LOW COST AMBIENT AIR QUALITY MONITORING

Developing a simple dust collecting system in Rustenburg in South Africa

LAHDEN AMMATTIKORKEAKOULU
Tekniikan ala
Ympäristöteknologian koulutusohjelma
Ympäristötekniikka
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Kimmo Salokannel

Lahden ammattikorkeakoulu
Ympäristöteknologian koulutusohjelma

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TIIVISTELMÄ

Tämän opinnäytetyön aihe on matalan budjetin menetelmät ilmanlaadunvalvonnassa. Työn käytännön osuudessa kokeiltiin onko tavallisilla muoviämpäreillä mahdollista saada näyte ilmasta laskeutuvasta pölystä. Käytännön osuus tehtiin vuonna 2008 Etelä-Afrikassa, Rustenburgin kaupungissa.

Näytteitä kerättiin useista kohteista kaupungin alueella ja ne tuotiin Suomeen jossa niistä tehdyistä kokoomanäytteistä analysoitiin eräitä raskasmetalleja. Näytteenotossa ja kokeen suunnittelussa tapahtuneiden virheiden vuoksi laboratoriotulokset eivät ole luotettavia mutta itse menetelmä osoittautui toimivaksi ja sitä kannattaisi tutkia lisää.

Tämä menetelmä ei todennäköisesti tule koskaan antamaan tietoa jota voitaisiin käyttää esimerkiksi vertailtaessa paikallisia pitoisuuksia ilmanlaatuindekseihin. Sen sijaan menetelmää edelleen kehittämällä saattaa olla mahdollista, että saadaan tuloksia joita voidaan verrata tilastollisesti saman mittauspaikan arvoihin eri mittausjaksoilla.

Avainsanat: ilmanlaatu, ilman saastuminen, raskasmetallit, ympäristön tila, ympäristövalvonta, pienhiukkaset

Lahti University of Applied Sciences
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ABSTRACT

The topic of this thesis is low budget methods in air quality monitoring. The practical part of this work was a test-run where dust samples were collected by suing ordinary plastic buckets as dustfall jars. The test run was done in 2008, in South Africa, in City of Rustenburg.

Samples were collected at several location within the city proper and they were brought to Finland were combined samples were analyzed at a laboratory for heavy metal concentrations. Because of errors made in planning and sampling, thre laboratory results are not reliable but the method itself proved promising and it is worth studying more.

This method, in all likelihood, will never give results that could be used in comparison with the air quality indexes. However, with further development it is possible that such results are gained that can be compared statistically with results from the same monitoring site but of different sampling period.

Key words: air quality, air pollution, heavy metals, state of the environment, environmental monitoring, particulate matter.

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1 INTRODUCTION

This thesis was motivated by the writer’s experiences during a work placement period in 2008 in South Africa organized by the The North South Local Government Co-operation Programme between the City of Lahti, Finland, and Bojanala Platinum District Municipality, South Africa. The Bojanala Platinum District Municipality (BPDM) Environmental and Waste Management Unit expressed their wish that the writer would focus his efforts towards the general field of air quality during the work placement

The question for this thesis is, with low resources, can some simple method provide more information on the air quality. Low resources in this context mean the lack of scientific equipment, trained personnel and general funding. Lack of awareness can also be an issue.

Answers for this question have been searched by literary research and by using Finland and the City of Lahti as examples. A three-month visit to Rustenburg and other municipalities with in BPDM provided personal experience and some of the information in this work is based on the writer’s own experiences and discussions with local authorities and citizens. Local conditions were studied during the period and a test-run for simple dust collecting system was conducted in the Rustenburg Municipality.

The test-run of the simple dust collecting system was a field test to see if a sample of dust could be collected by letting it settle from the ambient air to a collector for further analyzes. The purpose of this was to gain experiences so the system could be further developed. It was decided that the system could provide information on air quality if a sample was collected and it could be weighed and analyzed for heavy metals in a commercial laboratory.

2 ARGUMENTATION FOR AIR QUALITY MONITORING AND PREVENTION OF AIR POLLUTION

In industrial countries the urban air is mostly polluted by traffic and heavy industry. In developing countries, the stoves for cooking and warming the homes and the burning of trash add to the effects of heavy industry such as mines and foundries. (Hakala 2003, 26)

2.1 Why the air quality must be monitored

Air quality is monitored because we are worried about the effects air pollution has on us humans and on the environment. This worry drives the government to set air quality standards through legislative means. These standards can only be met through limiting the emissions at the pollution sources. Reducing emissions at the source can there for reduce the levels of pollutants in the ambient air so that the effects of these pollutants will only have acceptable undesirable effects. (Seinfeld 1986, 68-69)

2.2 Examples of threats air pollution poses

The effects air pollutants have on humans and on the environment have been studied widely. Even so, a lot still remains unknown. This is because an almost endless list of pollutants, physical conditions and subjects suffering the direct or indirect effects of these pollutants. It can also be very difficult to study for example the toxicity of a certain chemical compound on humans due to the fact that direct testing on humans is not usually possible.

Air pollution can pose a life threatening danger to those with cardiovascular or respiratory diseases (Hakala 2003, 41). For example if sulfur dioxide is present in ambient air with concentrations of 0,11 to 0,19 ppm, with 24-hr mean, hospital admissions of older people will increase as will the number of people calling in sick to work (Liu, Lipták & Bouis 1997, 244).

Acid rain causes the acidification of the soil and as a result of this the plants experience greater difficulties obtaining nutrients and can suffer from the effects of the rising levels of harmful substances (Hakala 2003, 74). For example aluminium, cadmium and copper are mobilized (Hakala 2003, 76). Acid rain also has negative effects on freshwater ecosystems. For example phosphorus will precipitate from the water thus reducing the productivity of the ecosystem as it is no longer available to organisms (Hakala 2003, 80) Impurities in the air can also damage the surface of the leafs and sulfuric compounds can also inhibit the plants ability to regulate its cellular respiration causing, for example, the plants to dry (Hakala 2003, 77). Sulfur dioxide at concentrations of 0,03 ppm as an annual mean can cause chronic plant injury and excessive abscission of leafs (Liu, Lipták & Bouis 1997, 244).

Air pollution poses a risk to buildings and structures too. Exposed materials will deteriorate faster when air pollution levels are higher. For example metals will corrode, stone will weather and paint will darken faster (Liu, Lipták & Bouis 1997, 242). Studies show that sulfur dioxide level of 0,12 ppm, accompanied by high levels of particulate matter, can cause steel to corrode 50% faster (Liu, Lipták & Bouis 1997, 244).

2.3 Environmental legislation in Finland

Laws govern our actions. In Finland top most is the Finnish Constitution. It states that the government must strive to secure a healthy environment for everyone. It also states that the responsibility of nature and its diversity belongs to everyone. Finland is a member of the European Union (EU) and each member state has the responsibility to legislate according to the directives passed in the EU. Finland has also ratified a number of international treaties and the legislation aims to fulfill the commitments of these treaties. Here we discuss, as an example, the acts and ordinances of Finland that deal with air pollution and monitoring of air quality or responsibilities of the municipality regarding these issues.

Environmental protection law and the corresponding ordinance aim to prevent the contamination of the environment, including the air. It also provides means to ensure a healthy living environment and gives the citizens opportunities to influence matters concerning the environment. It also aims to fight the climate change. The law gives the municipalities the right to give ordinances to protect the environment in certain cases. According to the law, a permit is required by such activities that bring about a danger for the environment. These include such activities as foundries, smelters, mines and landfills. The environmental permit regulates the operation of the activity by for example setting threshold values for emissions and giving responsibilities for monitoring the emissions. This law also states that the municipality must use all means available to prevent air pollutant levels from exceeding air quality threshold values set by the government. These means include further limiting emissions or traffic. The citizens must be warned if the threshold values are exceeded. (Ympäristönsuojelulaki)

Ordinance on Air Quality (Valtioneuvoston asetus ilmanlaadusta) defines different threshold values. These values are defined to protect humans and the ecosystems. For example particulate matter (PM_{10}) threshold value is defined for a 24 hour period as 50 µg/m3 and the threshold value cannot be exceeded more than 35 times per a calendar year.

Burning of fossil fuels is a major source of greenhouse gasses and air pollutants. Because of this, the government of Finland is controlling emissions of these substances by legislation. For example taxation of cars is formed partly by the age of the car but also according to its weight thus promoting the use of smaller cars (Ajoneuvoverolaki). Roughly half of the consumer price of petrol is formed by taxes (Laki nestemäisten polttoaineiden valmisteverosta). Some tax reductions are given to vehicles using methane, liquefied petroleum gas or natural gas (Ajoneuvoverolaki, Laki polttoainemaksusta).

The industry in Finland is subject to EU emissions trading either directly or through energy prices. Law regulates it and the purpose of these laws is to promote cutbacks on greenhouse gasses in away that is most cost affective. EU

Emissions trade scheme is a way for the EU countries to enact their commitment to the Kyoto Protocol.

There are also laws that regulate the behavior of the authorities. For example there is a law that states that the authorities must assess the environmental impacts their actions have when making new plans about e.g. roads, land use or energy services (Laki viranomaisten suunnitelmien ja ohjelmien ympäristövaikutusten arvioinnista).

Municipalities are obliged by law to organize environmental management within their jurisdiction in a manner that preserves healthy living environment for the citizens (Laki kuntien ympäristönsuojelun hallinnosta 24.1.1986/64, § 3 ja 4). Municipal environmental protection authority monitors and manages environmental protection and monitors the state of the environment (§ 5 and 6). The law also states that the environmental protection authority must be heard if any branch of the municipal government is discussing a matter with significant environmental effects (§ 6 and 10).

2.4 Environmental legislation in South Africa

The constitution states that all South Africans have the right to a healthy living environment and the right to have the environment protected (Government Communications 2009). To enact the will of the constitution, a wide set of acts have been decreed. These acts range from general protection of the environment and nature to more specific ones of e.g. waste and water. Table 1 lists some of the essential legislation associated with air quality.

