ASSESSMENT OF CADMIUM (Cd) AND LEAD (Pb) CONTAMINATION IN THE SOILS OF PRE-SCHOOL FACILITIES IN THE CITY OF CAPE TOWN

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BY

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DECLARATION

I, Mrs. Nozi 'Mabafokeng Nkoe, hereby declare that the contents of this thesis represent my own work, and that the thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

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ABSTRACT

In the last two centuries, the natural state of the environment has changed significantly due to anthropogenic activities. With an estimated half-life of 15 – 1100 years for cadmium in soils, the metal remains a threat to the ecosystem. In general, most soils contain <1 mg/kg, except those contaminated from discrete sources or developed on parent materials with very high cadmium contents. Anthropogenic lead in soil has several well recognized major sources, namely, lead based paint, mining and smelting activities, manures, sewage sludge usage in agriculture and contamination from vehicle exhausts. Since lead is a heavy metal, over time it will settle down and build up in soil. The main aim of this study was to determine the degree of cadmium and lead contamination of soil, in and around selected pre-school facilities in the City of Cape Town (CCT). A number of pre-school facilities, particularly those nearby heavy traffic, were selected in the CCT. Natural soil and sandpit soil samples were collected and analysed for cadmium and lead. Low soil moisture is normally associated with high pH, as found in the present study. High pH values are in turn associated with low toxicity of metal contaminants. Most urban populations rely heavily on motor vehicles and vehicle-related pollution has been an increasing concern in recent years (before 2006). Air pollution in the CCT is trapped by inversion layers. In this study it has been found that cadmium is not a significant contaminant in the soils of pre-school facilities in the CCT. The Cape Town administration area was found to be the most contaminated with this metal. This study showed that the Cape Town administration area also had the highest lead concentrations in pre-

school soils in the CCT. This can be attributed to the higher density of industry and traffic activities (study conducted pre-2006) in this area. There is a need for further research to determine the relationship between soil metal concentrations and blood metal levels, especially in children.

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Chapter 1

INTRODUCTION

1.1. BACKGROUND

Heavy metals occur naturally in soils, usually at relatively low concentrations, as a result of the weathering and other pedogenic processes acting on the rock fragments from which the soil develops (Alloway, 1995a). However, in the last two centuries, this natural state of the environment has changed significantly due to anthropogenic activities (CCT, 2003). The industrial power-generating and transport activities of today's society, involve chemical and physical transformations of matter of great diversity. Processes such as the combustion of fossil fuels with special additives, such as antiknock compounds in vehicle fuel, along with the extraction and smelting of metals and a variety of chemical industries, all result in the emission of small particles into the atmosphere. Most of these particles contain various metals in one chemical form or another and may have atmospheric residence time of up to one month. Such particles may be deposited not only close to the site of emission but can spread on a larger scale in the environment (Hughes et al., 1980).

Geochemical and botanical evidence shows that lead in ecosystems situated away from industries and roads are deposited to a greater extent in the present era than was the case two hundred years ago. Similar results were found for copper, zinc, nickel and cadmium (Hughes et al., 1980).

A considerable number of metals or metalloids are potentially toxic to humans. The toxic effects of heavy metals, such as lead and cadmium, have been known since the period of Classical Greece (Settle and Patterson, 1980).

1.2. SOURCES OF METAL CONTAMINANTS

* *Mining*: Mining may release metals into soil and air that may exceed toxic concentrations due to natural weathering. Pollution of the soil is usually restricted to the immediate area and around spoil tips where metal concentrations are too low to be extracted economically but are high enough to exert toxic effects on plants and animals. Transport of metals away from the immediate source may take place via wind-blown particles or may be dissolved in acidic groundwater (Khan & Frankland, 1983; Hopkin, 1989; Gummow et al., 1991).

* *Smelting*: Metals contained in mined ores must be purified by a smelting process. An example is the smelting unit of the copper mine in Phalaborwa. This facility causes ellevated levels of copper in grass surrounding the area (Gummow et al., 1991). Secondary smelting can also be used to recover metals from scrap. In modern smelting works, efforts have been made to reduce the amount of metal pollutants released into the atmosphere. Waste gasses are passed through fine filters and treated with electrostatic precipitators, to remove most metal-containing particles from the gasses before they are released into the atmosphere. Unfortunately, even the most modern equipment working at removal efficiencies approaching 100%, are unable to completely remove metals from these gasses (Hopkin, 1989). At

the Avonmouth smelting plant in England 10 0000 tonnes of zinc, 40 000 tonnes of lead and 300 tonnes of cadmium are produced annually, while some 50 tonnes of zinc, 30 tonnes of lead and 3 tonnes of cadmium are released into the atmosphere each year (Harrison & Williams, 1983; Coy, 1984). Soil contaminated by this plant has been reported to be 25km away from the actual activity (Martin & Coughtrey, 1982; Hopkin, et al., 1986).

* *Combustion of fossil fuels*: Lead is added to petroleum because it is a cheap way of raising the octane level of gasoline. When the fuel undergoes combustion, the added lead is expelled along with the carbon dioxide, water, as well as the unreacted parts of the fuel. Thus, lead molecules are released into the atmosphere by car exhausts, as fine particles. The smaller molecules are lighter and therefore able to travel greater distances than the bigger molecules, which generally settle near to the point of expulsion. This means that the adverse effects of lead can be observed over large distances and are not only centred on the major roadways, which is where most cases of lead-based symptoms are found (Calow, 1998).

* *Agriculture and horticulture*: One of the major sources of metal pollution in agriculture is the use of pesticides. Pesticides, containing arsenic, tin and mercury were often used in the past in the agricultural sector. These metals persist for a long period of time in the environment. This made them ideal for preventing infestations of fungi and invertebrate pests, like molluscs (Godan, 1983). In South Africa, metal-containing fungicides are used extensively on vineyards to protect crops from a range of fungi. These metals may have

negative effects on non-target organisms in the environment (Vermeulen et al. 2001; Eijsackers et al. 2005; Snyman et al. 2005).

* *Other*: Metals are also used in the construction industry. Lead piping is now used on a small scale as a result of concerns and issues around lead slowly dissolving in soft water and posing a risk to public health. Metals can also be used in plastic formulations, as stabilizers, plasticizers, colorants, antioxidants and fire retardants (Sorensen et al., 1997).

1.3. CADMIUM

1.3.1. Cadmium in the environment

Cadmium is a relatively rare metal belonging to group IIB in the Periodic Table of elements making it the 67^{th} element in order of elemental abundance (Alloway, 1995b). Cadmium is a silver–white, blue–tinged, lustrous metal that melts at 321 °C and boils at 765 °C (Eisler, 1985). It is not essential for biological function and it is highly toxic to plants and animals (Alloway, 1995b). Cadmium is estimated to occur at an average concentration of 0.1 mg/kg in the earth's crust (Bowen, 1979). It is also closely associated with zinc in its geochemistry, as both elements have similar structures and electro-negativities (Rose et al., 1979; World Resource Institute, 1992). It is estimated that globally, anthropogenic activities add roughly 3 to 10 times more cadmium (3,100 to 12,000 t/yr) into the atmosphere than natural sources (Yeast and Bewers, 1987; Nriagu and Pacyna, 1988).

Cadmium is widely used in industries as a component of many alloys, which in turn is used in the manufacturing of electroplating and electro-conductors. It is usually emitted in industrial fumes and in some cases it might contaminate the water supply in the industrial areas (Robertson, 2000). Cadmium concentrations in the air normally range from 1 to 50 ng/m^3, depending on the distance from emitting sources. The deposition of aerosol particles from urban or industrial air pollution also affects the soil in most industrial regions. Cadmium from this source can also be absorbed directly into plants through foliage (Alloway, 1995b).

Even before cadmium was used commercially, contamination occurred from a wide range of materials containing cadmium impurities. Phosphatic fertilizers are an important example of this: their cadmium contents vary, but their continual use has led to significant increases in the cadmium contents of many agricultural soils (Alloway, 1995b).

For western countries the relative contributions of cadmium from the major anthropogenic sources have been estimated to be: phosphatic fertilisers 54-58%, atmospheric deposition 39-41% and sewage sludge 2-5% (Davies, 1995).

Cadmium is a hazardous metal that may have toxic effects on crop production, human health (Wagner, 1993; Grant et al., 1998) as well as in animals (Odendaal & Reinecke, 1999). Although not an essential mineral nutrient, cadmium is very easily taken up by plant roots and accumulates in plants at concentrations that place higher trophic levels in the food chain at risk. Accumulation of cadmium in plant tissues can also be toxic at the cellular level, limiting growth and development. Prevention of cadmium uptake by plant roots is, therefore, an important strategy to minimize the adverse biological effects of cadmium (McLaughlin et al., 1999).

A close relationship between cadmium and zinc exists. Nan et al. (2002) showed that increases in cadmium application enhanced zinc concentrations in wheat and *vice versa*. Similar observations were also made by Smilde and Luit (1992). Very recently, Wu and Zhang (2002) found that increasing zinc application could alleviate cadmium toxicity stress in barley plants by improving growth and reducing membrane damage.

1.3.2. Cadmium in soil

The most common sources of cadmium in soils are Pb-Zn mining, smelting and heavy applications of sewage sludge over many years. The disposal of wastes containing cadmium, such as the incineration of plastic containers, and batteries and burning of fossil fuels also pose a risk to the environment (Hutton, 1982). Since concentrations of this metal in uncontaminated soils are usually low, sources of contamination and the behaviour of cadmium in the contaminated soils are the main concern. With an estimated half-life of 15 – 1100 years for cadmium in soils, the metal remains a threat to the ecosystem (Kabata and Pendias, 1992).

Soils derived from igneous rocks would have cadmium contents of 0.1-0.3 mg/kg, those in metamorphic rocks would contain 0.1-1.0 mg/kg cadmium and those derived from sedimentary rocks 0.3-11 mg/kg of cadmium. In general, most soils contain <1 mg/kg, except those contaminated from discrete sources or developed on parent materials with very high cadmium contents, such as black shales. The latter soils can have significantly elevated total cadmium concentrations even in the absence of marked contamination from anthropogenic sources (Alloway, 1995b).

1.3.3. Human exposure to cadmium

There are two main routes of exposure to general human population, namely, ingestion and inhalation (Trzcinka-Ochocka et al., 2004). Cadmium is known to be deposited and concentrated in the leaves of tobacco plants. As a result, smokers are more exposed to cadmium than non-smokers (Friberg, 1974; Willers et al., 1992).

A study suggested that cadmium accumulation in the human body is a function of age (Piscator and Lind, 1972). There is a 200-fold increase in the cadmium content of the body in the first 3 years of life (Henke et al., 1970).

Food is the main route by which cadmium enters the body. The highly labile behaviour of cadmium in soils which are contaminated with high concentrations of this metal, is an important factor in the accumulation of cadmium through the human diet (Alloway, 1995b).

1.3.4. Health effects of cadmium in humans

In the general population cadmium accumulates gradually in the human body during life and has the ability to cause renal damage and impairment of other organs (Nogawa, 1981; Nomiyama, 1986; Alloway, 1995b). Cadmium also accumulates in the liver and reproductive organs (Vezirogiu, 1990). DNA damage may also occur due to excessive exposure to cadmium (USEPA, 1985). Cadmium depresses growth and reduces protein and fat digestion, and this may explain why young children who are exposed to cadmium are overweight (Vezirogiu, 1990). Cadmium exposure in childhood may have a stronger impact on the renal function, particularly tubular re-absorption, compared to the case for mature persons (Trzcinka-Ochocka et al., 2004).

