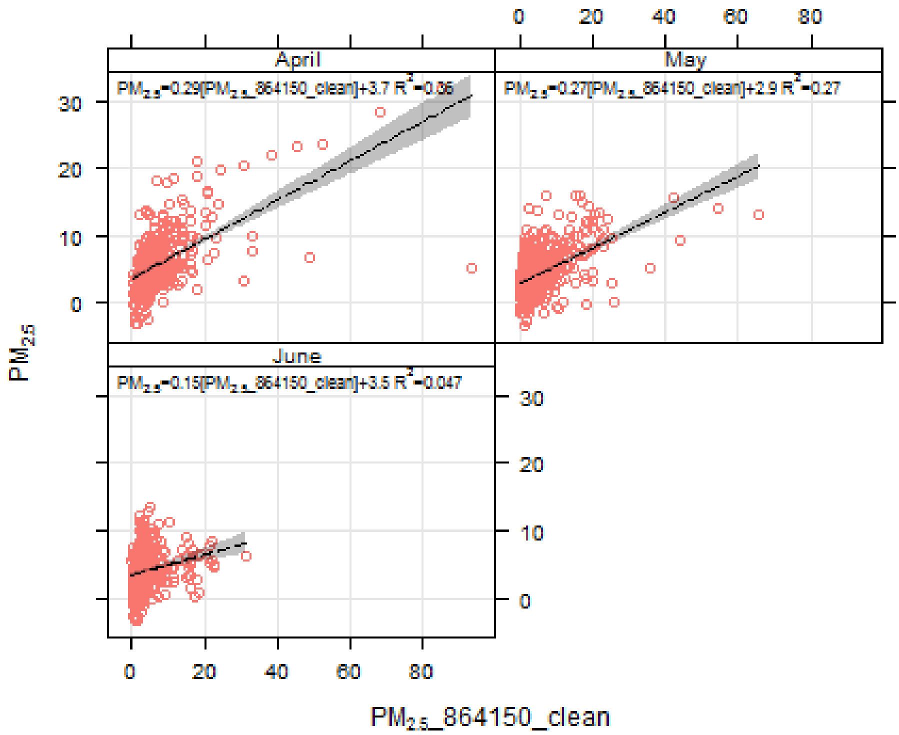

Figure 60: Monthly Scatter Plot of $PM_{2.5}$ from pods and Kirkeveien

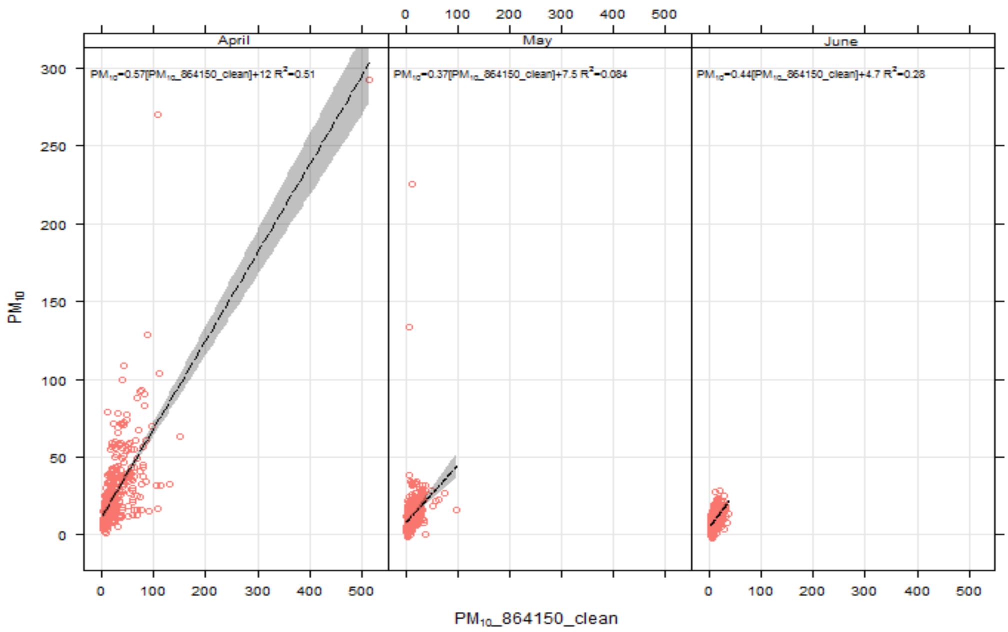

Figure 61: Monthly Scatter Plot of PM_{10} from pods and Kirkeveien

C.2 Statistics of linear regression models

Statistics after the application of linear regression model for the calibration of data received from low-cost static sensor (all 24-pods)

Table 16: Statistics for 24-pods for NO for the period 13.04.2015 to 24.06.2015

Pods	FAC2	MB	MGE	NMB	NMGE	RMSE	R	COE
688150	0,790249	3,43E-14	4,402129	1,75E-15	0,22402	6,565391	0,960757	0,72275
712150	0,58125	9,81E-15	9,129374	4,60E-16	0,429131	11,46252	0,881207	0,440479
715150	0,705338	-1,57E-14	4,904456	-8,59E-16	0,268095	6,543889	0,951573	0,664237
718150	0,542702	1,26E-14	9,872837	6,44E-16	0,507601	13,37321	0,789475	0,343117
733150	0,767211	4,62E-14	3,84455	2,53E-15	0,210289	5,689556	0,963512	0,736202
737150	0,755131	4,60E-14	3,794647	2,52E-15	0,208019	5,147974	0,970183	0,739401
743150	0,755131	5,89E-14	3,695855	3,23E-15	0,202603	4,949614	0,972469	0,746185
744150	0,672905	-2,31E-14	4,986539	-1,37E-15	0,296309	6,621405	0,924903	0,621698
746150	0,594368	-4,52E-14	8,789264	-2,35E-15	0,45732	12,28103	0,823644	0,410185