The Legislator of South Africa is active with air quality issues. The new National Ambient Air Quality Standards were published March 31st of 2010. The standard sets limit values for sulfur dioxide (SO2), ozone (O3), PM10 etc. It also sets a limit value for lead (Pb) at 0,5 µg/m3 as a one-year average. (Department of Environmental Affairs 2010)

The National Environmental Management Air Quality Act 39 of 2004 has also been amended recently. This act was decreed to provide pollution prevention tools and to set national norms and standards. (Parliament of the Republic of South Africa 2010)

TABLE 1. Some of the essential legislation (City of Cape Town 2010)

Air Quality Act 39 of 2004
Atmospheric Pollution Prevention Act No. 45 of 1965
Bill of Rights, Chapter 2 of the Constitution of the Republic of South Africa, 1996
Environment Conservation Act (ECA) No. 73 of 1989
Environmental Laws Rationalization Act No. 51 of 1997
Municipal Systems Act No. 32 of 2000
National Environmental Management Act (NEMA) No. 107 of 1998 and its amendments
Protected Areas Act – No. 57 of 2003
Waste Act – No. 59 of 2008

3 BASICS OF AIR POLLUTION

Clean tropospheric air is composed primarily of nitrogen, oxygen and several noble gases. These gases comprise 99% of the atmosphere and the concentrations of these gases have probably been constant for millions of years (Pepper 2006, 47). This is not true for some gases. Gases such as water vapor, ozone and carbon dioxide occur in small amounts compared to the forementioned gases; however, their local concentrations can sometimes vary greatly (Seinfeld 1986, 7). These gases are known as trace gases (Pepper 2006, 47). Many of the gases considered to be air pollutants also behave this way. Table 2 catalogs some common air pollutants. (Seinfeld 1986, 7)

The first type of air pollution was recognized in cities like London and New York. The problem was typified by high concentrations of sulfur compounds, mainly primary pollutant SO_2 and particles containing secondary sulfates. The source of this pollution was the combustion of coal and high-sulfur-containing fuels for electric power generation and domestic heating. (Seinfeld 1986, 6)

Automobile exhaust were later identified as the main cause of photochemical smog, first in Los Angeles and later in most heavily trafficked metropolitan areas such as Tokyo, Athens and Rome. Smog occurs with high temperatures, sunlight and low humidity. This kind of smog consists of primary pollutants nitric oxide and hydrocarbons and secondary pollutants like ozone, organic nitrates and oxidized hydrocarbons. The secondary pollutants are responsible for such effects as eye irritation and damage to flora. (Seinfeld 1986, 6)

It is important to understand that even though the ratios of the different constituents of the atmosphere remain relatively constants, the gases are in a constant cycle. Compounds are released in to the atmosphere by man and nature and they are either transforming because of the chemical processes or they are being absorbed, for example, by the oceans or the biological organisms. This cycle gives a gas molecule an average residence time it spends in the atmosphere. This time can vary between some hours and millions of years. (Seinfeld 1986, 7-8)

When discussing compounds with a residence time in the shorter end of the spectrum, current physical conditions also affect the actual residence time. Temperature can change the time it takes for a compound to react. Temperature can also create vertical turbulence taking pollutants away from the ground level or bringing them down and changing the distance the pollutants travel. Inversion effect also controls how the pollutants move sometimes causing smog to form. Also the humidity plays a role as water droplets scavenge water-soluble pollutants thus changing the rate of removal. (Pepper 2006, 49).

This residence time can help us understand how some compounds affect the atmosphere as a whole and some more locally. Methane (CH4) has an approximate average residence time of seven years where as halogens have no such cycle. SO2 has a residence time of 40 days. (Seinfeld 1986, 8) With the right weather conditions, a large point source of SO2 emissions can affect the air quality over distances of 1000 km for several days (Seinfeld 1986, 36).

Air pollutants travel with atmospheric winds. These winds determine, not only, the speed they spread from the source, but also the path that they take. (Pepper 2006, 49) When combining the information about the residence time in current conditions with the information about the winds we can model how the pollutants spread and disperse.

3.1 Air pollutants and their categorization

Air pollutants can be categorized in many ways such as the state of the matter or source of the pollutant. We can also consider whether the pollutant is in the state it was released or if it has changed to another form. (Liu, Lipták & Bouis 1997, 232-233) We can also classify airborne matter according to chemical composition (Seinfeld 1986, 5).

If we look at air pollution purely by their chemical compositions we can use for example the following six groupings for air pollution: sulfur-, nitrogen-, carbon-and halogen-containing compounds, toxic substances and radioactive compounds. It can be seen that the toxic substances can encompass compounds also belonging to other groups such as halogen-containing compounds, however these compounds deserve extra attention. (Seinfeld 1986, 5)

TABLE 2. Concentrations (ppb) of common air pollutants (Seinfeld 1986, 16)

Species	Clean Troposphere	Polluted Air
Sulfur dioxide (SO_2)	1-10	20-200
Carbon monoxide (CO)	120	1000-10000
Nitrogen oxide (NO)	0,01-0,05	50-750
Nitrogen dioxide (NO_2)	0,1-0,5	50-250
Ozone (O_3)	20-80	100-500
Nitric acid (HNO_3)	0,02-0,3	3-50
Ammonia (NH_3)	1	10-25
Formaldehyde (HCHO)	0,4	20-50
Formic acid (HCOOH)		1-10
Nitrous acid (HNO_2)	0,001	1-8
Peroxyacyl nitrates ($CH_3C(O)O_2NO_2$)		5-35
Non-methane hydrocarbons (NMHC)		500-1200

TABLE 3. Some threshold values for air pollution concerning health risks defined by the law in Finland

Sulfur dioxide (SO_2)	124 µg/m^3 over 24h period
Nitrogen dioxide (NO_2)	200 µg/m^3 over 1h period
Particulate matter (PM_{10})	50 µg/m^3 over 24h period
Lead (Pb)	0,5 µg/m^3 over 1 year period
Carbon monoxide (CO)	10000 µg/m^3 over 8h period
Benzene (C_6H_6)	5 µg/m^3 over 1 year period

When looking at the source of the pollution we can first divide them in to two parts, which are natural and man-made. Natural sources can be such as wind-blown dust, volcanic activity or lighting generated forest fires. Man-made sources can be further divided by the geographic shape of the source. These shapes are point, line and area. Point source can be an industrial process stack and a line source something like a heavily traveled highway. A town center with a dense street grid with heavy traffic represents an area source. (Liu, Lipták & Bouis 1997, 232-233)

If considering the state of the matter we have two distinct groups. The first group is gaseous emissions such as carbon monoxide and nitrogen oxides and the second particulate emissions that consists of any dispersed matter larger than single small molecules and smaller than 500 micrometers in diameter. Of particulate matter we are especially interested in the particles that are under 10 micrometers in diameter because these are known to cause most particulate matter related health effects on humans. (Liu, Lipták & Bouis 1997, 232-233)

When we take into consideration the atmospheric chemistry we can see one more categorization between primary and secondary air pollutants. Primary pollutants are such groups like sulfur dioxides, nitric oxides and hydrocarbons that have been released from natural sources or human activity. Secondary pollutants are results of the atmospheric chemistry. For example tropospheric ozone is formed as a result of reactions between nitric oxide and hydrocarbons aided by sunlight hence we can call tropospheric ozone a secondary air pollutant. (Liu, Lipták & Bouis 1997, 259)

3.1.1 Particulate matter

Particulate matter is usually measured as the total weight of particles less than 10 nanometers in diameter suspended in the sampled air (Anttila 2003, 44). This diameter is defined as an aerodynamic diameter. This is known as PM_{10} and the concentration is given as micro grams per cubic meter of air. (Pepper 2006, 125)

These particles can be divided into three parts. First part is the primary particles that are mostly emissions from the industry and of the use of fossil fuels. Primary particles also include the material from smaller scale burning of different materials such as wood stoves at homes. Secondary particles are the particles that have chemically formed in the air, for example sulfate and nitrates. (Anttila 2003, 44) These particles are usually smaller qualifying as $PM_{2,5}$ (Pepper 2006, 127). Third is the so-called particulate re-suspension, which means the dust that is lifted in to the air from different surfaces like roads or simply the ground. Re-suspension can be caused by human activities such as farming, traffic and construction or by natural phenomenons like wind. (Anttila 2003, 44)

Smaller dust particles travel further than larger particles because of the smaller air friction. This can be further explained by the Stokes' law (Pepper 2006, 126). The smaller particles are of most importance when studying e.g. human health effects because they enter deeper into the lungs, into the alveoli and even to the blood stream.

Traffic emissions are of most importance for human health because they occur close to the ground. This also means that traffic particulate emissions and also re-suspension caused by the traffic are dominant in PM_{10} samples. In Finland the total particulate emissions in the year 2000 were approximately 74 thousand metric tonnes. Of this, two thirds was PM_{10} and half was categorized as $PM_{2,5}$. (Anttila 2003, 44) In Finland the PM_{10}-levels are low compared to much of the Europe. In Southern Europe threshold values are reported to have been exceeded even in the background areas. This is largely explained by the low levels of rain and the barren ground surface allowing re-suspension. Also Southern Europe suffers from dust brought in by the wind from Sahara. (Anttila 2003, 48) According to one estimate fifty percent of the PM_{10} measured in the City of Berlin is brought in by the wind from other areas and this segment consists of secondary particles or of particles from natural sources (Anttila 2003, 44). Major source of particulate matter in USA is the unpaved roads (Pepper 2006, 127).

Particulate matter emissions pose a risk to health and cause acidification of the environment. It can also cause an aesthetic damage by settling on surfaces or staining them. Particulate matter does reduce the effects of greenhouse gasses slightly but overall the effects are more damaging than beneficial. (Hakala 2003, 100) Reduced visibility can also be seen as a negative effect of particulate matter (Liu, Lipták & Bouis 1997, 244).

When inhaled, particulate matter can cause symptoms including decreased pulmonary function, chronic coughs, bronchitis and asthmatic attacks but the specific causal mechanisms are not well understood. These symptoms can be pre-existing ones, made worse by the particulate matter, or completely new. (Pepper 2006, 125) However, before mentioned symptoms are worse on senior citizens and patients with heart and lung problems (Pepper 2006, 127).

Studies show that the daily respiratory mortality rate increases by 1,4% per every 10 μg/m3 over the base level of 20 μg/m3. Similarly hospitalizations increase by 0,8% and emergency room visits for respiratory illnesses grows by 1,0%. Also the effects of particulate matter can be seen at schools and workplaces as days of restricted activity due to respiratory symptoms increasing by 9,5% and school absenteeism rising by 4,1%. (Pepper 2006, 127)

The health effects of particulate matter are somewhat dependent on the source of the particles. Wood burning and other such sources can contain organic substances that have additional health effects (Pepper 2006, 127). Some studies show that diesel exhausts can increase the chance of lung cancer by 20-50% (Pepper 2006, 127). Heavy metals can be absorbed to the dust particles and enter the body through the respiratory system.