1.4. LEAD

1.4.1. Lead in the environment

Lead, a metal known since antiquity, occurs ubiquitously in nature. So far the greatest input of lead into the environment, however, has been from human activity (Southwood, 1983). Lead is a member of Group IVB of the Periodic Table of the elements. Elemental lead is a dense (11.3 pg/cm^3) blue-grey metal which smelts at 327 °C and boils at 1744 °C (Richardson and Gangolli, 1994).

Lead was one of the first heavy metals to have been smelted, and lead ores were mined extensively throughout ancient times, mainly for their silver content. From the mining, smelting, and refining of lead, and from the use and production of lead-based products, lead is emitted into the environment and therefore deposited in soil, dust, food and water. Studies have shown how, over time, lead levels have risen over the whole of the earth's surface, especially since the industrial revolution and the addition of lead additives to petrol (Murozumi et al., 1969). The positive association between the degree of urbanisation and the raised blood lead levels is now well established (Trepka et al., 1997; Murgueytio et al., 1998; Paoliello et al., 2002).

1.4.2. Lead in soil

Anthropogenic lead in soil has several well recognized major sources, namely, lead based paint, mining and smelting activities, manures, sewage sludge usage in agriculture and contamination from vehicle exhausts (Davies, 1995). Lead and its compounds tend to accumulate in soils and sediments where, due to their low solubility and relative freedom from microbial degradation, they will remain bio-available far into the future. Lead is neither an essential nor a beneficial element for plants and animals. It is known, however, for being toxic to mammals and there are fears that human body burdens below those at which clinical symptoms of lead toxicity appear, may cause mental impairment in young children. Many investigations have been carried out on lead in environmental materials, including soil, over the last twenty years and we now have detailed understanding of its environmental chemistry and ecological and health significance. Lead is present in uncontaminated soils at concentrations <20 mg/kg but much higher concentrations have been reported in many areas as a consequence of anthropogenic emissions, often over many years (Davies, 1995).

1.4.3. Human exposure to lead

There are various routes of exposure of humans to lead:

* *Food*: Lead may contaminate food but the contaminant cannot be seen, tasted nor smelled. Canned food was a major source of lead in the diets of the Americans until lead linings in cans was phased out during the 1980's (ATSDR, 1999).

* *Water*: In potable water, lead occurs through leaching from lead-containing pipes, faucets and solder, which can be found in plumbing of older buildings. The acceleration of leaching at times is due to acidity, hot water or stagnation for extended periods. Lead occurs for an estimated 3.8 million children whose drinking water lead level has been estimated at a greater than 20 mcg/dl (ATSDR, 1999).

* *Air, soil and dust*: Industrial and mining activities may release lead and lead compounds into air and the soil. People can be affected by lead through ingestion or through inhalation of lead contaminated dust and soil. Abandoned lead mines and smelters may be a threat to public health (ATSDR, 1999). Workers bringing lead-rich dust into their homes from their working places via their clothes, hair and shoes may put children engaging in hand-to-mouth activities at a high risk of lead exposure (Chiaradia et al., 1997).

* *Hobbies and activities*: Cosmetics containing lead, such as surma and kohl, mostly used in some Asian countries, is one route of exposure to lead.

Smoking cigarettes or breathing second-hand smoke also increases exposure, as tobacco smoke contains small amounts of lead (ATSDR, 1999).

1.4.4. Health effects of lead in humans

Lead has long been known to be highly toxic to organisms, including humans. The impacts on humans, especially children, caused by lead are well documented. Soil and dust are important sources of lead for young children and lead in blood can be related directly to lead in soil (Davies, 1995). Lead was also shown to be a contributing factor, concerning neurological impairment and negative effects on higher cognitive functions. A report showed that children within the age group of 2-3, may be most at risk for exposure to lead-contaminated soil (Mahaffey et al., 1982).

There is no known biological function for lead and any lead absorbed by humans is toxic (Ember, 1980). Once in the bloodstream, lead is primarily distributed among the three compartments: blood, soft tissue and mineralising tissue. The absorption and biological fate of lead, once it enters the human body, depend on a variety of factors. The most essential factors are the physiological characteristics of the exposed person, including nutritional status, health and age. Children can absorb up to 70% of ingested lead, while adults typically absorb up to 20% by inhalation (ATSDR, 2003).

Lead poisoning is essentially chronic, as the accumulation of a significant body burden occurs over a period of time. At low exposure levels it may take months or even years before clinical symptoms appear and certain biochemical effects and neuropsychological effects may be present long before clinical symptoms occur. At higher levels of exposure, accumulation to toxic levels may occur within weeks and damage to tissues is caused (Grandjean & Fischbein, 1980).

Effects at low levels of lead absorption (below 40 μgPb/dl blood) include intellectual impairment, behaviour disorders and certain biochemical disorders (Needleman et al., 1979). It has been shown that exposure to lead causes high blood pressure and a heightened risk of cardiovascular disease (Pirkle et al., 1985). At very high blood lead concentration (above 80 μgPb/dl blood) it can cause acute brain damage, leading to encephalopathy and may eventually result in death (Wessel, 1977).

Researchers found that children are at higher risk of lead poisoning compared with adults, and there is sound evidence of biochemical, haematological and neuropsychological effects in children. Results from studies conducted around the world have shown a relationship between lead exposure during fetal development and deficits in neurobehavioral performance (von Schirnding et al., 2001). Marecek et al. (1983), Needleman (1983) and Fulton et al. (1987) concluded that lead exposure had a negative effect on the behavior and development of children.

There have been no national blood lead surveys carried out in South Africa, but studies on lead exposure among children in the Cape Town area indicate that children in urban areas are at risk. School-aged and pre-school children in the Cape Town area have been found to have median blood levels around 16μg/dl. In 1984, 8% of children living in the Woodstock suburb of Cape Town were found to have blood levels greater than or equal to 25 μg/dl, the previous USA action level. Traffic was found to influence blood lead levels of children attending schools close to heavily travelled roads. At such schools in Woodstock blood levels averaged between 18 and 21 μg/dl. This was at a time when the maximum permissible lead level in petrol was 0.836 g/l. Also, children living in old, deteriorating houses in Woodstock were found to be at risk of increased lead exposure (von Schirnding et al., 2001). Studies done by Paoliello et al. (2002) and Murgueytio et al. (1998) also indicated that children living in urban areas are more at risk especially in residential areas close to industries.

1.5. STATEMENT OF RESEARCH PROBLEM:

When metals are released into the atmosphere they have a long half-life in the environment. In the past years traffic and the industrial activities in the City of Cape Town expanded to such an extent that there is a possibility that the environment in the CCT has been put under increased toxic stress due to increased emission of heavy metals, such as lead and cadmium (CMC, 1998).

Cadmium is known to cause damage to organs, especially the kidneys (Alloway, 1995b). Children are also more sensitive to cadmium exposure than adults, making them more at risk (Trzcinka-Ochocka et al., 2004).

Pre-school children and fetuses are usually the most sensitive group when exposed to lead (ATSDR, 1988). The efficiency of lead absorption from the gastrointestinal tract is greater in children than in adults. Young children are more likely to play in dirt and then put their hands and other objects in their mouths, increasing the opportunity for soil and metal ingestion (pica tendency). Nutritional deficiencies of iron or calcium, which are prevalent in children, may facilitate lead absorption and exacerbate the toxic effects of lead (ATSDR, 2003).

Many pre-school facilities in the City of Cape Town are situated in close proximity to major roads. Most of these schools have sandpits on the playgrounds. However, it is not known to what extent these sandpits and the natural soil on the premises of these schools are contaminated with lead and cadmium.

1.6. AIM OF THE STUDY

1.6.1. General aim:

To determine the distribution and degree of cadmium and lead contamination of soil, in and around selected pre-school facilities in the City of Cape Town.

1.6.2. Specific objectives:

- To determine cadmium and lead concentrations in soils in and around selected pre-school facilities.
- To compare concentrations of cadmium and lead of the different sampling sites[1].
- To compare concentrations of cadmium and lead of the different sampling areas[2].

[1]The specific sites where the samples were collected.
[2]The administration areas in the City of Cape Town.

Chapter 2

MATERIALS AND METHODS

2.1. STUDY AREA

A number of pre-school facilities, particularly those nearby heavy traffic, were selected in the CCT. These sampling sites are listed in Table 1, and the study area is shown in Figure 1.

Table 1: Sampling sites in the City of Cape Town.

Sampling areas	Sampling sites
Blaauwberg	Atlantis
	Table View
	Milnerton
Cape Town	Pinelands
	Mowbray
	Gugulethu
	Mitchells Plain
	Phillipi
	Kloofnek
Helderberg	Somerset-West1
	Somerset-West2
	Strand1
	Strand2
	Gordons Bay
Oostenberg	Kraaifontein
	Brackenfell 1
	Brackenfell 2
	Kuilsriver
	Blue Downs
South Peninsula	Wynberg
	Muizenberg
	Hout Bay
Tygerberg	Durbanville
	Bellville
	Ravensmead
	Bonteheuwel
	Delft

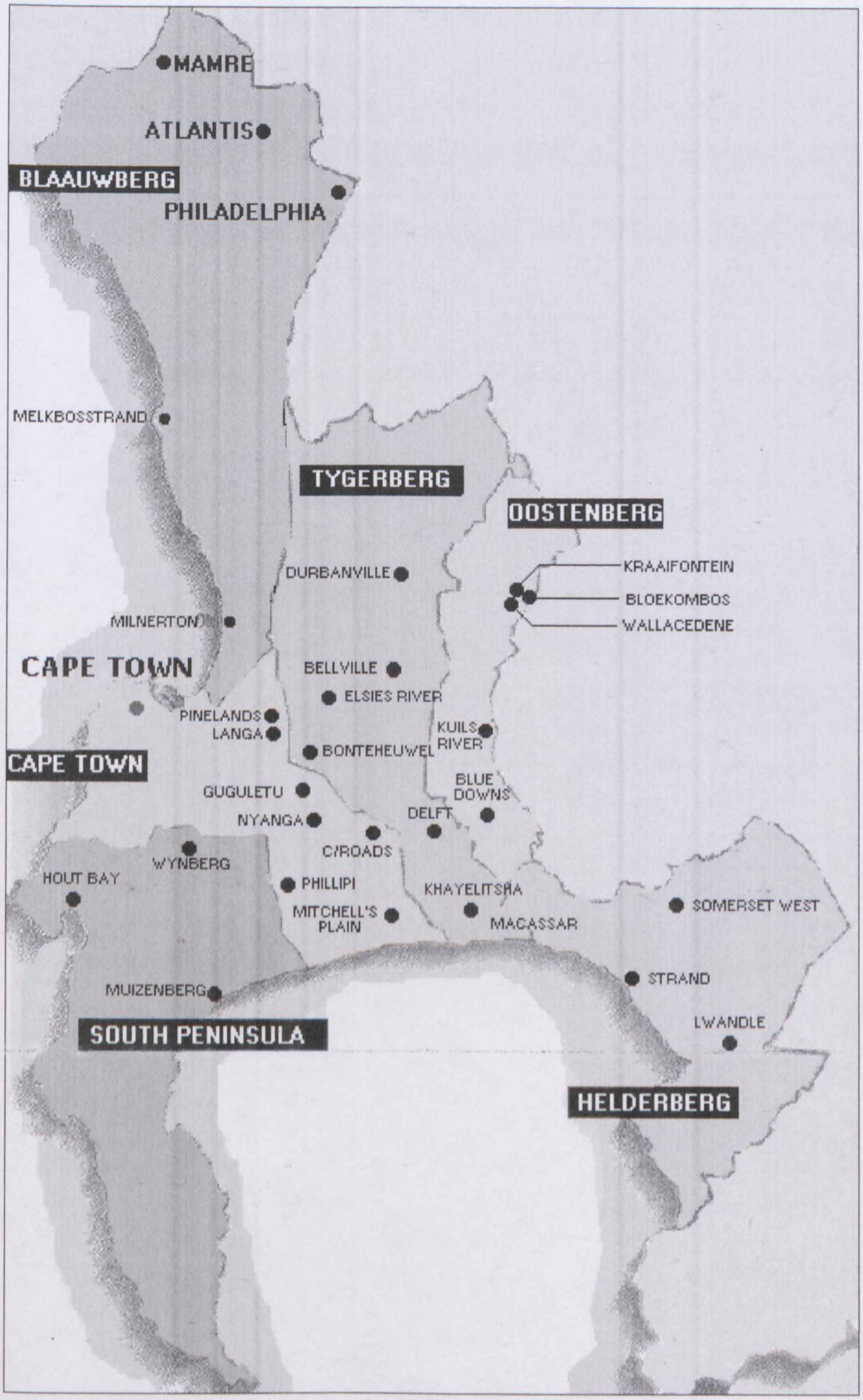

Figure 1: Map of study area. (Source: CMC, 1998)