750150	0,6398	3,32E-14	5,987105	1,81E-15	0,326722	7,763606	0,931207	0,590379
751120	0,715243	-3,99E-14	5,045674	-2,32E-15	0,293634	8,714172	0,918792	0,656028

756150	0,755839	1,75E-14	3,835557	9,59E-16	0,210262	5,241122	0,969077	0,736591
764150	0,779901	5,34E-14	3,336048	2,93E-15	0,182879	4,559931	0,976683	0,770895
785150	0,5637	-6,50E-15	9,956995	-3,75E-16	0,569515	14,15217	0,600328	0,260606
828150	0,520382	6,14E-15	8,467981	3,17E-16	0,43742	11,3794	0,866208	0,465454
846150	0,579882	1,67E-14	12,28951	6,94E-16	0,510422	16,13847	0,795228	0,350968
849150	0,542008	3,99E-14	8,823334	1,99E-15	0,439533	12,02464	0,865086	0,472777
850150	0,454044	-1,33E-14	15,88866	-5,32E-16	0,634914	19,89177	0,724583	0,241096
855150	0,428916	-9,41E-15	10,8059	-5,86E-16	0,672916	14,58344	0,642598	0,233287
856150	0,427549	1,99E-14	15,30708	7,95E-16	0,611867	19,08671	0,742556	0,255338
861150	0,499169	-2,02E-16	8,899617	-1,11E-17	0,468822	11,61782	0,855137	0,429145
862150	0,504188	2,01E-14	8,163533	1,18E-15	0,481823	10,10252	0,817186	0,386451
863150	0,505545	5,88E-15	8,79804	3,07E-16	0,459591	11,77467	0,862035	0,455636
864150	0,507154	1,85E-14	8,613394	9,89E-16	0,459437	11,31173	0,859467	0,437567

Table 17: Statistics for 24-pods for NO_2 for the period 13.04.2015 to 24.06.2015