3.1.2 Acidification

Acidification is caused by fallout that includes sulfuric and nitrogen compounds (Hakala 2003, 70). Carbon monoxide also adds to this effect (Liu, Lipták & Bouis 1997, 245). This fallout can be wet where these compounds have dissolved into rainwater falling to the ground or dry where the dust particles fall to the ground due to air currents and gravity (Hakala 2003, 71). The wet deposition of acids is called the acid rain however the dry deposition is equally important since it can be responsible for as much as 20 to 60% of total acid deposition (AEA 2010).These compounds are mostly emissions from the burning of fossil fuels and they effectively form an acid when dissolved into water (Hakala 2003, 71). In European Union approximately two thirds of nitrogen oxides are released by traffic (Hakala 2003, 72).

The fallout can travel hundreds or even thousands of kilometers away from the original source (Hakala 2003, 72). This acid fallout can cause the soil pH levels to drop causing negative effects on plants and the mobilization of heavy metals (Hakala 2003, 74-76). Acidification also has negative effects in lakes.

Sulfur also causes discomfort through its unpleasant odor (Anttila 2003, 58). For example hydrogen sulfide (H_2S) can be categorized as a nuisance gas because of it can be perceived at levels of 10ppb. Although it is also toxic with levels over 300ppm causing severe respiratory symptoms and levels of 700-800ppm being lethal. (Pepper 2006, 49)

3.1.3 Heavy metals

Heavy metals are an ill-defined subset of elements. Even though there is no clear definition for heavy metals this term is used widely to cover a group off elements that are toxic and exhibit metallic properties. However some of these elements are vital to organisms in small amounts. One definition describes heavy metals as metals with density greater than 5 g /cm^3 (Hakala 2003, 143).

Table 4 contains a list of common elements that are usually considered as heavy metals. Most harmful of these to organisms are mercury, lead and cadmium (Hakala 2003, 143).

TABLE 4. Common heavy metals

English name	Symbol
Arsenic	As
Cadmium	Cd
Cobalt	Co
Chromium	Cr
Copper	Cu
Mercury	Hg
Manganese	Mn
Nickel	Ni
Lead	Pb
Tin	Sn
Thallium	Tl

As heavy metals are elements they will not decay but can only form different chemical compounds. For example arsenic is metabolized in human body through a process of methylation and excreted (Koulu & Tuomisto 2007, 1095). Some heavy metals stay, or accumulate, in bodies of animals or plants permanently or for a very long time such as decades. This means that they are subject to biomagnification where the elements accumulate in the food chain often affecting most those at the top of the chain, for example humans.

All heavy elements occur naturally in nature but most of them are in mineral form in earths crust. The concentrations are not constant. Human activity, mostly through mining, brings heavy metals into our environment thus exposing animals and plants to them. Other source of heavy metal emissions include burning of coal or waste based fuels. (Hakala 2003, 143-146) It is also possible that acidification causes heavy metals, such as aluminium, copper and cadmium, to mobilize from the soil (Hakala 2003, 76).

Of the heavy metal particles in air the ones under two micrometers are most often results from human activity. These particles can remain airborne anywhere between some days to several weeks. Because of the long time they remain in the air they can travel distances in order of magnitude of one thousand kilometers. (Fergusson 1990, according to Salminen et al. 2004, 7, 10-11). For example cadmium is more readily absorbed through the lungs than through the gut (Koulu & Tuomisto 2007, 1093).

3.1.4 Tropospheric ozone (O_3), peroxyacyl nitrates (PAN) and Volatile organic compounds (VOC)

Even though ozone layer in the stratosphere is protecting us from the ultraviolet light, in lower atmosphere it is considered a pollutant. It is not directly emitted but a secondary pollutant created by primary pollutants, such as volatile organic compounds (VOC) or nitrogen oxides (NOx), reacting in the sunlight. (Hakala 2003, 98)

Ozone is very reactive hence causing a health hazard to humans and animals and damaging plants. It also corrodes materials and so slowly damages buildings and other structures. Because of its re-activeness the ozone molecules (O_3) decay to ordinary diatomic oxygen or other compounds relatively fast, perhaps within weeks or months (Hakala 2003, 98) In humans ozone damages the respiratory system with the most discernible short-term symptoms being coughing and painful deep breathing (Liu, Lipták & Bouis 1997, 245).

Peroxyacyl nitrates (PAN) are a secondary air pollutant just like ozone. The PAN compounds also cause irritation and they are toxic. Since these compounds do not break as easily as ozone, they can travel over long distances. After they break up NOx molecules are released thus increasing the concentration of ozone even in non-urban areas. Direct health effects of Volatile organic compounds are more common when discussing indoor air quality.

3.1.5 Carbon monoxide (CO)

Globally carbon monoxide (CO) is not usually considered as an air pollutant. This is because microorganisms living in the soil adsorb and oxidize it relatively fast to carbon dioxide (CO_2). However, locally, often in larger cities, carbon monoxide concentrations can rise to harmful levels with long-term exposure causing cardiovascular health to deteriorate. Larger quantities can be lethally toxic. (Pepper 2006, 127)

Carbon dioxide (CO_2) has significant environmental effects because it is a greenhouse gas but it is not considered as an air pollutant.

3.1.6 Radioactivity

Radioactivity is a very large subject. However in this context it should be mentioned, as the mining waste contains radioactive particles (Liu, Lipták & Bouis 1997, 1372). The wind picks the dust up from the mining dams and blows it to the residential areas. Also the burning of coal in the power plants releases radioactivity into the atmosphere in the form of radon (Rn) (Liu, Lipták & Bouis 1997, 1372). Even if the radioactivity levels are too low for them to pose a significant danger externally, as is the case with alpha radiation, when these radioactive particles are inhaled the sensitive parts of e.g. the lungs are exposed to radiation (Liu, Lipták & Bouis 1997, 1376).

Matter absorbs the energy of the radiation when it passes through it. This energy strips electrons from atoms and causes damage to e.g. human tissue. When discussing environmental health hazards the radiation sources are usually inhaled gases or particles or digested particles. (Liu, Lipták & Bouis 1997, 1376)

4 AIR QUALITY MONITORING OF A MUNICIPALITY

Air quality can be monitored on several levels and for many purposes. Monitoring ambient air presents challenges because of ever changing meteorological conditions, low concentrations of pollutants, and different physical and chemical properties the air pollutants have. Also some of these substances react easily therefore changing after sampling. (Liu, Lipták & Bouis 1997, 303-304)

4.1 Sampling of air pollutants

There are advanced, highly technological, portable instruments that can be used to measure air pollutants. These instruments are very expensive but can be used to provide accurate information. In this chapter we cover only some basic manual methods to help us understand how some of these more advanced instruments work and to give us ideas on how to develop simple and cheap methods for sampling.

Sampling of gas and vapor can be very simple. A bottle or a bag is filled with the sample of air and the sample is taken to a laboratory for analyzes. If the laboratory is using gas chromatography or gas-phase infrared spectroscopy a sample the size of a liter maybe be enough. When selecting the bottle or bag the choice of material is crucial. The contaminant must not be able to diffuse through the material in significant amounts and the materials the containers are made of cannot contaminate the sample. These effects can also be limited by analyzing the sample as quickly as possible. Speed is important also because of reactions within the sample. Cold temperature can slow these reactions. (Liu, Lipták & Bouis 1997, 305)

More advanced methods do exist. Sample gases can for example be absorbed into a medium and this medium can then be analyzed. This can be as simple as comparing the color change of the medium to a color chart. Ready-made analyzer tubes can be bought for many pollutants and different concentrations. The air is sucked through the tube containing the absorbent and then the scale printed to the side of the tube is read to give the concentration. (Liu, Lipták & Bouis 1997,.305-306)

The adsorption effect can also be used. Adsorbent such as activated carbon can be used to to collect many vapors and gases from the air. With this method it can sometimes be difficult to quantify the concentrations. Sometimes it is also possible to isolate the pollutant from air by cooling it. (Liu, Lipták & Bouis 1997,.306-307)

Particulate matter sampling is easiest with a filtering system. However this is often not possible. Removing the sample from the filter can be difficult. Filters can also contain the very substance to be analyzed, therefore distorting the results. It can also be impossible to measure the weight of the filter reliably since the filters are often hygroscopic so the weight can change as the relative humidity of the air changes. Perhaps the best filters for air sampling are membrane filters that are made of gel consisting of polymeric substances. These filters are usually of high chemical purity and are not subject to shifts in weight due to moisture so they are suited for trace metal analyzes and can be weighed before and after use to gain the weight of the sample. (Liu, Lipták & Bouis 1997, 307-308)

Impactors are devices for PM sampling where air is passed through small holes and made to impact a solid surface. These devices are often built in such a way that several impactors are layered and the first layer collects the largest particles and the bottom most layer collects the finest particles. The air streaming through the layers gains speed. The faster the air and the particles travel the greater the impaction potential is and so the particles are separated based upon their size. This kind of setup can provide more useful information since different particle fractions can be analyzed separately. (Liu, Lipták & Bouis 1997, 308-309; Pepper 2006, 510)

Particulate matter can also be precipitated from air using electrostatic forces. The particles are charged and the electrostatic force moves them to an oppositely charged surface. Devices performing this task are available commercially. This method is very efficient but the electrical forces involved can change the chemical compounds in the sample reducing its usability. Small amounts of particles for microscopic study can also be collected by using thermal precipitators (Liu, Lipták & Bouis 1997, 309)

4.2 Automatic air quality monitoring stations

Automatic monitoring stations are the current standard. They can be set up to measure any of the common air pollutants. This kind of equipment can be expensive and usually requires trained personnel and expert assistance. The motivation behind the setting up of such stations is to gain data that can be compared to the air quality standards set by the government. (Liu, Lipták & Bouis 1997, 309-310)

The most important thing, when planning an automatic monitoring station, is its location. A monitoring station can be set up to monitor a single problem area or pollutant, or to get a general idea of the air quality in the area. The location is decided with the knowledge of the local conditions and emission points. The exact monitoring location is determined after a wind rose is formed based on the meteorological statistics, and dispersion calculations can be made to further the knowledge on how the pollutants are spread. When the monitoring is done at a location that is considered to have the highest concentrations of some pollutant and the concentrations are measured to meet the air quality standards, then it is likely that other places also meet the standards. (Liu, Lipták & Bouis 1997, 310-311)