2.2. COLLECTION AND PREPARATION OF SOIL SAMPLES

Natural and sandpit soil samples were collected (topsoil 0-3 cm depth) from different locations selected in the CCT and those soil samples were put into 50ml plastic vials for storage. One sample containing soil from various spots at a particular site was collected. The collection of samples was a once off event. Samples were taken from the sandpits where children normally play at each pre-school facility, as well as from the natural soil occurring at that site. All samples were accurately labeled. Two parameters were measured immediately after collection of the samples, namely, soil pH and soil moisture. The HANNA pH 211, microprocessor pH meter was used to measure pH values, and a Precisa soil moisture meter was used to measure the soil moisture of the samples.

For metal analysis samples were dried for 48 hours at 60°C. The dried samples were sieved through a 0.5mm sieve to obtain a homogenous sample, and then weighed on a Precisa balance. Five sub samples per site of approximately 0.3g each were prepared for digestion.

2.3. ACID DIGESTION OF SOIL SAMPLES

After sieving and weighing, each sample was put into a Pyrex glass tube and 10 ml of 55% nitric acid was added. The portion of the soil metal content that is not released by nitric acid is very unreactive and from an environmental perspective, may have a very low potential impact (Sauvé, 2002). Samples were digested in a Grant dry block heater at 40°C for an hour, after which the temperature was raised to 120°C for three hours.

The samples were then allowed to cool. A blank digestion was also performed together with each set of digestions in order to identify any contamination during the digestion process.

2.4. FILTRATION OF THE DIGESTED SOIL SAMPLES

The solutions were filtered through Whatman No.6 filter paper, into 20 ml volumetric flasks and each sample was diluted to 20 ml with distilled water. These filtered solutions were micro-filtered into 30 ml plastic vials, using Whatman Cellulose Nitrate Membrane filters (0.45 μm) and syringes. Plastic containers were used since metals do not adsorb to this type of surface (Ebdon, 1982). Labeled sample solutions were stored in a refrigerator at 8 °C until they were analyzed for metals.

2.5. METAL ANALYSIS

The lead and cadmium concentrations of the samples were determined by using an ICP-AES (Inductively Coupled Plasma - Atomic Emission Spectrophotometer). These metal analyses were done by the Department of Chemistry at the University of Stellenbosch.

In order to determine the concentrations of lead and cadmium in each sample, this formula was used:

$$\frac{\text{(Reading from ICP minus Blank) X 20 ml dilution}}{\text{mass of soil sample (g)}}$$

Metal concentrations were expressed as mg per kg (mg/kg).

2.6. STATISTICAL ANALYSIS

Descriptive statistics and graphics were done with MS Excel. The Sigmastat 3.1 statistical package was used for statistical analysis.

Statistical comparisons were made between:

a) Sandpit soil samples from the same sampling areas.

b) Natural soil samples from the same sampling areas.

c) Sandpit and natural soil samples from same sampling area.

d) Sandpit samples from different sampling areas.

e) Natural soil samples from different sampling areas.

Statistical comparisons were done by means of the Rank Sum Test and the Analysis of Variance on Ranks.

Chapter 3

RESULTS

3.1. SOIL pH AND MOISTURE

The pH values measured in natural and sandpit soil at the sampling sites in the City of Cape Town are shown in Table 2. Most of the natural soil was found to have relatively high pH (>7.5).

The soil moisture values measured in natural and sandpit soil at the sampling sites in the City of Cape Town are shown in Table 3. Soil moisture was found to be very low in natural soils (7% and below) except for Brackenfell 2 (11.41%), Somerset-West 2 (12.86%), Kuilsriver (17.64%), Delft (23.40%) and Durbanville (38.09%). Sandpit soils were very dry with the maximum soil moisture of 15.42% at Milnerton and the rest all under 7%.

Table 2: pH values of soil from different sampling sites.

Sampling Site	Soil pH	
	Natural soil	Sandpit soil
Blaauwberg		
Atlantis	8.30	7.81
Table View	7.97	8.95
Milnerton	8.18	8.07
Cape Town		
Pinelands	7.77	8.52
Mowbray	8.76	8.32
Gugulethu	8.02	No sandpit
Mitchells Plain	8.81	9.30
Phillipi	8.27	8.70
Kloofnek	7.98	9.02
Helderberg		
Somerset-West 1	8.45	9.05
Somerset-West 2	7.60	7.97
Strand 1	8.81	8.62
Strand 2	8.20	7.95
Gordons Bay	8.97	No sandpit
Oostenberg		
Kraaifontein	7.04	9.33
Brackenfell 1	8.88	8.67
Brackenfell 2	9.03	8.82
Kuilsriver	8.41	8.21
Blue Downs	9.47	9.23
South Peninsula		
Wynberg	8.60	8.89
Muizenberg	8.44	8.64
Hout Bay	8.70	9.09
Tygerberg		
Durbanville	8.70	9.49
Bellville	7.75	8.19
Ravensmead	9.68	9.37
Bonteheuwel	8.87	No sandpit
Delft	9.23	9.34

Table 3: Moisture (%) of soil from different sampling sites.

Sampling Site	Soil moisture (%)	
	Natural soil	**Sandpit soil**
Blaauwberg		
Atlantis	1.04	0.81
Table View	1.01	4.02
Milnerton	1.17	15.42
Cape Town		
Pinelands	2.33	0.96
Mowbray	1.16	0.92
Gugulethu	0.99	No sandpit
Mitchells Plain	0.65	0.68
Phillipi	0.92	0.75
Kloofnek	1.91	0.55
Helderberg		
Somerset-West 1	2.26	1.09
Somerset-West 2	12.86	1.04
Strand 1	1.12	0.92
Strand 2	1.39	0.64
Gordons Bay	1.34	No sandpit
Oostenberg		
Kraaifontein	6.019	1.41
Brackenfell 1	5.86	1.78
Brackenfell 2	11.41	1.98
Kuilsriver	17.64	5.86
Blue Downs	1.04	0.66
South Peninsula		
Wynberg	1.72	0.69
Muizenberg	0.85	0.82
Hout Bay	0.61	0.90
Tygerberg		
Durbanville	38.09	1.56
Bellville	6.61	6.29
Ravensmead	6.13	0.66
Bonteheuwel	3.33	No sandpit
Delft	23.40	1.76

3.2. CADMIUM CONCENTRATIONS

Table 4: Mean cadmium concentrations (±SD) (mg/kg) in natural and sandpit soil at sampling sites in the City of Cape Town. (n=5) ND= not detected.

Sampling sites	**Cadmium concentrations (mg/kg)**	
	Natural soil	**Sandpit soil**
Blaauwberg		
Atlantis	0.038 (±0.084)	ND
Table View	ND	ND
Milnerton	ND	ND
Cape Town		
Pinelands	0.352 (±0.359)	ND
Mowbray	1.049 (±1.943)	ND
Gugulethu	0.149 (±0.083)	No sandpit
Mitchells Plain	ND	ND
Phillipi	ND	0.016 (±0.022)
Kloofnek	2.150 (±0.150)	ND
Helderberg		
Somerset-West 1	0.037 (±0.003)	ND
Somerset-West 2	0.196 (±0.009)	ND
Strand 1	0.026 (±0.024)	ND
Strand 2	0.201 (±0.014)	ND
Gordons Bay	0.023 (±0.021)	No sandpit
Oostenberg		
Kraaifontein	1.744 (±3.607)	0.034 (±0.019)
Brackenfell 1	0.101 (±0.106)	0.148 (±0.311)
Brackenfell 2	0.034 (±0.019)	0.111 (±0.098)
Kuilsriver	0.282 (±0.090)	0.021 (±0.019)
Blue Downs	0.052 (±0.037)	0.035 (±0.001)
South Peninsula		
Wynberg	ND	0.097 (±0.093)
Muizenberg	ND	ND
Hout Bay	0.388 (±0.638)	ND
Tygerberg		
Durbanville	ND	ND
Bellville	ND	ND
Ravensmead	ND	ND
Bonteheuwel	ND	No sandpit
Delft	ND	ND

3.2.1. Comparisons of cadmium concentrations in the natural soils

There were no significant differences in cadmium concentrations in the natural soil samples from any of the sampling sites in Blaauwberg ($p>0.05$) (Table 4; Figure 2). Cadmium was only detected in the Atlantis natural soil samples (0.038 ±0.084 mg/kg).

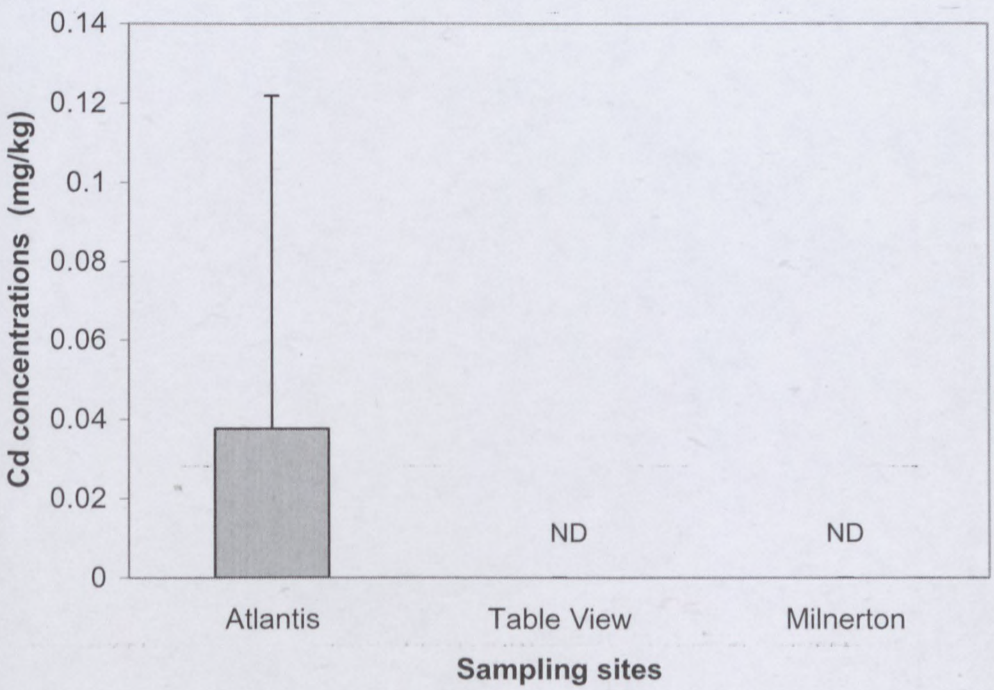

Figure 2: Mean cadmium concentrations (±SD) (mg/kg) in the natural soil samples of sampling sites in Blaauwberg. (n=5) ND = not detected.