Pods	**FAC2**	**MB**	**MGE**	**NMB**	**NMGE**	**RMSE**	**R**	**COE**
688150	0,759954	-3,96E-15	6,094161	-2,63E-16	0,40288	7,783009	0,651877	0,197385
712150	0,7487	-5,37E-15	7,122002	-3,14E-16	0,418047	9,337728	0,554056	0,16213
715150	0,700901	-1,40E-14	7,350708	-9,16E-16	0,482055	9,503689	0,363714	0,050393
718150	0,731209	-1,63E-15	6,725376	-1,10E-16	0,45152	8,670185	0,488491	0,103092
733150	0,7291	-3,02E-14	6,691139	-2,04E-15	0,452092	8,666466	0,481894	0,102631
737150	0,712046	-2,25E-14	6,681278	-1,55E-15	0,461054	8,495272	0,47629	0,081292
743150	0,700434	-5,52E-16	6,952736	-3,81E-17	0,478786	8,90075	0,401238	0,051873
744150	0,798701	-3,55E-14	5,34302	-2,57E-15	0,38723	6,94836	0,587966	0,210458
746150	0,701807	-4,53E-15	6,83506	-3,11E-16	0,467661	8,760987	0,454812	0,082684
750150	0,708543	-2,34E-15	6,724682	-1,61E-16	0,463837	8,552522	0,469649	0,078417
751120	0,739161	-1,01E-14	6,321579	-6,97E-16	0,436767	8,155581	0,535051	0,130004
756150	0,713918	-1,07E-14	7,50331	-6,70E-16	0,471813	9,841791	0,359002	0,066609
764150	0,646766	1,07E-14	9,194463	6,07E-16	0,523787	12,29276	0,213262	0,039471
785150	0,775792	-8,12E-15	5,584556	-5,89E-16	0,405219	7,259584	0,532076	0,173069
828150	0,696078	-1,89E-15	8,732573	-1,08E-16	0,501694	11,31086	0,249076	0,030919
846150	0,857749	3,26E-14	4,945183	2,25E-15	0,341934	6,718258	0,717086	0,318235
849150	0,776912	-3,34E-15	6,035202	-2,31E-16	0,417379	8,072906	0,546792	0,168194

850150	0,810333	9,26E-15	5,629524	6,42E-16	0,389253	7,58421	0,61718	0,223888
855150	0,799513	-2,43E-14	5,440273	-1,76E-15	0,394278	7,067181	0,568449	0,196087
856150	0,791785	-1,63E-14	5,793993	-1,13E-15	0,400697	7,664267	0,606757	0,201439
861150	0,756026	2,92E-14	6,36115	2,01E-15	0,436607	8,26304	0,52642	0,131422
862150	0,793806	-5,06E-15	5,377936	-3,67E-16	0,390147	6,791043	0,611526	0,204488
863150	0,715247	1,27E-14	6,883403	8,68E-16	0,470916	8,880998	0,420011	0,067969
864150	0,699531	1,34E-15	8,079834	8,13E-17	0,491049	10,52128	0,300962	0,045732