When choosing the exact location of the measuring site, it must be made sure that there are no tall buildings or large trees obstructing the free flow of air. The so-called canyon effect of the streets can also have an effect on the results. The monitoring stations also have to be safe from vandalism but they must be easily accessed by the maintenance crew. (Liu, Lipták & Bouis 1997, 311-312)

4.2.1 Measuring stations in Finland

In Finland most of the larger municipalities have some kind of air quality monitoring stations. For example the City of Lahti has five monitoring stations and four additional sites where volatile organic compounds (VOC) were measured with passive methods. These stations measure different pollutants with the most common groups in Lahti being nitrogen oxides (NOx) and VOC. Particulate matter (PM_{10} and $PM_{2,5}$) and ozone (O_3) are also measured at some stations. Computers at the stations collect the data and it is automatically sent to a database where it is converted in to an air quality index that has values good, satisfactory, undesirable, poor, very poor. The city also has a weather monitoring station supporting the air quality monitoring activities. (Autio 2009, 13-16)

To compliment the monitoring network created by the municipalities, the Finnish Meteorological Institute maintains monitoring stations. These stations are placed in the countryside in order provide information about long-range air pollution and background concentration. The Meteorological institute also maintains a database where all data from their own stations is collected and where the municipalities upload their own data. (Anttila 2003, 7)

4.2.2 Some examples of monitoring technologies used in Finland

Different pollutants require different means of sampling or measuring. In Finland SO_2 is measured by using a continuous UV fluorescence analyzer combined with the DOAS method (Differential Optical Absorption Spectroscopy). (Anttila 2003, 19) Analyzers using chemiluminescence-phenomenon, sometimes using the DOAS method, are used to continuously monitor the NO_2-levels (Anttila 2003, 30).

Particulate matter levels are monitored continuously either with automatic systems using microscales with TEOM (tapered element oscillating microbalance) or with a system where the sampled air is bombarded with beta radiation and the dampening of the radiation is measured to define the amount of particles in the sample. These methods heat the sample so some easily vaporizing compounds can be lost. At some stations particulate matter samples are also collected with manual methods. (Anttila 2003, 40-41, 52)

TRS (Total Reduced Sulfur) concentrations are measured using a converter oven where sulfur compounds are oxidized into SO_2. The SO_2 concentration is then measured using a UV fluorescence and from this result the original amount of TRS can be gained. (Anttila 2003, 58)

Carbon monoxide (CO) is measured with a method based on the absorption of infrared light by the CO. CO absorbs a certain wavelength of the light and the nondispersive infrared sensor (NDIR) measures how much light came through the sample giving the CO concentration in the sample. Ozone (O_3) is also monitored by measuring the amount of light not absorbed by the sample but using ultraviolet light. (Anttila 2003, 64, 70)

5 AIR QUALITY IN RUSTENBURG

5.1 Overview of Rustenburg

Rustenburg is a municipality located in the North West Province of South Africa. The seat of Bojanala Platinum District Municipality (BPDM) is located in Rustenburg. The city has a reported population of 400 000 during the 2001 census but unofficial estimates place the number higher.

The Magaliesberg mountain range and the flat areas of the Highveld plateau and the Karoo semi-desert dominate the geography of the Rustenburg area. The desert of Kalahari is also close to the area and the sand desert of Namib is roughly 500 kilometers from Rustenburg. Rustenburg is in the middle of the continent with over 500 kilometers to the Indian Ocean and 1000 kilometers to the Atlantic Ocean. The area has no significant bodies of water. The rivers are relatively small and mostly seasonal drying out during the local winter. Larger lake like waters are found in the form of the man made reservoirs that are locally called as dams.

Climate is temperate and dry. Amount of rain is notably low during the winter months of May, June, July and August. Temperature can drop just below zero during the winter nights.

Though South Africa is one of the biologically megadiverse countries, the Rustenburg area is simpler because of its climate. The Flora consists of different grasses, low shrubs, and acacia trees, mainly camel-thorn and whitethorn. Many African mammals are found in the area. These include lions, leopards, white and black rhinos, hyenas, hippopotamus, giraffes, wildebeest and many antelopes such as impalas and kudus. Most wildlife can only be found in the fenced national parks and game reserves. More common animals to be spotted are such farm animals as cows, chicken and goats. A major game reserve, Pilanesberg, is close to Rustenburg.

The life in Rustenburg is dominated by the mining industry. Three major mining companies operate in the area: Anglo Platinum Limited, Impala Platinum and Xstrata. Most of the people living in the area are employed by the mining industry either directly or by supporting activities. The main product of the mines in the area is platinum. Rustenburg is sitting on top of the Merensky reef and the UG2 reef, the world's largest reserves for the platinum group metals. The mines also produce valuable by-products such as chromium, gold, copper and nickel. Unwanted by-products have changed the scenery in Rustenburg. The mining waste piles, called mining dams, are often measured in square miles and they can be dozens of meters high.

IMAGE 1. Mining dam (photo by Sakari Autio)

In North West Province 65 % are Tswana speakers but there are also large groups of workers that have moved from other areas of Southern Africa. Less than seven percent of the population is white but the working language is English. The crime in South Africa is one of the worst in the world but based on the writer's own experiences, Rustenburg is not one of the worst places in the country. Still, poverty remains a great problem. Bojanala is slightly under the national average GDP and the unemployment is possibly higher than the national average. (Pauw 2005)

A special question in Rustenburg, and the whole of Southern Africa, is the HIV/AIDS that has reached pandemic proportions. Officially 12 % of South Africans have HIV but locally this percentage can be anything. This is emphasized by the insufficient health care available to people.

Rustenburg has a long Afrikaner history and it was the home of the former president of South Africa, Paul Kruger. The urban character is very different from European cities of the same size. The center of Rustenburg is very under developed and the local white population considers it too dangerous to frequent. There is a modern shopping mall outside the center.

Upper and middle class people prefer to live to the south of the center. Best locations being south of the N4 highway. The less well of people live in Apartheid era townships were population is dense. These townships often provide their inhabitants with housing in small standard concrete or brick structures with three small rooms, running water on the property, basic plumbing and electricity. There are also slums in Rustenburg. In European standards, large apartment buildings are rare in Rustenburg.

The waste management in Rustenburg is insufficient. The collection of the waste does not reach everyone and small unofficial landfills are common. There are plans to improve the system with a new landfill under planning.

In Rustenburg the traffic is congested, especially so in the central business district and on the main entrance roads. Those who can afford, own one or more cars. The pick-up trucks, or bakkies in South African English, are most popular. The mining and industrial areas have significant amounts of heavy trucks. The largest road in the area is the N4 highway, which is an important arterial road for the Southern Africa. The N4 links Pretoria to the capital of Botswana, Gaborone, and it forms the South African section of the highway crossing Southern Africa from the the Pacific Ocean to the Atlantic Ocean. Fuel prices have risen in resent years but they are still significantly lower than in Finland.

Public transportation is underdeveloped but it is relatively cheap and fast. The minibuses using the taxi rank as a hub are practically the only mode of public transportation. The minibuses can carry roughly 12 people although some larger buses exist on longer routes. The minibuses don’t have schedules as such but depart when they are full, dropping of people where they want. Getting on the minibus along the route is difficult. There is no taxi service and bus services, like the ones in Finland are rare. There is also no apparent rail service for passengers in Rustenburg.

5.2 Factors affecting air quality in Rustenburg

Industrial processes are a significant source of particulate matter. These processes include mining, construction, materials handling and processing of metals and chemicals. Many of these processes also release particles because they involve burning of fossil fuels for generating heat. (Vallius 2005, 19)

During heavy winds dust is picked up from the mining dams. As these dams are very high the dust is carried long distances and spread all over the area. This dust most likely contains all of the metals mined and all of the chemicals used in the process.

Energy production through fossil fuels is a major source of air pollutants. Power plants and residential combustion emits particulate matter (Vallius 2005, 19). Residential combustion in this context means the coal used by the poorest people to warm their houses and cook their dinners.

Traffic affects air quality locally, regionally and even globally. It causes direct and indirect emissions. These include exhaust gasses, vaporizing fuels and the dust caused by the wear of the tires, brakes and the road. Traffic also kicks up other particles of the road. Traffic emissions are the biggest source of emissions affecting the urban air quality. (Kuukka-Ruotsalainen 2001, 18)

Particulate matter from exhaust gases of vehicles using fossil fuels is small in particle size. The size varies between 10 to 80 nm emitted by gasoline vehicles and 100 nm emitted by vehicles with diesel engines. These particles are mainly carbonaceous agglomerates matter (Vallius 2005, 18)

Exhaust gasses contain toxic components, mostly heavy metals, and the local plants and microorganisms in the soil absorb these toxins. Exhaust gasses also contain chemicals that cause acid rains and eutrophication. Traffic also causes troposphere ozone formation. Oil and fuel leaks also have an effect on the local air quality and accidents may cause other harmful or toxic substances to be released (Kuukka-Ruotsalainen 2001, 18-19).

Burning of waste even on industrial level is a difficult task when it comes to preventing the formation and emission of air pollutant. In Rustenburg people burn waste because they want to get rid of it or because they need the fuel. Burning of waste, for example plastic, in fireplaces or in ones backyard creates toxic fumes and pollutants such as carbon monoxide and dioxins. These fumes are not the only problem. Workers are often making small fires to warm up in the cold mornings of South African winters. These fires spread in the dry grass. Grass fires are a common sight and most likely pose a significant threat to the air quality

5.3 Air quality monitoring

The municipality monitors the air quality in Rustenburg. The municipality has three automatic air quality monitoring stations. These stations were all visited during the test-run of the simple dust collecting system. During that time the stations were still at the running-in phase.

One of the stations is in Boitekong, one in Marikana and one is in Thlapane. The stations are heavily fenced to provide security and all three locations have municipality personnel working close by at least during the business hours. The fencing can be seen in the image one. The station in Boitekong is at the front yard of the library and across the road is the local police station. The Marikana station is at a community center and the one in Thlapane is on a schoolyard. They all have residential areas in the close proximity and the mines and related activities are close by.

The stations sample the air and automatically measure concentrations of pollutants such as ozone (O_3), carbon monoxide (CO), nitrogen oxides (NOx) and sulfur dioxide (SO_2). The measurements are automatically sent to Germany where a consultant processes the results. Some of the sampling instruments can be seen in images 2 and 3.