The cadmium concentrations in the natural soil in the Cape Town area are shown in Table 4 and illustrated in Figure 3. The cadmium concentrations found at Pinelands were statistically significantly higher than those found at Mitchells Plain and Phillipi ($p<0.05$), but significantly lower than those measured at Kloofnek ($p<0.05$). The cadmium concentrations found at Mowbray were statistically significantly higher than those found at Mitchells Plain ($p<0.05$) and Phillipi, where no cadmium were detected. Gugulethu's cadmium concentrations were statistically significantly higher than those of Mitchells Plain and Phillipi ($p<0.05$) but lower than those measured at Kloofnek ($p<0.05$). The cadmium concentrations found at Kloofnek (2.150 ±0.150 mg/kg) were statistically significantly higher than all other sampling sites ($p<0.05$), apart from Mowbray ($p>0.05$), where the variation in cadmium concentrations were quite large.

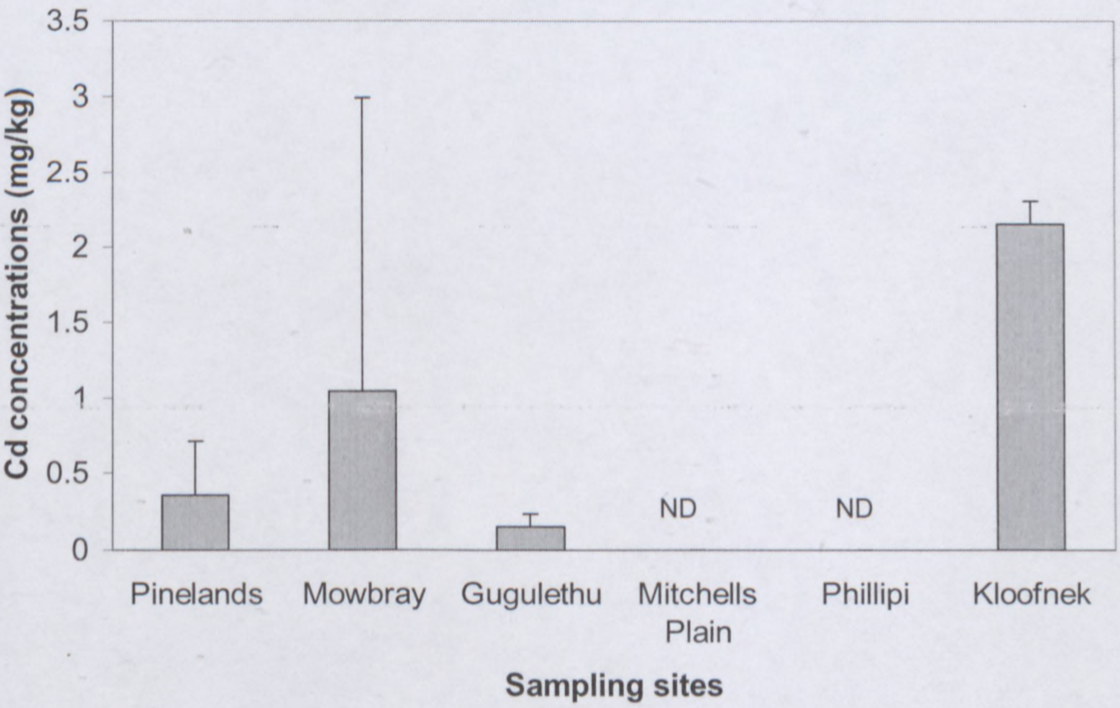

Figure 3: Mean cadmium concentrations (±SD) (mg/kg) in the natural soil samples of sampling sites in Cape Town. (n=5) ND = not detected.

The cadmium concentrations in the natural soil in the Helderberg area are shown in Table 4 and Figure 4. The cadmium concentrations found at Somerset-West 1 were statistically significantly lower than those of Somerset-West 2 and Strand 2 ($p<0.05$) but did not differ from Strand 1 and Gordons Bay ($p>0.05$). Somerset-West 2 cadmium concentrations (0.196 ±0.009 mg/kg)) were statistically significantly higher than all other sites ($p<0.05$), apart from Strand 2 (0.201 ±0.014 mg/kg) ($p>0.05$). The cadmium concentrations found at Strand 1 were statistically significantly lower than those of Somerset-West 2 and Strand 2 ($p<0.05$), but there were no significant differences from Somerset-West 1 and Gordons Bay ($p>0.05$). The cadmium concentrations found at Strand 2 were statistically significantly higher than those found at Gordons Bay ($p<0.05$).

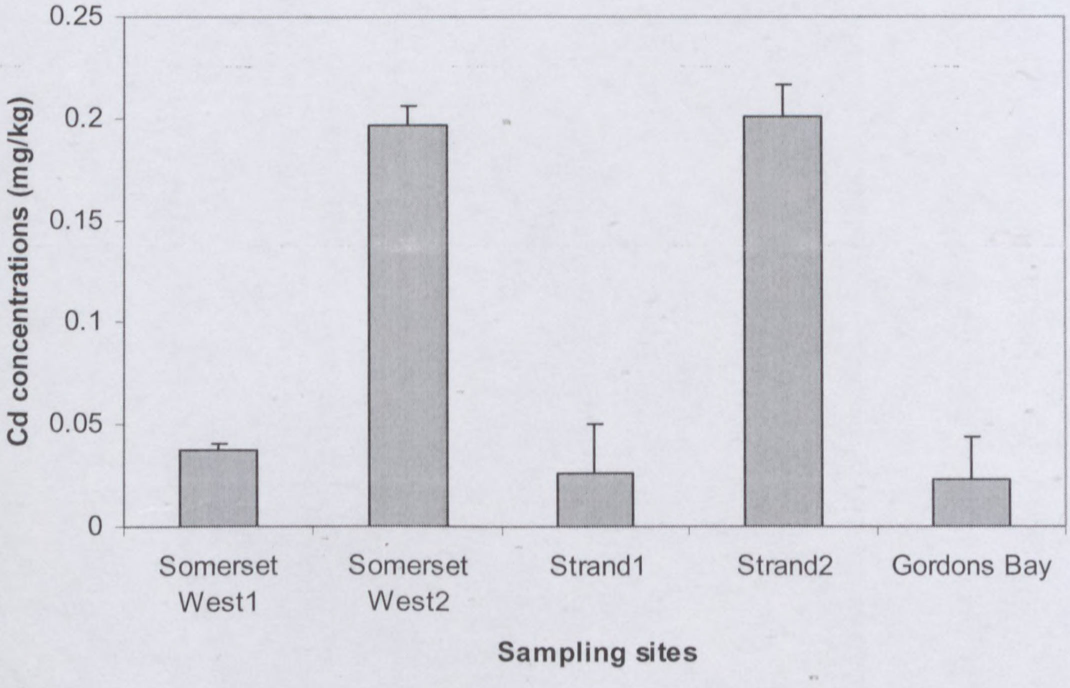

Figure 4: Mean cadmium concentrations (±SD (mg/kg) in the natural soil samples of sampling sites in Helderberg. (n=5)

The cadmium concentrations in the natural soil in the Oostenberg area are shown in Table 4 and illustrated in Figure 5. Cadmium concentrations found at Kraaifontein (1.744 ±3.607 mg/kg) were statistically significantly higher than those of Blue Downs ($p<0.05$), but were not significantly different from those measured at Brackenfell 1, Brackenfell 2 and Kuilsriver ($p>0.05$). No significant differences in cadmium concentrations were found at Brackenfell 1 compared to those found at the other sampling sites of Oostenberg ($p>0.05$). The cadmium concentrations found at Brackenfell 2 were statistically significantly lower than those of Kuilsriver ($p<0.05$). The cadmium concentrations found at Kuilsriver were also found to be statistically significantly higher than those of Blue Downs ($p<0.05$).

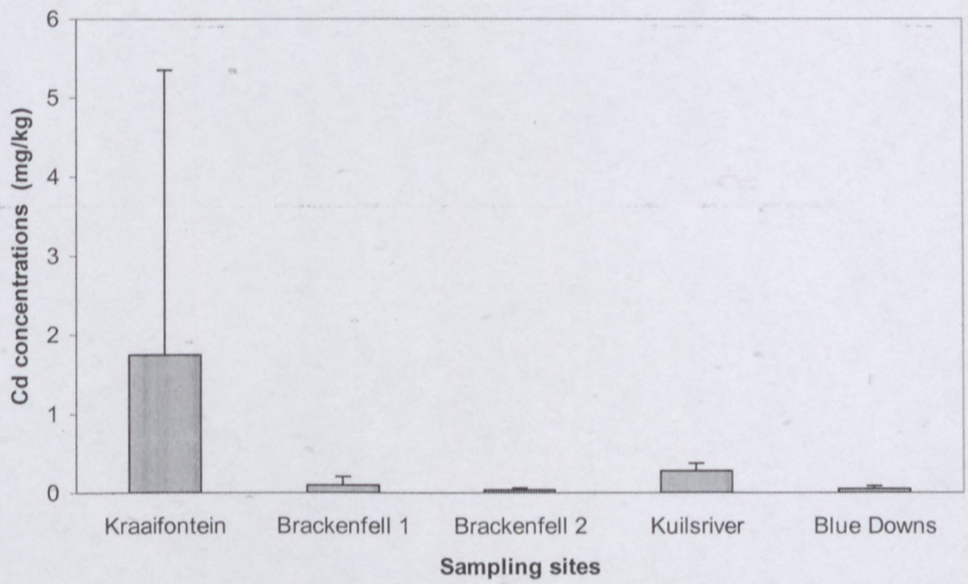

Figure 5: Mean cadmium concentrations (±SD) (mg/kg) in the natural soil samples of sampling sites in Oostenberg. (n=5)

There were no significant differences in cadmium concentrations in the natural soil samples from any of the sampling sites in the South Peninsula area ($p>0.05$) (Table 4; Figure 6). Cadmium was only detected at the Hout Bay site (0.388 ±0.638 mg/kg).