Table 18: Statistics for 24-pods for O_3 for the period 13.04.2015 to 24.06.2015

Pods	**FAC2**	**MB**	**MGE**	**NMB**	**NMGE**	**RMSE**	**R**	**COE**
688150	0,929563	1,22E-14	2,084885	1,06E-15	0,181171	2,68384	0,808052	0,445571
712150	0,881836	-3,79E-16	3,109605	-3,32E-17	0,27261	3,835041	0,549237	0,180587
715150	0,893017	-6,14E-15	2,986175	-5,19E-16	0,252784	3,715559	0,519703	0,160738
718150	0,927703	3,51E-15	2,358905	2,96E-16	0,199693	2,985467	0,727076	0,337117
733150	0,91889	8,54E-15	3,072411	6,93E-16	0,249394	3,842298	0,386119	0,103333
737150	0,942802	-6,47E-15	2,281359	-5,46E-16	0,192427	2,819973	0,75617	0,353302
743150	0,934337	1,92E-14	2,208005	1,59E-15	0,182501	2,949118	0,710594	0,354797
744150	0,933921	-1,08E-14	2,719164	-8,00E-16	0,201077	3,557747	0,218526	0,021037
746150	0,943698	2,44E-15	2,180108	2,06E-16	0,184557	2,746445	0,775302	0,387361
750150	0,952041	6,15E-15	2,116298	5,16E-16	0,177514	2,650792	0,78337	0,392899
751120	0,924724	3,54E-14	2,406986	2,97E-15	0,202241	3,080496	0,698273	0,314705
756150	0,890421	-7,48E-16	3,099692	-6,29E-17	0,260404	3,886134	0,477206	0,14776
764150	0,871442	3,68E-15	3,814337	3,15E-16	0,326153	4,591615	0,093704	0,007444
785150	0,983333	-2,56E-15	1,636677	-1,70E-16	0,108634	2,4348	0,431058	0,135761
828150	0,898912	-1,51E-14	3,219756	-1,28E-15	0,272568	4,011669	0,385879	0,095207
846150	0,92987	6,57E-15	2,739285	5,16E-16	0,215044	3,531601	0,488684	0,16446
849150	0,942727	-1,78E-14	2,480266	-1,40E-15	0,195249	3,253091	0,549574	0,215375
850150	0,902769	-1,05E-16	2,914782	-8,69E-18	0,246088	3,735551	0,510078	0,178178
855150	0,925756	5,73E-15	2,679023	4,74E-16	0,221417	3,456735	0,534778	0,201502
856150	0,918417	-3,20E-15	2,711745	-2,59E-16	0,219778	3,549916	0,519616	0,199372
861150	0,928937	1,05E-14	2,476818	8,92E-16	0,209593	3,106525	0,69934	0,303452

862150	0,929876	1,53E-14	2,811025	1,28E-15	0,235771	3,444843	0,551582	0,165645
863150	0,919399	1,26E-15	2,794761	1,04E-16	0,230687	3,496764	0,557687	0,18501
864150	0,894231	2,86E-15	3,327198	2,42E-16	0,281423	4,119194	0,318903	0,06392

Table 19: Statistics for 24-pods for PM_{10} for the period 13.04.2015 to 24.06.2015

Pods	**FAC2**	**MB**	**MGE**	**NMB**	**NMGE**	**RMSE**	**R**	**COE**
688150	0,843395	1,43E-14	5,817672	8,94E-16	0,362866	13,4161	0,726573	0,420666
712150	0,777778	-1,99E-14	7,190535	-1,24E-15	0,448335	14,97011	0,64204	0,28432
715150	0,805361	-3,13E-15	6,249876	-2,14E-16	0,428686	13,10383	0,604658	0,235312
718150	0,734848	-8,91E-15	7,354182	-6,10E-16	0,504432	15,37372	0,35608	0,100198
733150	0,818182	1,40E-15	5,955283	9,42E-17	0,40848	12,37001	0,659298	0,271356
737150	0,777389	1,01E-14	6,707562	6,93E-16	0,46008	14,3084	0,493577	0,179313
743150	0,795455	6,15E-15	6,39545	4,22E-16	0,438672	13,09426	0,605423	0,217501
744150	0,812256	2,33E-14	5,692794	1,73E-15	0,422566	12,74616	0,572084	0,201487
746150	0,798368	1,90E-15	6,442585	1,31E-16	0,441905	13,49842	0,57169	0,211734
750150	0,798951	1,08E-14	6,207621	7,37E-16	0,425788	12,89733	0,620845	0,240482
751120	0,80303	-9,67E-16	6,12078	-6,43E-17	0,419832	12,73754	0,632915	0,251107
756150	0,800117	1,27E-15	6,261303	8,86E-17	0,42947	13,19727	0,597102	0,233914
764150	0,80711	-1,48E-14	6,194233	-1,01E-15	0,42487	12,85375	0,624174	0,24212
785150	0,832355	1,27E-15	5,339738	9,32E-17	0,397187	12,07954	0,627029	0,247524
828150	0,794289	5,91E-15	6,443538	4,03E-16	0,44197	13,51688	0,570076	0,211617
846150	0,803613	-1,93E-14	6,185913	-1,32E-15	0,424299	12,98713	0,613889	0,243138
849150	0,821096	-1,58E-14	5,901794	-1,08E-15	0,404811	12,08055	0,678838	0,277901
850150	0,81352	-1,37E-14	6,093599	-9,42E-16	0,417967	12,54515	0,646956	0,254433
855150	0,763364	6,59E-15	6,426677	4,92E-16	0,477041	14,64955	0,333711	0,098547
856150	0,701049	-3,30E-15	7,899641	-2,24E-16	0,541846	16,13627	0,19499	0,033459
861150	0,728438	-1,05E-15	7,444275	-7,30E-17	0,510612	15,55775	0,325212	0,089175
862150	0,811308	-2,96E-14	5,497224	-2,19E-15	0,407456	12,29062	0,612963	0,227986
863150	0,782634	3,24E-15	6,569125	2,20E-16	0,450584	13,69343	0,554292	0,196251
864150	0,815851	2,08E-15	5,887981	1,42E-16	0,403864	12,05165	0,680734	0,279591