IMAGE 2. Air quality monitoring station in Boitekong

IMAGE 3. Air quality monitoring instruments

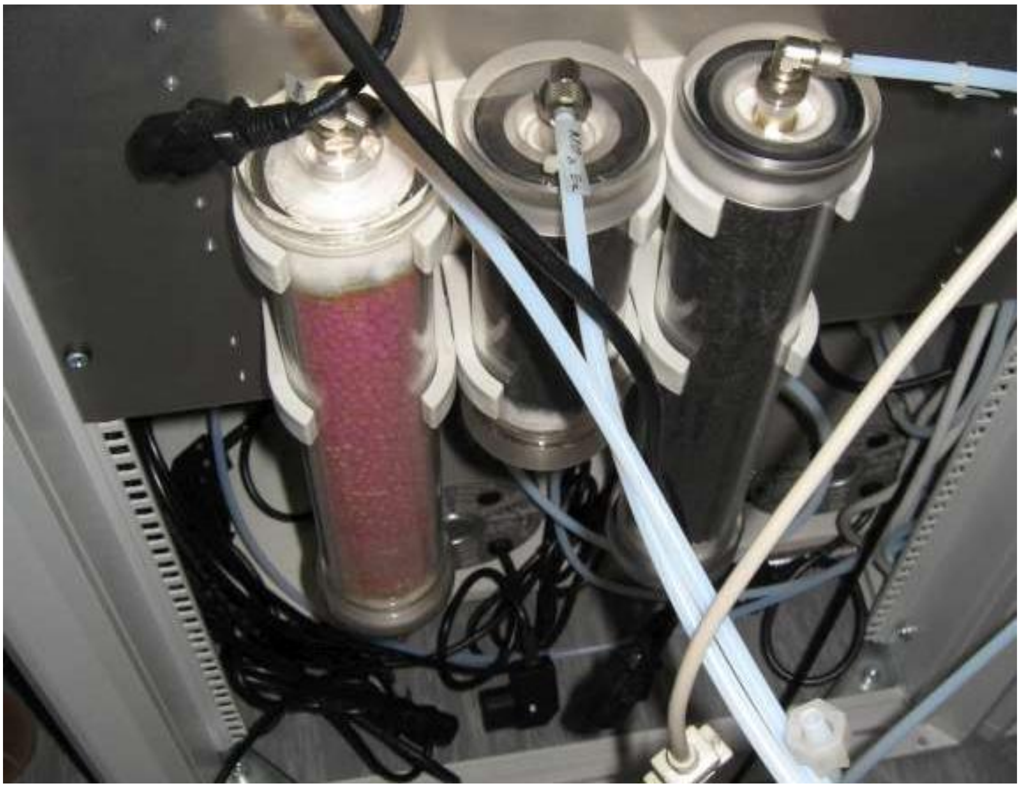
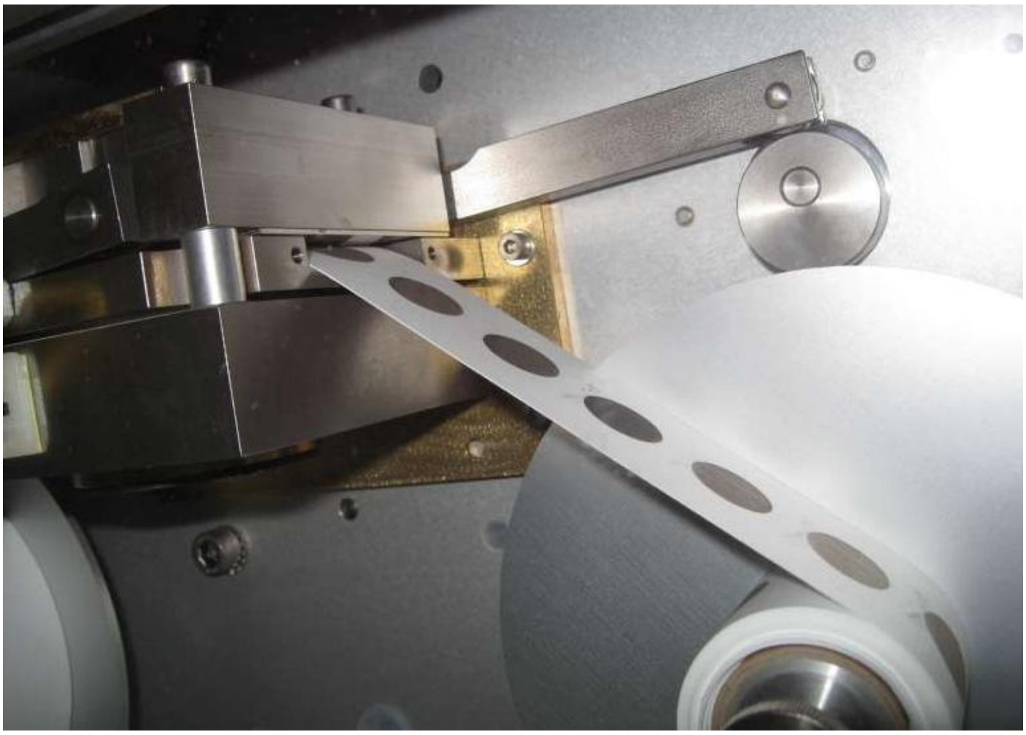


IMAGE 4. Detail of the air quality monitoring station



The mining companies have different activities all over the municipality. Only air quality monitoring that was seen during tours of different facilities was the monitoring of the mining shafts. A small laboratory had some instruments, e.g. an accurate scale, and they had filters in the ventilation systems which were collected for analyzes in the laboratory.

During the test run of the simple dust collecting system, Helsinki University was running an experiment in Rustenburg to measure air quality. The purpose of this was to study air pollution on a global scale.

6 FEASIBILITY STUDY OF A SIMPLE DUST COLLECTING SYSTEM

This study was conducted because the Bojanala Platinum Distrinct Municipalities Environmental and Waste Management Unit had Air quality as one its agendas for the year 2008.

Monitoring air quality can be very expensive and funding for it can be scarce. This is especially true in a city such as Rustenburg (SA) where there are other great problems such as fighting poverty and the HIV/AIDS epidemic. This created the idea of researching and testing for monitoring methods that would give useful results and would be cheap and easy to use. The field-testing would be done in Rustenburg, South Africa.

This kind of test-run for a simple dust collecting system was suggested to and accepted by the authorities of both BPDM and Rustenburg municipality. Different methods were looked upon but finally a simple dustfall jar experiment was devised.

When this was planned it was not known that the City of Rustenburg has three Air Quality monitoring stations. If this had been known, it could have been accounted in the planning phase.

Dustfall jars are the simplest method to monitor the air quality. They collect dust particles that commonly are above the 10 μm size. Particles of this size seldom travel further than 800 meters. If small amounts of particles are collected, it does not mean that the air quality is good but if large amounts are collected it is usually a sign of significant air pollution. Previous studies have determined some levels for comparisons to be made (Liu, Lipták & Bouis 1997, 312).

The purpose of this experiment was to see if it was possible to collect a sample of the dust that settles from the ambient air. The main goal was to be able to weigh the sample. The idea was to collect a dust sample over a period of weeks and then weigh it and bring the sample back to Finland for heavy metal analyzes in a commercial laboratory. This would prove that if the collector was accurate enough the process would work and it could be used to get monitoring data of the air quality. This sample was to represent the dust particles in the air so analyzing it we would get an idea of e.g. heavy metal concentrations in the air. The collector should be built using locally acquired equipment and the whole experiment should be so simple that someone who is not a trained engineer could reproduce it with written instructions. The use of a Finnish laboratory was decided because of technicalities in the funding of the project. Heavy metals were chosen as the pollutant to be analyzed because they are stable enough for the long sampling time and for the long time it would take to get the samples to the laboratory.

It was assumed that no research equipment would be available with the possible exception of a scale. However a pocket size scale was carried just in case. It was acknowledged at an early stage of the project that comparing the collected samples against each other would be difficult and that the best results would probably be with the sample of a single location compared to a sample taken from the same location next year. This would provide some information on the trends. This kind of sampling could even be repeated every month, so that the seasonal changes would show.

6.1 Planning

The experiment was planned before traveling to South Africa. An idea how this test could be done was gotten from the standard SFS 3865. This standard was not to be followed strictly because it was assumed that the jars with the specified measurements could not be manufactured or bought and it could be impossible to place the collectors in locations defined by the standard. Also the sampling time was left open because of uncertainties with the schedules, though it would happen during the South African winter, from the month of May to July, in the year 2008.

The collector itself should provide a reasonably large open surface. It should be deep enough to provide protection for the sample. Plastic was chosen as a material for the buckets because it is cheap and would contain the sample and would not likely contaminate it. Preferably the collector should be set up in such a way that the jar could be taken indoors for the sample to be bagged. The collector should be placed well of the ground, if possible, at the height of an average person.

Adding water to the collectors was considered but finally it was decided against it. Water would probably capture the dust particles better but it would present new challenges and complications. Water is heavy and transporting liquid samples in the airplane could possibly be very difficult. Filtering the water for the dust would reduce the weight but would complicate the procedure and create more error. Also filtering would not work if at a later point in time it would be necessary to start monitoring for other pollutants. For example nitrogen dioxide reacts with water forming nitric acid (Antila 2005, 137).

An additional idea that was to be tried was to weigh the jar before the sampling period and then after it with the dust to get the weight of the sample. It was assumed that because of the connections to the city and to the mining companies in the area that a scale accurate enough could be used.

The sampling period length was not decided before hand as there was no way of knowing how fast the dust would accumulate in the collector. The plan was to monitor one or more of the collectors visually and take them down after there would seem to be enough dust, thus setting a standard for the sampling method. Another reason for not having a preset sampling period was that there was no way of knowing when the buckets could be collected as the resources allocated to this project were unknown.

The problems with the method would be many. The big question was how well would the sample represent the dust settling in the general area of the collector? Buildings and trees would affect the wind. The wind might also pick dust out of the collector or bring in larger items such as leafs and compromise the sample. It could also rain. Wildlife could influence the sample. Theft was also a concern as poverty and crime are serious issues in Rustenburg.

6.2 Execution

After arrival to South Africa it was decided that a practical test would be attempted to see if it was possible to get a sample and what kind of problems would arise.