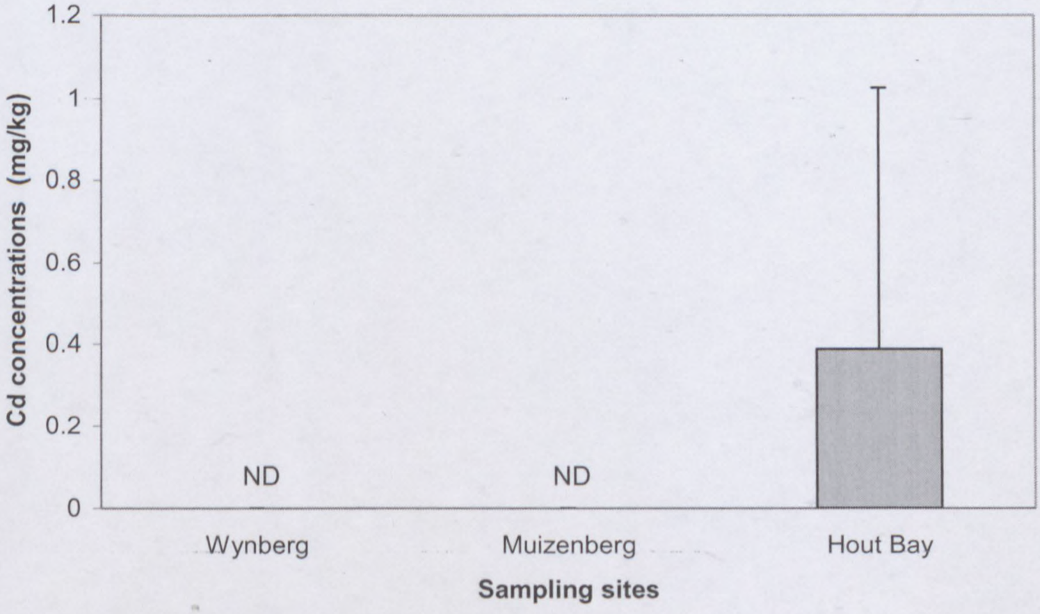

Figure 6: Mean cadmium concentrations (±SD) (mg/kg) in the natural soil samples of sampling sites in South Peninsula. (n=5) ND = not detected.

No cadmium was detected in the natural soil samples at any of the sites in Tygerberg (Table 4).

3.2.2. Comparisons of cadmium concentrations in the sandpit soils

No cadmium was detected in sandpit soil at any of the sampling sites in the administration areas of Blaauwberg, Helderberg and Tygerberg (Table 4).

There were no significant differences in cadmium concentrations in the sandpit soil samples between any of the sampling sites in the Cape Town area ($p>0.05$) (Table 4; Figure 7). Cadmium was only detected at the Phillipi site (0.016 ±0.022 mg/kg). The Gugulethu site did not have a sandpit.

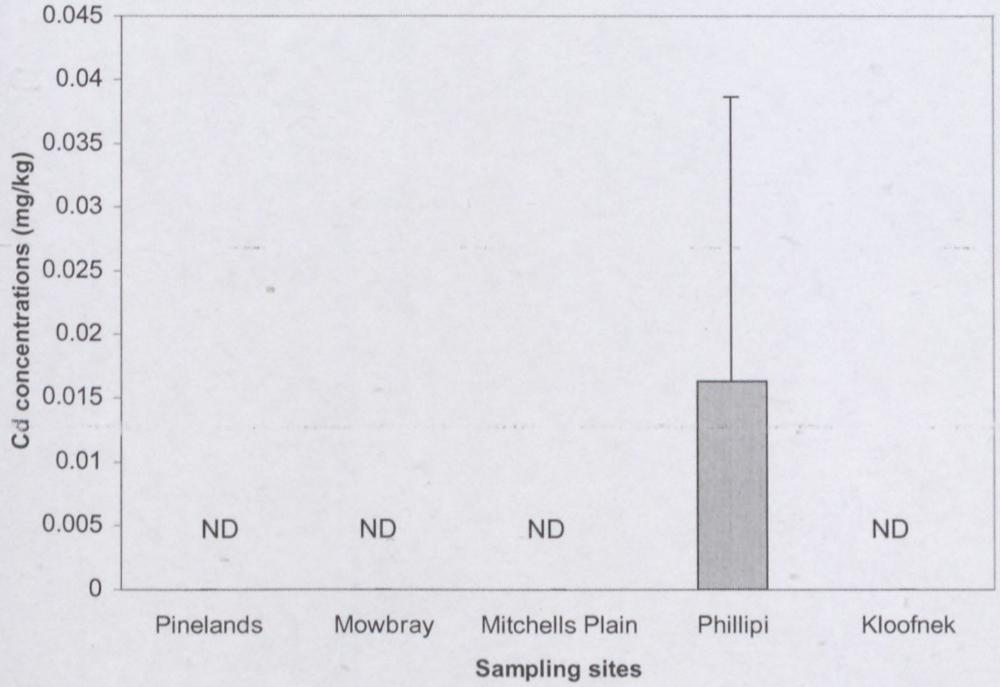

Figure 7: Mean cadmium concentrations (±SD) (mg/kg) in the sandpit soil samples of sampling sites in Cape Town. (n=5). No sandpit at Gugulethu site. ND = not detected.

There were no significant differences in cadmium concentrations in the sandpit soil samples between any of the sampling sites in the Oostenberg area (p>0.05) (Table 4; Figure 8).

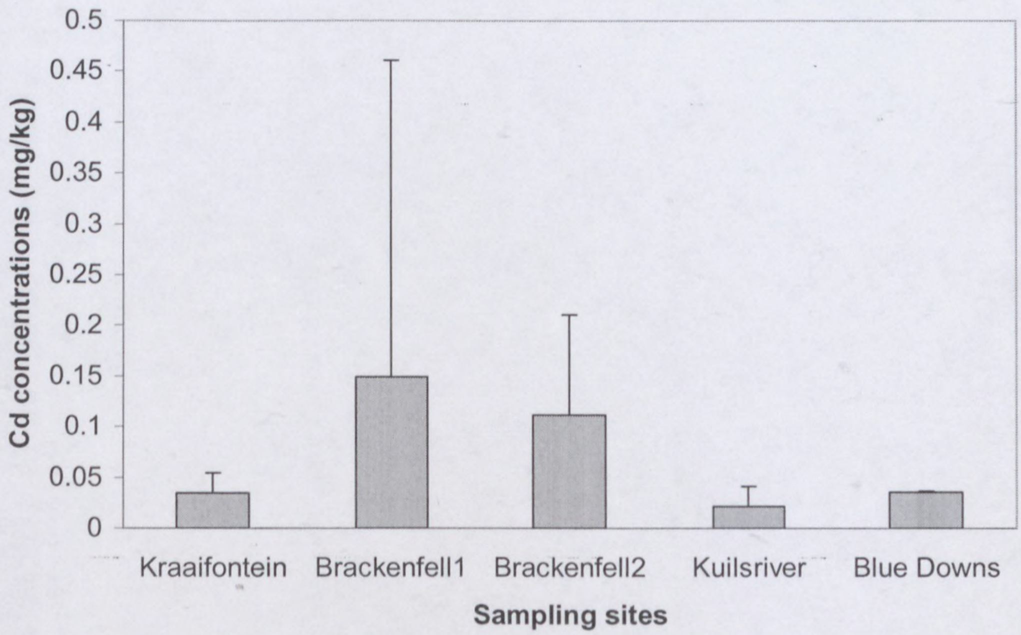

Figure 8: Mean cadmium concentrations (±SD) (mg/kg) in the sandpit soil samples of sampling sites in Oostenberg. (n=5)

There were no significant differences in cadmium concentrations in the sandpit soil samples between any of the sampling sites in South Peninsula area ($p>0.05$) (Table 4; Figure 9). Cadmium was only detected at the Wynberg site (0.097 ±0.093 mg/kg).

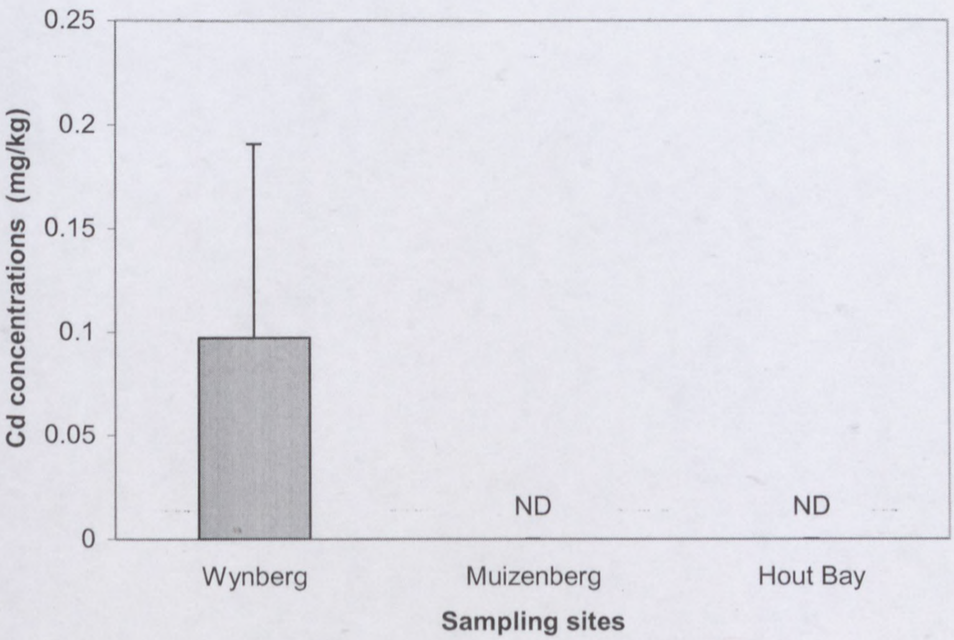

Figure 9: Mean cadmium concentrations (±SD) (mg/kg) in the sandpit soil samples of sampling sites in South Peninsula. (n=5) ND = not detected.

3.2.3 Comparisons of cadmium concentrations in the natural soils vs sandpit soils of the same sampling site

In the Cape Town area the concentrations of cadmium differed significantly ($p<0.05$) in terms of natural soil vs. sandpit soil, except for Phillipi and Mitchells Plain ($p>0.05$). Bonteheuwel did not have a sandpit. The cadmium concentrations in the Helderberg area differed significantly ($p<0.05$) at all sites, except for Strand 1. The Gordons Bay site did not have a sandpit. In the Oostenberg, South Peninsula and Blaauwberg administration areas there were no significant difference in the cadmium concentrations at any of the sampling sites when the natural soil and sandpit soil were compared ($p>0.05$). Cadmium was not detected in the Tygerberg area (Table 4).

3.2.4. Comparisons between the administration areas in terms of cadmium concentrations

Statistical comparisons of the natural soil's combined mean cadmium concentrations found at the different administration areas, show no statistical differences between the administration areas ($p>0.05$) (Table 5; Figure 10). No natural soil cadmium was found in the Tygerberg administration area.

Statistical comparisons between the sandpit soil's combined mean cadmium concentrations found at the different administration areas, show that the cadmium concentrations found at Oostenberg were statistically significantly higher than those of Blaauwberg, Helderberg and Tygerberg ($p<0.05$). None of the other comparisons showed statistical differences ($p>0.05$) (Table 5; Figure 11).

Table 5: Combined mean cadmium concentrations (±SD) (mg/kg) found in natural and sandpit soil for each administration area in the City of Cape Town. ND = not detected.