Table 20 : Statistics for 24-pods for $PM_{2.5}$ for the period 13.04.2015 to 24.06.2015

Pods	FAC2	MB	MGE	NMB	NMGE	RMSE	R	COE
688150	0,737949	6,10E-15	2,113498	1,34E-15	0,46434	2,833461	0,630207	0,177618
712150	0,719298	-9,70E-15	2,220462	-2,14E-15	0,48955	3,057682	0,531479	0,130448
715150	0,726476	4,52E-15	2,21484	1,01E-15	0,492437	2,96376	0,515327	0,123697
718150	0,719206	-1,71E-15	2,270698	-3,77E-16	0,503016	3,038274	0,492021	0,107053
733150	0,727485	6,84E-15	2,162112	1,52E-15	0,480768	2,854834	0,564736	0,144866
737150	0,727911	-8,31E-15	2,212777	-1,85E-15	0,493796	2,950581	0,495133	0,11912
743150	0,732164	7,03E-15	2,155578	1,56E-15	0,479315	2,882623	0,552814	0,14745
744150	0,706266	-3,26E-15	2,327663	-7,25E-16	0,518695	3,111361	0,420521	0,066341
746150	0,726156	-8,46E-15	2,18275	-1,89E-15	0,487095	2,916679	0,512253	0,131073
750150	0,727645	2,71E-15	2,218619	6,03E-16	0,493277	3,001827	0,496562	0,122202
751120	0,71937	1,18E-14	2,25358	2,62E-15	0,499168	3,046462	0,487418	0,113463
756150	0,729666	-7,40E-15	2,18796	-1,65E-15	0,488258	2,910589	0,515247	0,128999
764150	0,734933	-7,36E-15	2,181198	-1,64E-15	0,486749	2,910595	0,515244	0,131691
785150	0,72371	9,42E-15	2,221479	2,10E-15	0,495701	2,99173	0,485566	0,107099
828150	0,729398	8,28E-15	2,194421	1,84E-15	0,487897	2,945609	0,523956	0,131776
846150	0,728496	-8,37E-15	2,173877	-1,87E-15	0,485115	2,897418	0,521644	0,134606
849150	0,730994	1,16E-14	2,169372	2,58E-15	0,482383	2,857289	0,563698	0,141995
850150	0,730409	1,01E-14	2,191798	2,26E-15	0,487369	2,928009	0,532509	0,133125
855150	0,724363	9,77E-15	2,228219	2,18E-15	0,496618	3,001363	0,484206	0,10651
856150	0,723392	9,42E-15	2,199985	2,10E-15	0,490884	2,946661	0,49674	0,123902
861150	0,724985	-8,31E-15	2,226596	-1,86E-15	0,49688	2,979974	0,479627	0,113619
862150	0,712969	3,84E-15	2,297031	8,56E-16	0,512416	3,095795	0,431026	0,079439
863150	0,72232	5,61E-15	2,20623	1,26E-15	0,494447	2,943927	0,47306	0,115296
864150	0,725731	1,04E-14	2,200295	2,32E-15	0,490135	2,924742	0,526903	0,126671