First step of the experiment was to start the process of identifying the locations where the collectors would be placed and to start finalizing the design of the collector. The locations had to provide a safe enough spot for the collector protecting it, not only against vandalism but also against theft, as even a plastic bucket is seen as a valuable item among the poor. During storms the wind can be heavy in Rustenburg so the locations would have to provide a stable platform for the collector to be mounted on. They also had to be clearly of the ground but not too high, 1.5 to 3 meters, so that they would be in similar conditions to people living and breathing in Rustenburg. It was decided that one location should be in a location that would be away from roads and any mining activity and that this location would provide a background sample.

Poles were considered for the platform of the collector because they would be fairly easy to set up anywhere and the material was easily available in hardware stores in Rustenburg. The poles were already acquired but in the end they were not used. Plastic buckets and lids for them were also bought. These buckets were made of colorless plastic. Scrap metal and old building materials were also used in the construction of the collector.

Two old concrete blocks were used as a base for the collector. They would give the construct enough weight so it would stand against heavy winds. Also this way the whole collector was small enough to only require a level surface of less than one quarter of a square meter. A bowl shaped electric motor cover was screwed on the blocks. Though these covers were recovered from scrap metal yards, they were close enough to the shape and size of the plastic bucket. As the buckets were slightly tapered towards the bottom they made a tight fit and would not come off without reasonable force lifting it out thus providing an easy method of attaching the bucket to the collector base but still ensuring that the buckets were easy to collect after sampling. Before removing the bucket a lid would be placed to make sure no dust would fly off during detachment and transport.

IMAGE 5. Collector with the base at the Kgaswane nature reserve

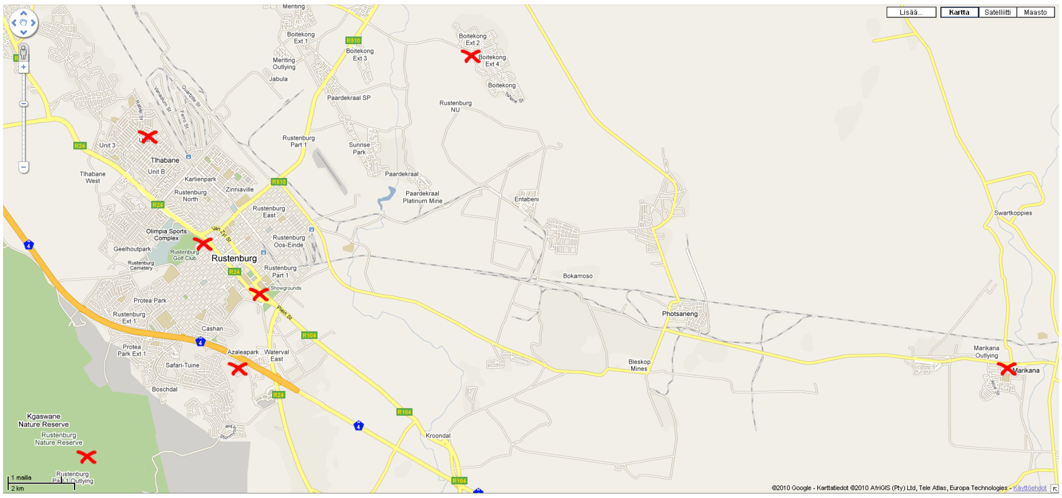
Locations were identified with the help of local authorities and their wishes were also taken into account. Roughly half of these locations were on sites belonging to the City of Rustenburg and the rest were in Bojanala Platinum District Municipality sites in Rustenburg area, seven collectors in total. The collectors were placed in Thlapane at a schoolyard, Boitekong library, Marikana community center, Bojanala Fire Department next to the Rustenburg taxi rank, Cashan, BPDM Environmental and Waste Management unit's office, and Kgaswane Nature Reserve. The distance between the Thlapane and Marikana collectors was roughly 30km.

Thlapane, Boitekong and Marikana were also the sites of the City of Rustenburg air quality monitoring stations so they had a site that was heavily fenced and guarded at least part of the time. In these three locations the collectors were placed on the roofs of the stations. These stations are built in to containers that are roughly the size of a one-car garage. Besides providing a secure location, there is an added benefit of a possibility of using the measurements taken by the stations electronic equipment to calculate a correction factor for the collectors. These three locations are in very poor neighborhoods, townships, located very close to the mines, refineries and mining dams.

The Fire Department is centrally located. The collector was placed on top of a small building next to the fence separating the lot from a heavily trafficked road and the busy central Taxi Rank. The BPDM Environmental and Waste Management Units office is located between the major exit and entrance roads to and from Rustenburg close to the city center. The collector was set up on the top of the fence. Cashan is a neighborhood of wealthy and rich people located in the hills on the southern part of Rustenburg. The collector in Cashan was located in the private backyard of BPDM Environmental and Waste Management Unit Manager Vuokko Laurila, on the fence separating two private backyards. Her house is close to the busy N4 freeway.

Kgaswane Nature Reserve is the southern most part of Rustenburg. The collector was placed here with the idea that it would collect the background sample. The collector was placed on a fence surrounding a municipal engineering site. Next to it was some housing for park employees, so some security was provided. An additional threat to the collector at this site was the baboons spotted nearby every time the site was visited. Information of this threat was given by the park employees, though the threat did not materialize.

IMAGE 6. Map of Rustenburg with sampling locations. Note that the Kgaswane location is in reality further into the park.



The buckets were marked with a permanent marker and weighed at a laboratory that was set up at one of the Anglo Platinum sites. The mining companies have laboratories but finding a suitable one and gaining access to its equipment required some pulling of strings and lots of driving around.

The buckets were placed quite high of the ground due to practical reasons. The top edges of the collectors were between 2250 and 3690 mm. The collectors were placed on the 3rd of June in the year 2008 during the afternoon and they were collected on the 16th of July also during the afternoon. This period was not chosen but dictated by practical matters such as acquiring a car and a driver. Placing the collectors took approximately seven hours. Most of this time was spent driving from one location to the next but it also took some time to set the collectors up. This time would in all likelihood be at least an hour shorter if the collector bases would already be in place. This is also supported by the fact that collecting the collectors took only about four hours.

After the buckets were collected all larger pieces were removed with tweezers. Next the dust was brushed gently onto a piece of paper and from there to a small plastic bag. The paper was used because otherwise it would have required the help of another person.

The samples were transported to Finland and stored to wait for the laboratory analyzes. When a suitable occasion turned up the samples were sent to a commercial laboratory. The laboratory later delivered the results via email thus closing the experiment.

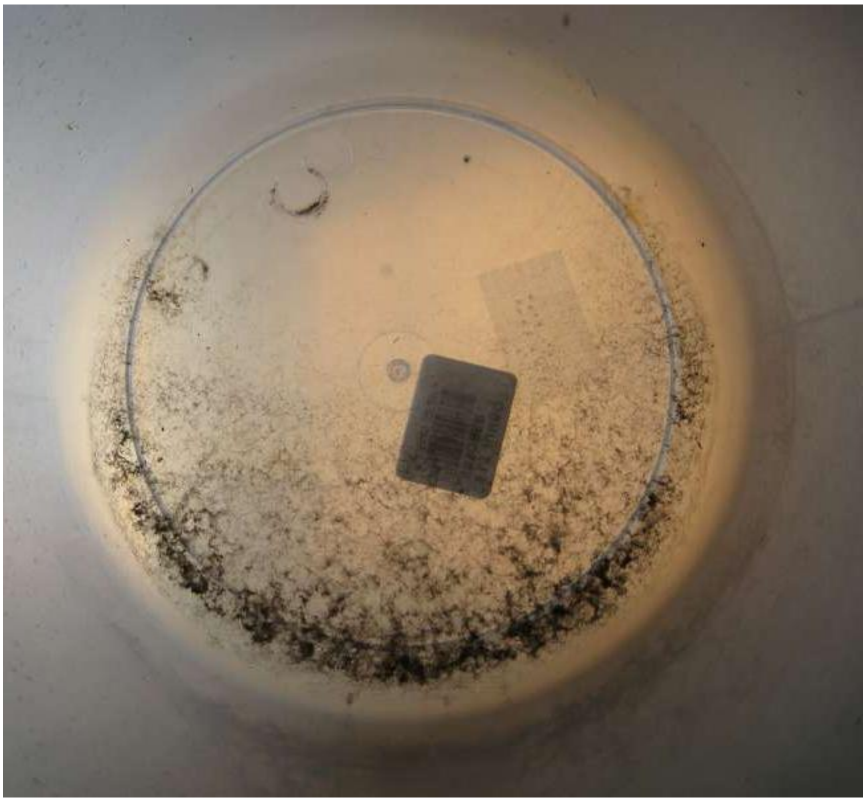
6.3 Practical problems and experiences

The experiment had many practical problems that would need to be worked on before attempting to collect samples again. However, based on this testrun, Rustenburg could be an ideal location for the development of the simple dust collecting system because of the local conditions. Its location on the African continent far from the oceans and the typical climate of the general region it can act as a model for many municipalities in Southern Africa. The heavy industry and mining in the area emit large amounts of air pollutants and they also have three automatic air quality monitoring stations that could perhaps be used to calculate a correction factor. The funding for air quality projects in this area is relatively good, atleast when comparing to poorer municipalities or to less developed countries.

6.3.1 Rain and impurities

It rained at least twice during the sampling period but these showers lasted only a couple of minutes at a time. At one time there was about five centimeters of rain in the collector but this water quickly evaporated. Two of the collectors had also collected some bird droppings. One of these was the collector that was placed on the wall next to the office of BPDM Environmental and Waste Management Unit so it was easy to monitor this collector during the sampling period and it was noticed that the bird droppings had appeared. Otherwise it would have been difficult to tell these droppings from other substances in the collector as the rain reshaped or melted them to some extent. These dropping and some twigs, leafs and bugs were removed from the samples. It is difficult to estimate how much dust was removed with these impurities and if they brought more heavy metals into the sample

IMAGE 7. The bottom of a collector with the dust collected



The sampling site at Kgaswane was not ideal. Even though the trees were not directly over the collector they proved to be to close. There were lots of small leafs, twigs and other debris in the collector. There were some dust that could be seen but the amount was very small compared to the other sites. The dust was stuck in some kind of sap-like substance and could not be retrieved. It seems likely that the sun and the rain had extracted this substance from the leafs and twigs thus ruining the sample. No dust was recovered from the collector at Kgaswane. Even though the Kgaswane sample was ruined, it is possible that the general area is suitable for background sampling.