Sampling area	n	Cadmium concentrations (mg/kg)	
		Natural soil	Sandpit soil
Blaauwberg	15	0.012 (±0.021)	ND
Cape Town	30	0.617 (±0.847)	0.003 (±0.007)
Helderberg	25	0.096 (±0.093)	ND
Oostenberg	25	0.443 (±0.734)	0.070 (±0.056)
South Peninsula	15	0.129 (±0.224)	0.032 (±0.056)
Tygerberg	25	ND	ND

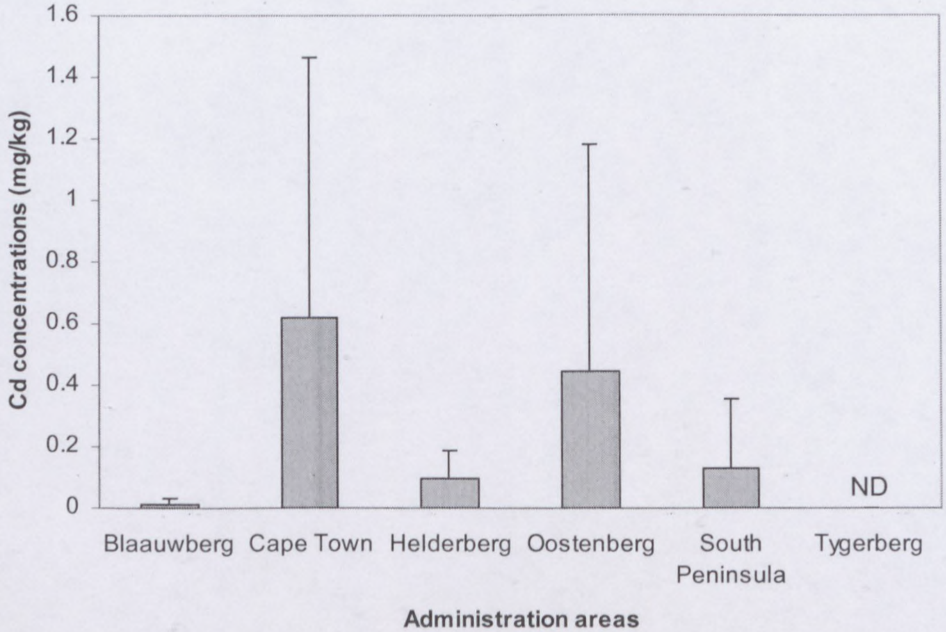

Figure 10: Comparison of mean cadmium concentrations (±SD) (mg/kg) in the natural soils of the different administration areas of the City of Cape Town. ND = not detected.

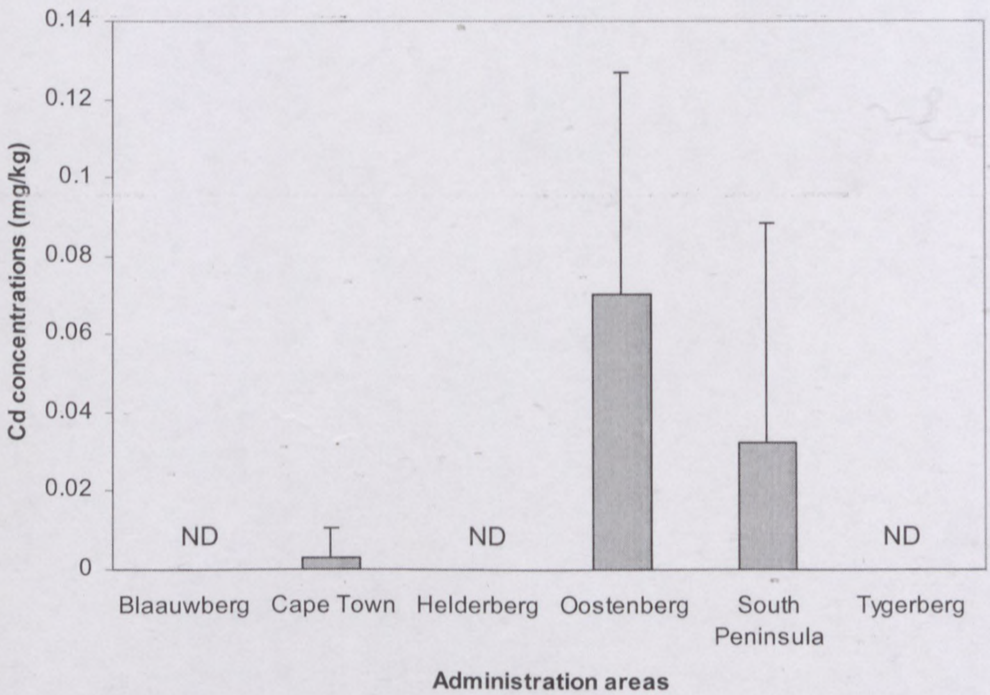

Figure 11: Comparison of mean cadmium concentrations (±SD) (mg/kg) in the sandpit soils of the different administration areas of the City of Cape Town. ND = not detected.

3.3. LEAD CONCENTRATIONS

Table 6: Mean lead concentrations (±SD) (mg/kg) in natural and sandpit soil at sampling sites in the City of Cape Town. (n=5) ND= not detected.

Sampling sites	Lead concentrations (mg/kg)	
	Natural soil	Sandpit soil
Blaauwberg		
Atlantis	5.354 (±2.276)	4.509 (±10.082)
Table View	0.670 (±1.498)	4.589 (±8.287)
Milnerton	14.687 (±5.100)	1.488 (±2.038)
Cape Town		
Pinelands	33.726 (±2.447)	1.751 (±3.916)
Mowbray	46.283 (±10.017)	20.932 (±5.689)
Gugulethu	26.631 (±3.105)	No sandpit
Mitchells Plain	111.953 (±72.743)	32.292 (±21.979)
Phillipi	2.461 (±2.253)	4.281 (±0.419)
Kloofnek	661.687 (±106.127)	6.583 (±3.784)
Helderberg		
Somerset-West 1	31.695 (±8.000)	ND
Somerset-West 2	34.334 (±33.239)	4.377 (±5.602)
Strand 1	21.983 (±9.048)	5.927 (±3.467)
Strand 2	19.476 (±2.988)	1.883 (±4.211)
Gordons Bay	5.289 (±2.579)	No sandpit
Oostenberg		
Kraaifontein	6.858 (±10.460)	2.621 (±2.428)
Brackenfell 1	6.335 (±2.669)	0.760 (±1.699)
Brackenfell 2	5.248 (±2.083)	4.053 (±0.293)
Kuilsriver	20.540 (±2.144)	3.606 (±0.221)
Blue Downs	4.251 (±1.658)	ND
South Peninsula		
Wynberg	15.457 (±2.756)	3.779 (±0.409)
Muizenberg	5.616 (±2.073)	3.710 (±0.410)
Hout Bay	9.231 (±3.925)	0.307 (±0.687)
Tygerberg		
Durbanville	3.868 (±2.890)	ND
Bellville	4.471 (±1.889)	0.378 (±0.612)
Ravensmead	ND	ND
Bonteheuwel	ND	No sandpit
Delft	7.342 (±2.824)	ND

3.3.1. Comparisons of lead concentrations in the natural soils

The lead concentrations in the natural soil of the sampling sites in the Blaauwberg area are shown and illustrated in Table 6 and Figure 12. The lead concentrations found at Atlantis were statistically significantly higher than those of Table View, but statistically significantly lower than those of Milnerton ($p<0.05$). Mean lead concentrations found at the Milnerton site were statistically significantly higher than those of the other sampling sites ($p<0.05$).

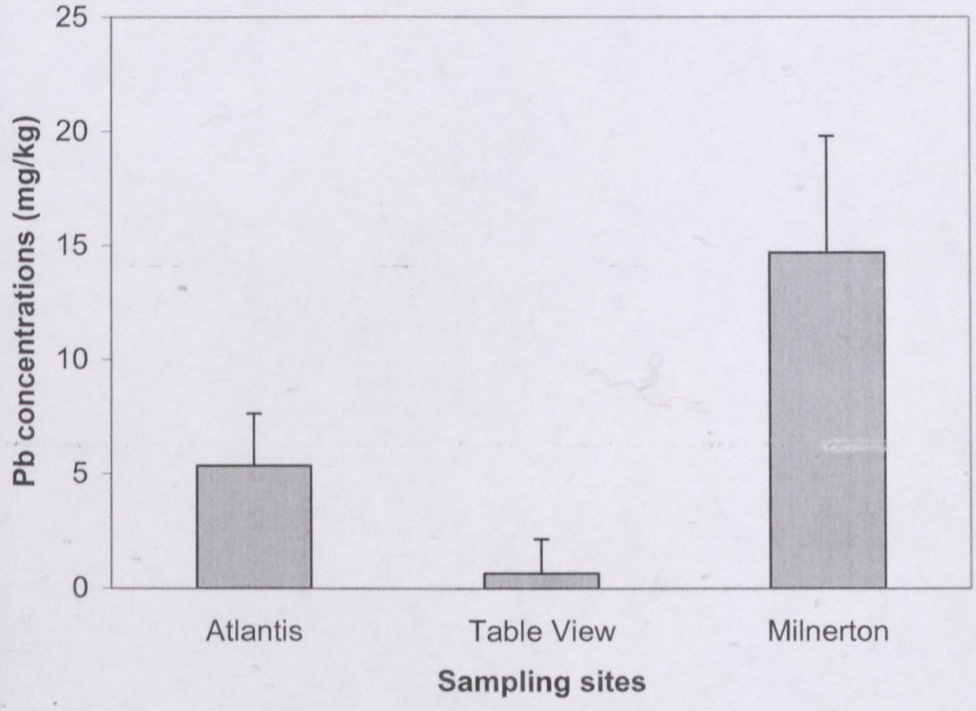

Figure 12: Mean lead concentrations (±SD) (mg/kg) in the natural soil samples of sampling sites in Blaauwberg. (n=5)

The mean lead concentrations in the natural soil samples of sites in the Cape Town area are shown in Table 6 and illustrated in Figure 13. The lead concentrations found at the Pinelands site were statistically significantly higher than those found at Gugulethu and Phillipi ($p<0.05$), but significantly lower than those found at Mowbray, Mitchells Plain and Kloofnek ($p<0.05$). The Mowbray site's lead concentrations were also statistically significantly higher than those of Gugulethu and Phillipi, but lower than those measured at Mitchells Plain and Kloofnek ($p<0.05$). The Gugulethu lead concentrations were statistically significantly higher than those found at Phillipi, but statistically significantly lower than those of all other sampling sites in the Cape Town area ($p<0.05$). The lead concentrations found in Mitchells Plain were statistically significantly higher than the natural soil concentrations found in all other sampling sites ($p<0.05$), apart from Kloofnek. The lead concentrations found at Phillipi were statistically the lowest in the Cape Town area ($p<0.05$). The natural soil lead concentrations measured at Kloofnek were found to be statistically the highest (661.687 ±106.127 mg/kg) in the Cape Town area, when compared to the other sampling sites ($p<0.05$).

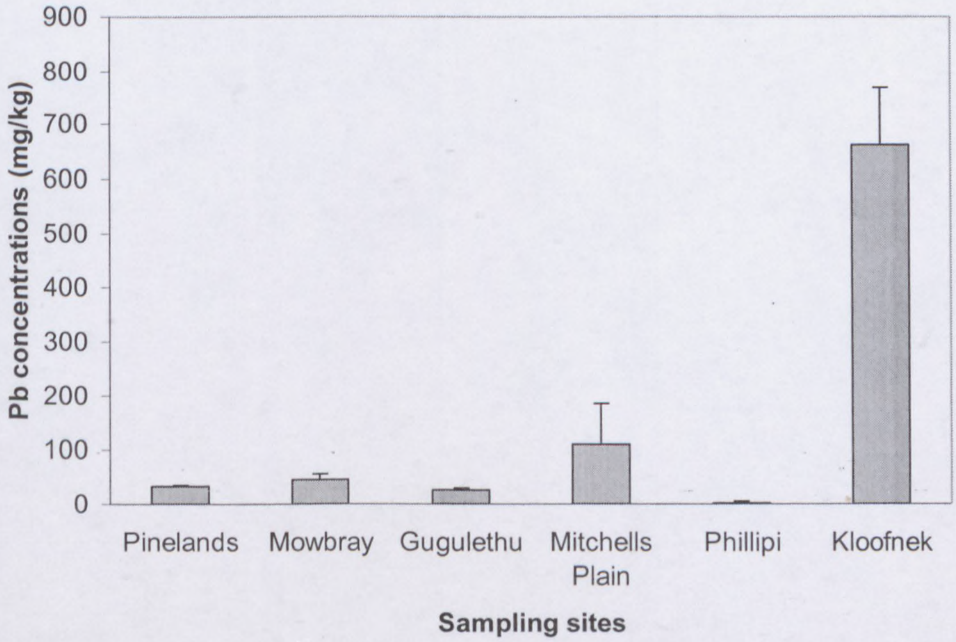

Figure 13: Mean lead concentrations (±SD) (mg/kg) in the natural soil samples of sampling sites in the Cape Town administration area. (n=5)

The mean lead concentrations found in the natural soil of the Helderberg area are illustrated in Figure 14 and shown in Table 6. The lead concentrations found at Somerset-West 1 were statistically significantly higher than at Strand 2 and Gordons Bay ($p<0.05$), but did not differ from Somerset-West 2 and Strand 1 ($p>0.05$). Somerset-West 2 lead were statistically significantly higher than those found in Gordons Bay ($p<0.05$), but did not differ from lead measured at the other sites ($p>0.05$). The lead concentrations found at the Strand 1 and Strand 2 sites were also statistically significantly higher than those of Gordons Bay ($p<0.05$).

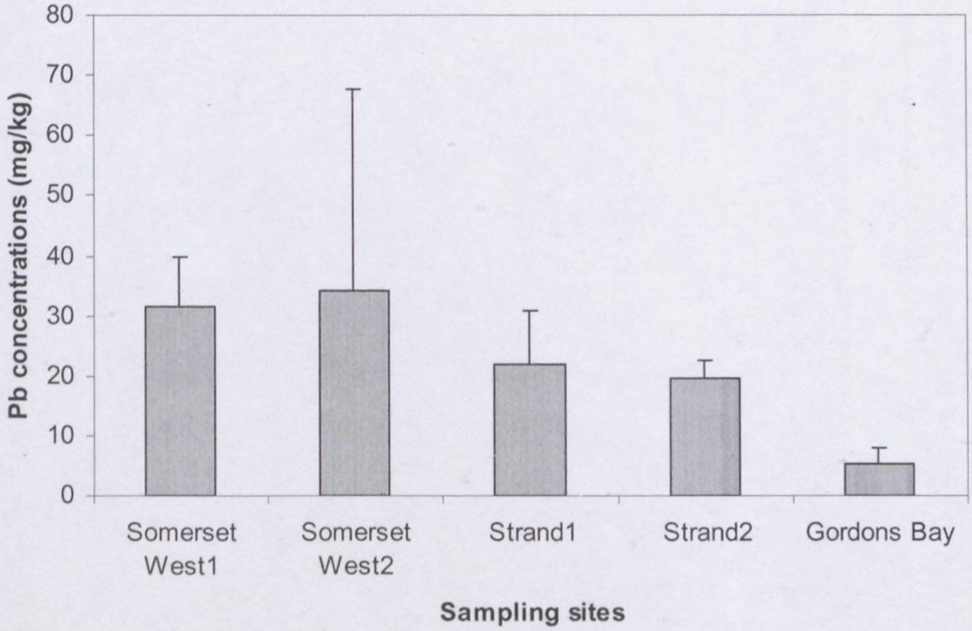

Figure 14: Mean lead concentrations (±SD) (mg/kg) in the natural soil samples of sampling sites in Helderberg. (n=5)

The mean lead concentrations in the natural soil of the Oostenberg area are shown in Table 6 and Figure 15. Lead concentrations measured in natural soil at the Kraaifontein site did not differ significantly from those of other sampling sites in the Oostenberg area ($p>0.05$). The lead concentrations found at the Kuilsriver site (20.540 ±2.144 mg/kg) were statistically significantly higher than those of the Brackenfell 1, Brackenfell 2 and Blue Downs sampling sites ($p<0.05$), but did not differ significantly from natural soil lead concentrations of the Kraaifontein site ($p>0.05$).

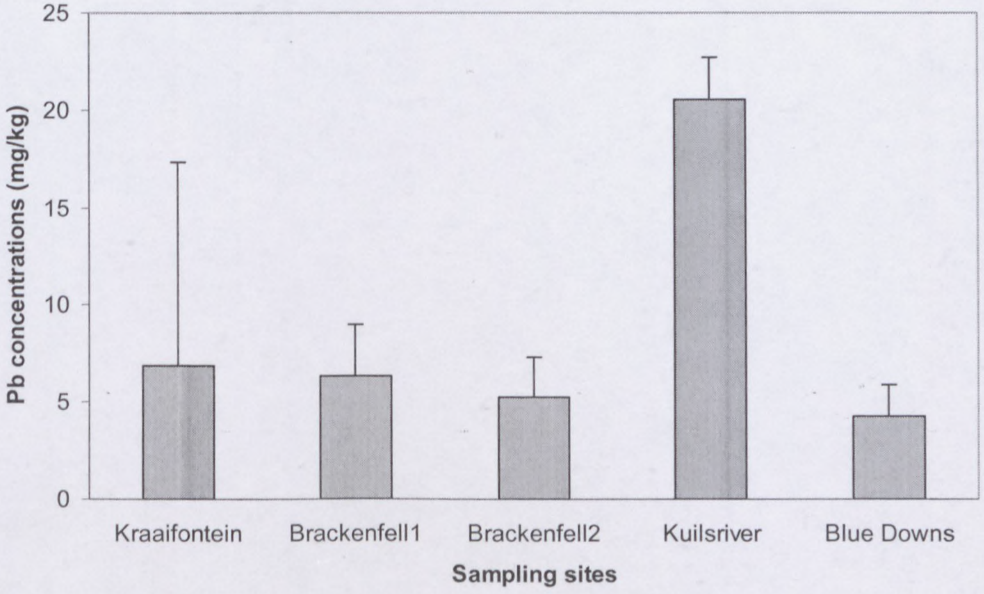

Figure 15: Mean lead concentrations (±SD) (mg/kg) in the natural soil samples of sampling sites in Oostenberg. (n=5)

Figure 16 and Table 6 show the lead concentrations in the natural soil of the South Peninsula area. The lead concentrations found at the Wynberg site (15.457 ±2.756 mg/kg) were statistically significantly higher than lead concentrations found in natural soil of the Muizenberg and Hout Bay sites ($p<0.05$). Lead concentrations found at the Hout Bay and Muizenberg sites did not differ from each other ($p>0.05$).

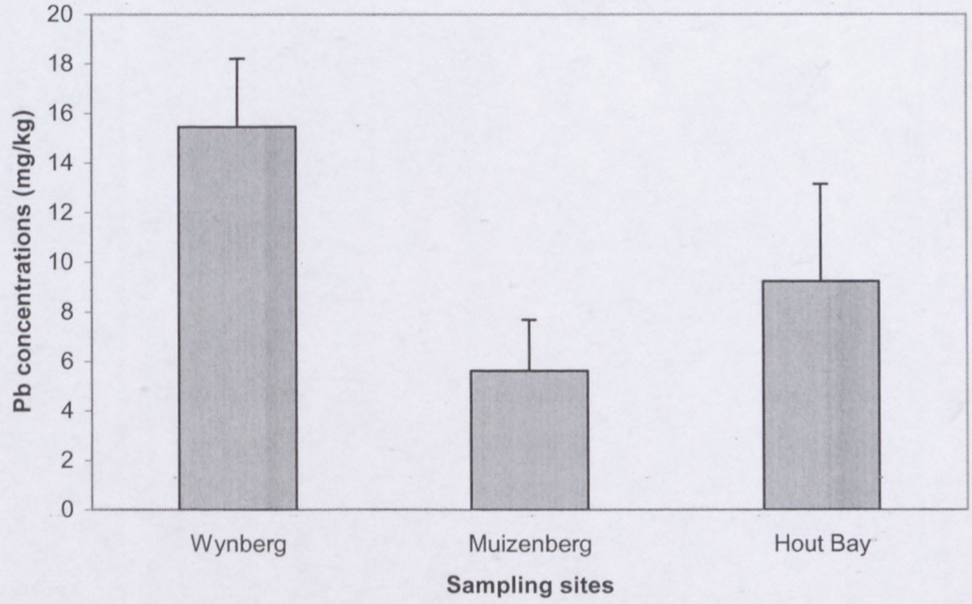

Figure 16: Mean lead concentrations (±SD) (mg/kg) in the natural soil samples of sampling sites in the South Peninsula. (n=5)

The lead concentrations measured in the natural soil in the Tygerberg area are illustrated in Figure 17 and shown in Table 6. The lead concentrations found at the Bellville site did not differ significantly from those of Delft and Durbanville ($p>0.05$). No lead was detected in the natural soil samples of the Ravensmead and Bonteheuwel sites.

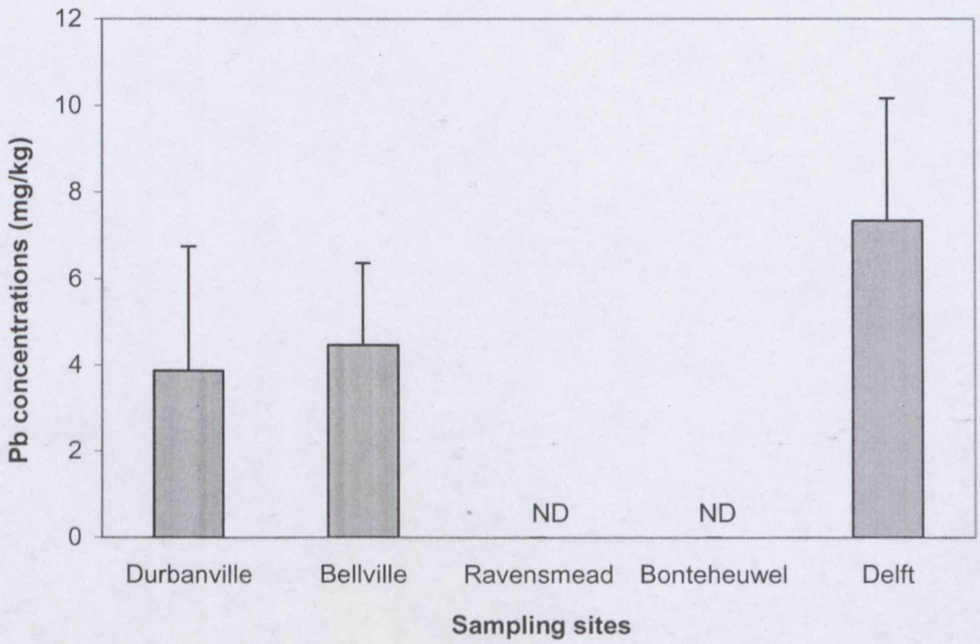

Figure 17: Mean lead concentrations (±SD) (mg/kg) in the natural soil samples of sampling sites in Tygerberg. (n=5) ND = not detected.

3.3.2. Comparisons of lead concentrations in the sandpit soils

Statistical comparisons between the sandpit soil lead found at the different sampling sites in the Blaauwberg area showed no statistical differences (p>0.05) (Table 6; Figure 18).