With all of the samples some dust was lost because of static electricity or static cling. The dust particles clung on to the edges of the bucket and it was impossible to completely recover it using a brush. It is unlikely that the weight of the sample changed significantly. However, it is difficult to say how the laboratory results would have changed if the smallest particles could have been recovered. As can be seen in the image 6, the dust seemed to gather at one edge of the bucket in most cases. At some of the collectors there were some kind of splatter marks on the walls of the bucket. They were probably formed by the rain and composed of the dust. The Kgaswane collector had no such marks.

6.3.2 Failed weighing

The buckets used as collectors were weighed before placing them at the sampling locations. It was thought that the buckets could be weighed after sampling with the dust to determine the weight of the sample.

The buckets were numbered for identification purposes. Due to haste, carelessness and stress, notes made about the numbered buckets and to which location they were placed were incomplete. As an example of the stress factors it could be mentioned that the collector at Boitekong was setup at half past six in the evening so it was already dark. Working in darkness next to barbwire and on ladders is stressful enough but the neighborhood in Boitekong was questionable at best.

On the scale used for the weighing, it said that the accuracy was 0,01g. As the room had heavy draft and the plastic buckets were quite large and light it turned out to be difficult to weigh the buckets. The weights were between 293,30 and 296,82g. The buckets were again weighed with the samples after the sampling period. The markings on the buckets were made with a permanent marker but they had disappeared so it was not possible to clearly identify where each bucket was placed and as the notes made during the placement of the buckets were incomplete we can only give some examples.

The bucket at the fence next to the office was weighed at 293,63g before sampling period and with the dust at 293,91g. This gives us the weight of the sample at 0,28g. As comparison we can say that the laboratory in Finland weighed the sample at 0,0341g.

The most extreme case was the bucket at the Fire station; it was 0,03g lighter with the sample. UV-light from the sun breaks plastic down. If we consider the weight of the sample in relation to the weight of the bucket we can see that it is 1/10000. It seems plausible that the plastic bucket could loose enough of its weight due to the harsh sun of South Africa to obscure the weight of the sample when weighed together.

Without complete notes we can only say that this method provided too many errors to be reliable. It seems likely that this method could not be used to weigh the sample.

6.3.3 Other problems

Doing the test run on the dust collecting system, there were some problems gaining access to certain locations. For example the Marikana site was behind locked gates with a stonewall topped with barbwire. Apparently the gates would have been open earlier but at that time it was necessary to climb over the wall. Some of the other sites were also such places were entrance could be gained only during business hours. However it seems possible to avoid this problem if the collectors could be set up faster during routine measurements. Together with the access problems and the great distances between the collectors, it seems that it would be difficult to have more collectors without more resources. For example if another team with a car could collect some of the buckets there could more collectors. Collecting the buckets during the same day seems important because of changing weather conditions. Just a couple of days could significantly affect the amount of dust collected.

There were some issues with the local work culture being different from the culture in Finland. Some problems with punctuality were experienced; it seemed that it is only natural to be five hours late and not call. However it seems only natural that this project would not take priority in the minds of the local people as they had their own responsibilities to full fill. Also it must be mentioned that when talking to people about the project their attitude towards it was respecful and they seemed to think it was important.

Also information was not eagerly shared. As an example there was no knowledge of the three automatic air quality monitoring stations in Rustenburg before traveling to South Africa.

6.4 Laboratory analyzes of the samples

It was decided to combine six samples into two composite samples. The first sample (C1) was a combination of the samples from the more central locations i.e. Thlapane, Fire Station, Office, and the sample from Cashan. The remaining two (C2), Boitekong and Marikana, were combined for the second composite sample. Though more information would have been gained from analyzing the samples independently, funding was limited. The reasoning behind the idea of combining the samples was that perhaps one or more of the samples would contain surprising levels of heavy metals so none should be excluded. There was no funding available for the analyzes of all samples. It is unlikely that the combining of samples has any effect on the laboratory's ability to analyze the samples so it does not affect the test-run of the dust collecting system. The mixing of the samples was done at the laboratory so the individual samples could be weighed. The weights of the samples can be found in the table 6.

The laboratory reported that they had used inductively coupled plasma mass spectroscopy (ICP-MS) to analyze the sample. Even though the actual concentrations are not of great importance for the test-run they may proof to be useful in the following test-runs so they can be found in the table 7. The report says that the uncertainty in the measurements is 20-25%.

TABLE 6. Sample weights

Thlapane (C1)	0,0939g
Cashan (C1)	0,0272g
Fire station (C1)	0,1332g
Office (C1)	0,0341g
Boitekong (C2)	0,0576g
Marikana (C2)	0,0505g
Kgaswane (C1)	No result

TABLE 7. Heavy metal concentrations of the samples

Element	Sample C1	Sample C2	Unit
Arsenic (As)	5,0	1,2	mg As/kg
Cadmium (Cd)	0,70	<0,2	mg Cd/kg
Chromium (Cr)	2100	340	mg Cr/kg
Copper (Cu)	250	100	mg Cu/kg
Lead (Pb)	67	12	mg Pb/kg
Zinc (Zn)	650	7500	mg Zn/kg
Tin (Sn)	4,4	<1	mg Sn/kg

6.5 Discussion on the laboratory results

It seems possible to collect dust samples to be weighed with the simple dust collecting system. These weights from the test-run cannot be used when compiling the statistics for longer periods as the error has probably grown too much. After some improvements, and possibly a second test-run so the errors of this method could be sufficiently reduced, the sampling should be performed periodically so the subsequent results from the laboratory could be compared to results from previous years.

Based on this study, it is impossible to say how the collected samples correspond to particulate matter concentrations in the lower atmosphere.

Results obtained with the simple dust collector system could be very difficult to compare with other studies. The results can be affected by very simple factors starting from the angle of the collector and the weather during sampling (Fergusson 1990, according to Salminen et al. 2004, 7, 10-11).

The results on the concentrations are not easy to interpret. It is important to remember that the laboratory results for the selected heavy metals are, in fact, concentrations in the collected samples. These concentrations should be proportioned with the weight of the dust sample.

It is in all likelihood impossible to determine, by using these results, how much e.g. lead is in the air at some given period of time. This would be required before anything could be said on whether or not the air quality is in compliance to the air quality standards. It is most likely that with this method the frequency of limit value exceedences cannot be determined but other interesting information can be obtained. It should be remembered that the suspended particles have health effects beyond heavy metals.

Table 8 presents some values for heavy metals in the soil as defined by the Finnish legislation. The natural concentration in this table is the value determined by Finnish authorities for moraine soil. The threshold values in this context mean that if the value is exceeded, the level of soil contamination must be determined and a plan of action must be made. These reference values are determined by the ecological and health threats.

TABLE 8. Threshold and reference values for soil samples for selected heavy metals (Finlex 2007)

Element	Natural concentration (mg/kg)	Threshold value (mg/kg)	Lower reference value (mg/kg)	Higher reference value (mg/kg)
Arsenic (As)	1	5	50	100
Cadmium (Cd)	0,03	1	10	20
Chromium (Cr)	31	100	200	300
Copper (Cu)	22	100	150	200
Lead (Pb)	5	60	200	750
Zinc (Zn)	31	200	250	400
Tin (Sn)	-	-	-	-

Even though direct comparison between the values in tables 7 and 8 can be difficult, it is alarming to notice that some of the values from the sample seem very high. For example the amount of zinc and chromium in both samples requires attention. Had these samples been taken from the soil in Finland, the soil would have to be cleaned before the land could be used. As a precaution it is advisable to take soil samples from the sampling sites where the dust was collected.

6.6 Future modes of operation

If an air quality monitoring system for a municipality is to include the simple dust collecting system, a proper laboratory is needed to provide reliable information. Two large-scale models could be suggested. The first model would be build around independent commercial laboratories with adequate certifications and it would require constants funding for the samples to be analyzed. The second model would incorporate government run laboratories. This model would possibly require the help of the more advanced nations in the form of training the personnel and funding the initial investment. The second model could make it possible to bring laboratories to the poorest countries and these laboratories could provide services to other environmental fields of study and beyond. It is difficult to say which model would work best and it is likely that there are situations were either could work.

An organization should be set up where a small team of experts could be dispatched to any municipality to plan the sampling grid. These experts would also teach the first generation of locals to run the system, as the basic idea is that very little training is required to keep the dust collecting system running. Also a field manual for the collector system should be written. This manual should be so simple that after the system is running, almost anyone could maintain it and collect samples. The manual would provide information on the basic principles of sampling, where to deliver the sample and how to report the results.

Also the analysis of the results could be centralized. This kind of sampling method produces very small amounts of figures compared to the automatic monitoring stations so the work would not be overwhelming even if the number of collectors would be large.

The collector used for the test-run was made from available parts but the further testing could also be done with parts that could be standardized. The bucket is the most important part and buckets with the same width and depth should be available also in the future. This is important because a bucket might be lost and it would have to be replaced. If the new bucket were different, comparison between different sampling periods would be difficult. Other municipalities could use a little bit smaller or larger buckets and the basic procedure should remain the same. One solution to this could be buying spare buckets in the beginning. The buckets should have lids as they proofed to be useful.

Co-operation with the mining companies should be further established and formalized. The companies could for example provide safe locations for the dustfall jars.

6.7 Further research

A lot has been learned with the test run but a lot can still be done to further test the simple dust collector system. Static cling was a problem. The dust was removed from the collector with a brush and most of it was recovered. However, some dust was lost and it looked like the smallest particles were the ones most likely to be left behind. It is unclear which factor is the most significant but it is possible that the brush used was responsible for some of the static electricity generated. Reducing static electricity can be done with chemicals but this might compromise the sample so other solutions should be explored. Possible solutions include increasing the humidity of the air while collecting the sample and reducing the charge with ion emitting devices. Depending on what information we are after and if the laboratory is close enough the collector could be sealed and taken for the analyzes as such because the laboratory could use clean water to rinse the buckets and analyze the water. Reducing the static cling should not compromise the simplicity of the system.

The buckets on the test-run were made of plastic. Other materials such as glass, steel or ceramics should be tested. The large size of the bucket was thought to be essential so that the samples would be large enough. However this could be questioned and smaller collectors should be tested because a smaller collector could be sent directly to the laboratory after the sampling period reducing error I the field.

A form should be drawn up where the details of the collectors and samples could be written down. There were errors in logging during the test run and it is likely that there would also be such errors later. Some of these errors might be avoided if the pre determined details would be written down every time in a form like document. These forms could then be archived and they would form a diary of the monitoring activities.

Longer and shorter sampling periods should be tested even though it looks like the six week period collected a convenient amount of dust. In the event of a spoiled sample, with shorter sampling period, less information would be lost. Longer time would reduce the effort of collecting the samples and would lower the cost of analyzing the samples.

Even though on the test-run, the water that rained into the collectors vaporized, this was just lucky. The buckets were collected after the water had evaporated, as there was no preset sampling time. For future, a method of drying the sample, without losing any dust, should be developed, as this would eventually be necessary when the monitoring period is set. Filtering does not seem like a viable solution. Some kind of setup where the water could evaporate without more dust falling in would seem like the obvious solution.

For the test-run, the collectors were set on top of different structures. Testing should be conducted for a stand for the collector that would be permanently set on the ground. This way the collectors would be at the same height from the ground and setting the collector at the exact same location for the next sampling period would be easy. Some kind of fence pole with solid foundation could perhaps work.

On the test run, some of the collectors collected some debris such as leaves and twigs. A study should be conducted on how far from a tree the collector can stand and only collect an acceptable level of debris. Some method of reducing bird droppings should be devised. The collector in the standard SFS 3865 has a ring on top of the collector and the ring is larger than the diameter of the collector so a bird would be more likely to sit on the ring and its droppings would fall outside the collector. An alternative is some kind of spike construction aiming to make it uncomfortable to sit on the edge of the collector.

Other sampling grid models should be tested. Interesting information could be obtained by placing the collectors on a vector away from a major dust source, downwind, towards some residential area.

Rustenburg has three automatic air quality monitoring stations and after the practical details of the simple dust collecting system would have been worked out, the next logical step would be to compare the results with the calibrated moitoring stations. During the test run the stations were still in initialization phase so at this time it was not possible to get results that could be compared to the results of the dust collectors

In the future it should also be tested if the samples are radioactive. The mining waste is likely radioactive to some extent and the mining waste dams are a major source of airborne dust.

As discussed in the chapter 6.5, sampling of the soil should be done to ensure the safety of the people of Rustenburg. These soil samples could also tell us about the history of air quality in Rustenburg. Taking biological samples, such as blood or urine from people or animals or plant samples, should also be looked into as heavy metals accumulate readily in living organisms.

7 ADDITIONAL PROPOSALS FOR IMPROVING THE AIR QUALITY IN RUSTENBURG

7.1 Policy instruments

More resources within the municipality should be directed towards the air quality monitoring and improving of the quality. The possibility of establishing another engineering position should be looked into. The municipality also should go through different policy instruments in its use to see where it could favor models of behavior and operation that are pro clean air.

As many of the problems in the Rustenburg area are related to the mining industry they should be involved in the air quality monitoring and reducing air quality problems. The mines already monitor the air quality inside the mining shafts so some of the equipment and personnel could perhaps be used to monitor the outdoors air quality at their facilities. However there could be problems with trust, as the mines would then be monitoring themselves. Perhaps a better way would be to obligate the mining companies to participate in the costs of a public monitoring network. In Finland the law requires the companies to protect the quality of air and to monitor the quality. In the City of Lahti the companies who have been required to apply for an environmental permit because of their emissions to air, have made a contract with the city and the city monitors the air quality for them and the companies pay for this service (Autio 2009, 3).

The waste management system in Rustenburg is expected to develop heavily. This is important also because of the air quality, as a lot of the waste seems to be burned. The waste piles up into unofficial landfills and sometimes these landfills burn. Also people often make fires to warm up on empty lots by the roads. Local authorities said that it is against the regulations to make these fires and that a fine has been set. This is inefficient since the regulation is not enforced and many of the people could not afford the fine anyway. This degree is clearly not working. Issuing a regulation that is not enforced undermines the credibility of the system.

More resources should be directed towards the enforcement of this regulation and other means should be considered. One possible solution might be to construct fire pits, where the fire would not spread, to select locations and provide clean fuel for the fire.

7.2 Awareness on air quality issues

Awareness on air quality issues is low. BPDM Environmental and Waste management unit has a tradition of awareness raising work especially on climate change. This experience should be utilized and invested in. If people knew of air quality issues they could better protect themselves and the environment. Topics could include the harm caused by the common practice of burning domestic waste and how air pollution affects those with HIV/AIDS. A warning system should also be built to warn the citizens of high concentrations of air pollutants. In Lahti the authorities inform the general public on air quality with video screens at public locations, bulletins to the local media and Internet web pages (Autio 2009, 34).

People should be involved in the work. Two ideas perhaps worth looking into are the so-called smell diaries and door-to-door interviews. The idea behind the smell diaries is that residents of a certain area have diaries where they give marks for different aspects of air quality each day based on their sensory perception. For example, 5 when there is no smell and 1 when it is too uncomfortable to go outside. Other aspects besides the smell could be visibility and irritation to the lungs and eyes. The group of diary keepers could be selected randomly from an area of interest or by certain features like respiratory diseases. The markings of one person will not give any information on the air quality but with large groups of people the information is more reliable. The interviews would provide similar information but would be difficult to conduct often enough. However they would give more chances to communicate new ideas to the residents. These methods could engage people and activate them in air quality protection.

7.3 Traffic

Traffic is one of the most significant sources of air pollution. Resources should be directed towards reducing these emissions and improving the sustainability of different travel and transport options.

Traffic must be fluent but it also has other targets for it to be sustainable. For it to be as friendly to the environment as possible it must be limited to a bare minimum and it must put to use the best available technology. Logistics must be planned in such a way that they will represent the values of the society. Ecological values must be incorporated with the economical values. (Kuukka-Ruotsalainen 2001, s 14)

When planning more sustainable logistical solutions one must take into account not only the routes but also the loading of the trucks and the appropriate size of the trucks. The traffic in the inner city should be minimized. (Kuukka-Ruotsalainen 2001, s 14) The traffic also needs supporting facilities that may have an effect on air quality (Kuukka-Ruotsalainen 2001, s 18).

New technological advances have helped, and will also help in the future, to control the negative effect of traffic on air quality. These include alternative fuels including electricity, reducing the emissions of the vehicles, more energy efficient vehicles and intelligent traffic systems. (Kuukka-Ruotsalainen 2001, s 15) Optimizing traffic lights or robots as they are called in South African English, can help to smooth the flow of traffic and help reduce the number of stops and starts an average car has to make. (Kuukka-Ruotsalainen 2001, s 27)

The amount of exhaust gas emissions depends also on the driving habits, tires, road surfacing material, time of the year and weather and also on the engine type, size, settings and condition (Kuukka-Ruotsalainen 2001, s). Companies and citizens should be informed of this and courses for ecological driving should be organized. The municipality should set a good example and also challenge the mining companies to work on the efficiency of their cars and trucks.

The public transportation needs developing. The current system of minibuses is a good foundation. However, its usefulness is limited. There is also very little information available on routes and schedules. As the minibuses only start when they are full of passenger they are energy efficient. However the age of the cars might be a concern. A small number of real bus lines could improve the service and make it more flexible and more accessible to people outside the current system. Also a reliable and safe 24h taxi service would compliment the public transportation. The current taxis are more safari-rides than a proper taxi service. Passenger rail service is non-existent. It is possible that there are practical reasons why it is so. Perhaps the ore transporting trains block the tracks making it impossible to run passenger trains on schedule. However, if this is not the case, a long distance service between major cities should be developed.

7.4 Monitoring

Air pollution caused by e.g. traffic can be quantified with some accuracy using indicators (Kuukka-Ruotsalainen 2001, s 26). Indicators are tools used to reduce complexity and they show trends and can be used to define a direction or a target (Kuukka-Ruotsalainen 2001, s 28). Emissions can be estimated using traffic calculations or fuel usage and ton or person kilometrage can be calculated from driving logs. It is also possible to do interview studies on health effects. The most accurate numbers can be attained using air quality analyzers but this requires expensive equipment and personnel. (Kuukka-Ruotsalainen 2001, s 26)

Ideas on developing a monitoring system with indicators can be found on the European Union publication TERM (http://www.eea.europa.eu/publications/TEC18/technical_18_part_1.pdf).

Co-operation between different researchers and engineers should be emphasized. For example, air quality researchers are not so interested in nutrient fallout. However, limnologists are, and they collect rainwater samples. From these samples the pH value could be measured and some information on acidification could be obtained, so with co-operation both parties could gain more information.

Low cost methods of monitoring the air quality should be developed and taken into use. These methods provide results that are difficult to convert into concentrations in the atmosphere but they are rather inexpensive when it comes to initial investments (Liu, Lipták & Bouis 1997, 313). The simple dust collector system tested for this thesis should be further developed but it is not the only possibility. Other possible solutions include simple rainwater monitoring sampling and tests where visibility over a long distance would be evaluated. Metal plates could be left at the mercy of the weather to rust for the engineers to see how fast the metal plate would corrode and the speed of this reaction could give us information on the acidification (Liu, Lipták & Bouis 1997, 313). Petri dishes with some reactant could also be used. The reactant in the Petri dishes would react with the pollutant and the rate of that reaction would provide some information on the concentration of that pollutant. For example aqueous mixture of lead peroxide and a gum tragacanth gel can be used to gain information on sulfur dioxide levels (Liu, Lipták & Bouis 1997, 312-313).

In Finland bioindicators are used to monitor the air quality. In bioindicator studies the researchers choose an indicator plant. Usually this is based on some standard. Then some suitable and representative areas of nature are chosen. For example the researcher could count the lichen species occurring on the trunks of the trees at the height of 50-200 centimeters or they could rate the condition of a certain lichen species on a scale of one to five. Then this is repeated at another year in the same locations to determine if the lichens are doing better or worse. Lichen is used in this example because they are sensitive to air pollution. Also samples could be collected for laboratory analyzes. (Vallius 2005, 7-8, 22) Some literary research on bio-indicators in South African conditions should be done to find out if there are easy methods that could be adapted for Rustenburg.

8 SUMMARY

A test-run was done on the simple dust collecting system. Even though there were lots of practical issues mounting the error, a sample was gained and analyzed. Most of the error factors seem to be solvable and as such the test-run was succesful. Already, some kind of handle on heavy metal concentrations was gained.

The simple dust collecting system could have a future in air quality monitoring in a variety of places. This is true for underdeveloped parts of Southern Africa but also for cities like Rustenburg or Lahti. Even with the automatic monitoring stations this kind of simple dust collecting system could be used to increase the coverage of the monitoring network.

The citizens in Rustenburg are not aware of air quality issues. Awareness needs to be increased so people can start making decisions in their personal lives and also when voting in elections.

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