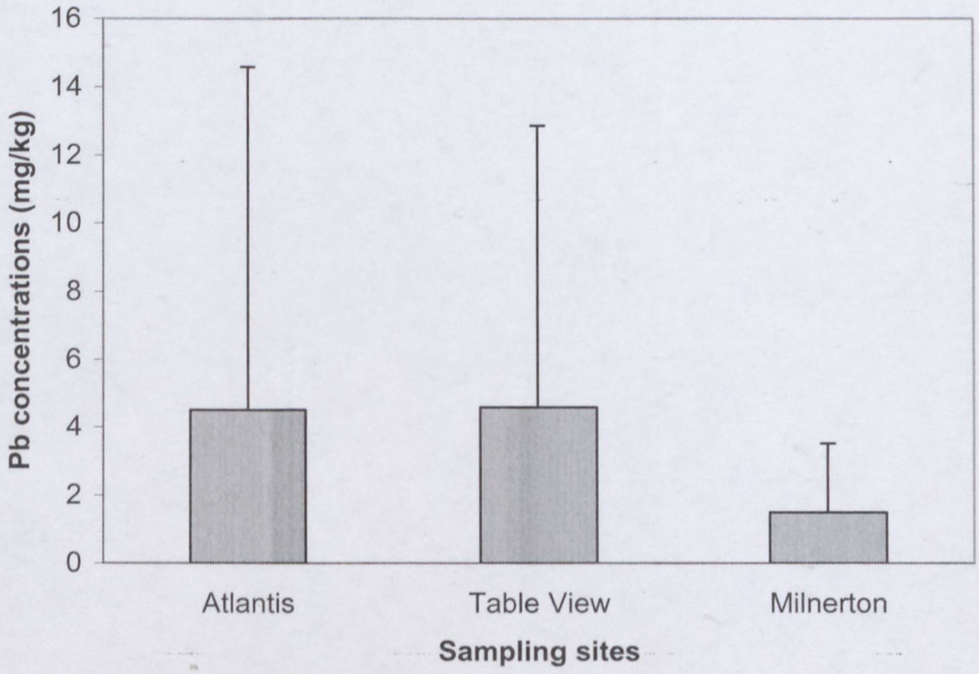

Figure 18: Mean lead concentrations (±SD) (mg/kg) in the sandpit soil samples of sampling sites in Blaauwberg. (n=5)

Figure 19 and Table 6 show the lead concentrations measured in sandpit soil samples in the Cape Town area. The Gugulethu site did not have a sandpit and were therefore excluded form this analysis. At the Mowbray site lead concentrations found in sandpit soil samples were statistically significantly higher than those measured at the Pinelands, Phillipi and Kloofnek sites (p<0.05). The lead concentrations found at the Mitchells Plain site were also statistically significantly higher than those found at the Pinelands, Phillipi and Kloofnek sites (p<0.05). The Pinelands, Phillipi and Kloofnek concentrations did not differ significantly from each other (p>0.05). Lead found in sandpit soil samples of Mowbray and Mitchells Plain also did not differ significantly from each other, with Mitchells Plain having the highest mean concentration of 32.292 ±21.979 mg/kg ($p>0.05$).

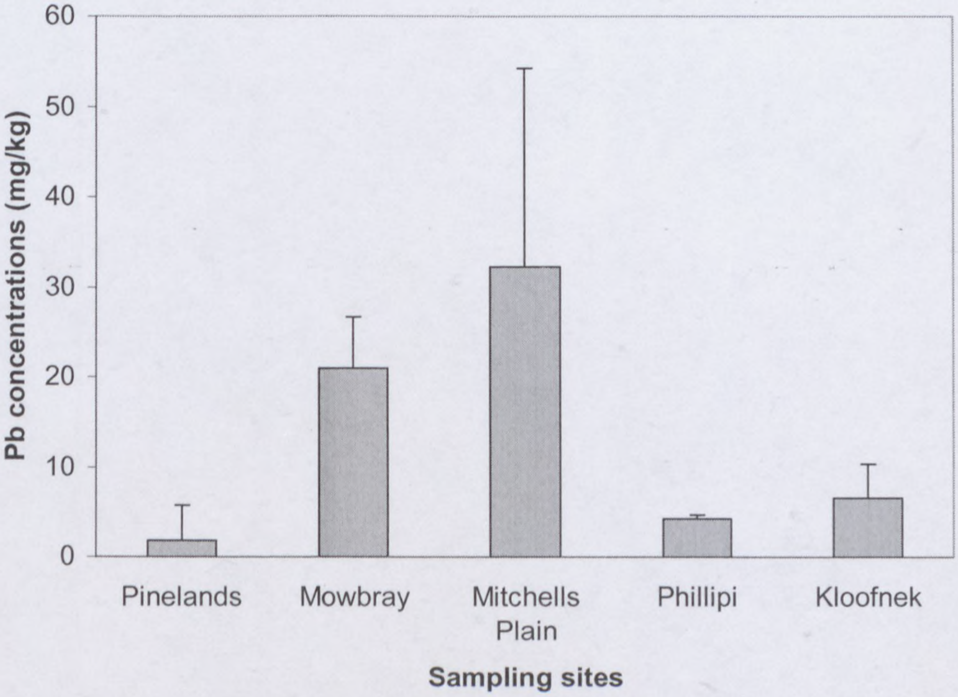

Figure 19: Mean lead concentrations (±SD) (mg/kg) in the sandpit soil samples of sampling sites in the Cape Town administration area. (n=5). No sandpit at Gugulethu site.

The mean lead concentrations in the sandpit soil in the Helderberg area are shown in Figure 20 and Table 6. The Gordons Bay site had no sandpit and was therefore excluded from the analysis. At the Somerset-West 1 site no lead could be detected in the sandpit soil, and were found to be statistically significantly lower than sandpit soil lead concentrations of the Strand 1 site ($p<0.05$). The lead concentrations found at the Somerset-West 2, Strand 1 and Strand 2 sites showed no significant differences from each other ($p>0.05$). The highest lead concentrations of 5.927 ±3.467 mg/kg were found in the Strand 1 sandpit soil.

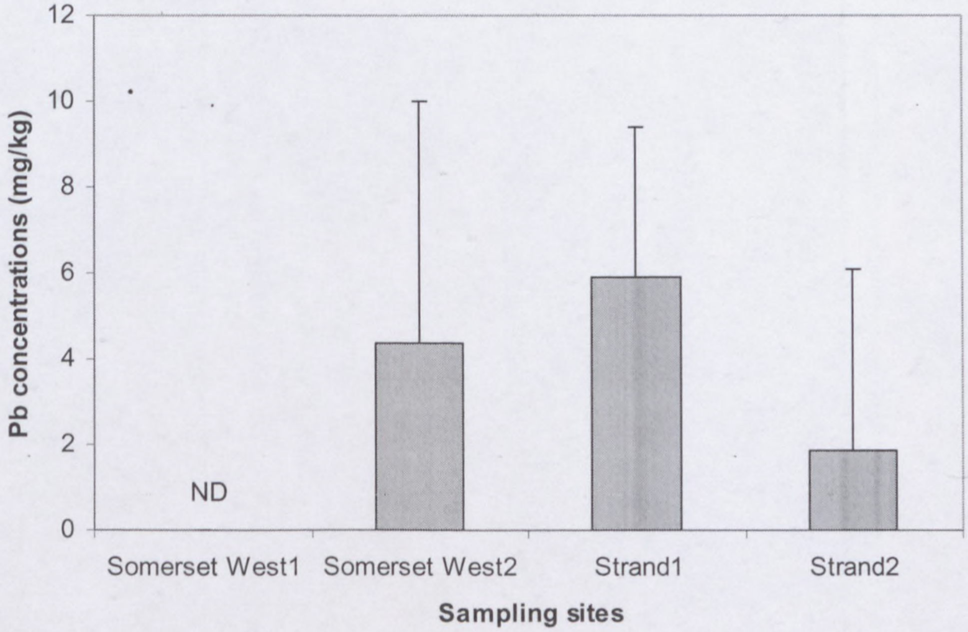

Figure 20: Mean lead concentrations (±SD) (mg/kg) in the sandpit soil samples of sampling sites in Helderberg. (n=5) No sandpit at Gordons Bay site. ND = not detected.

The lead concentrations measured in the sandpit soil in the Oostenberg area are illustrated in Figure 21 and shown in Table 6. There were no significant differences in lead concentrations found when the Kraaifontein site's sandpit soil lead were compared to all the other sampling sites' sandpit soil lead concentrations ($p>0.05$). The Brackenfell 2 site's sandpit lead concentrations (4.053 ±0.293 mg/kg) were statistically significantly higher than those of all other sampling sites ($p<0.05$), except for Kraaifontein ($p>0.05$). The lead concentrations found at the Kuilsriver site were statistically significantly higher than those found at the Blue Downs site ($p<0.05$).

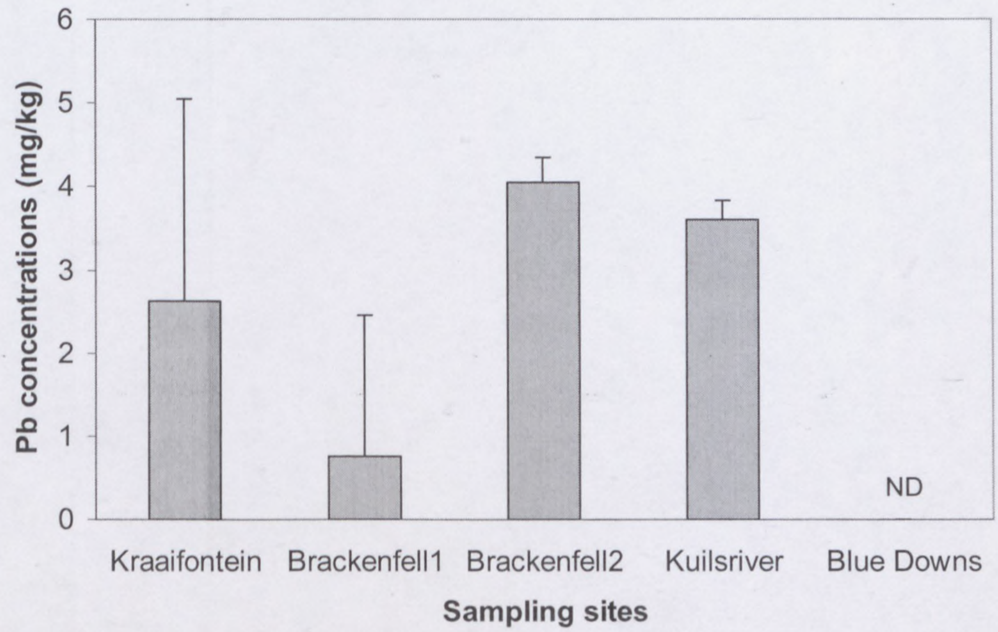

Figure 21: Mean lead concentrations (±SD) (mg/kg) in the sandpit soil samples of sampling sites in Oostenberg. (n=5) ND = not detected.

Figure 22 illustrate and Table 6 show the lead concentrations measured in the sandpit soil of the South Peninsula area. The sandpit soil lead concentrations found at Wynberg (3.779 ±0.409 mg/kg) were statistically significantly higher than those found at the Hout Bay site ($p<0.05$), but did not differ from those of the Muizenberg site ($p>0.05$). Sandpit soil lead concentrations at the Muizenberg site (3.710 ±0.410 mg/kg) were also found to be statistically significantly higher than those concentrations found at the Hout Bay site ($p<0.05$).

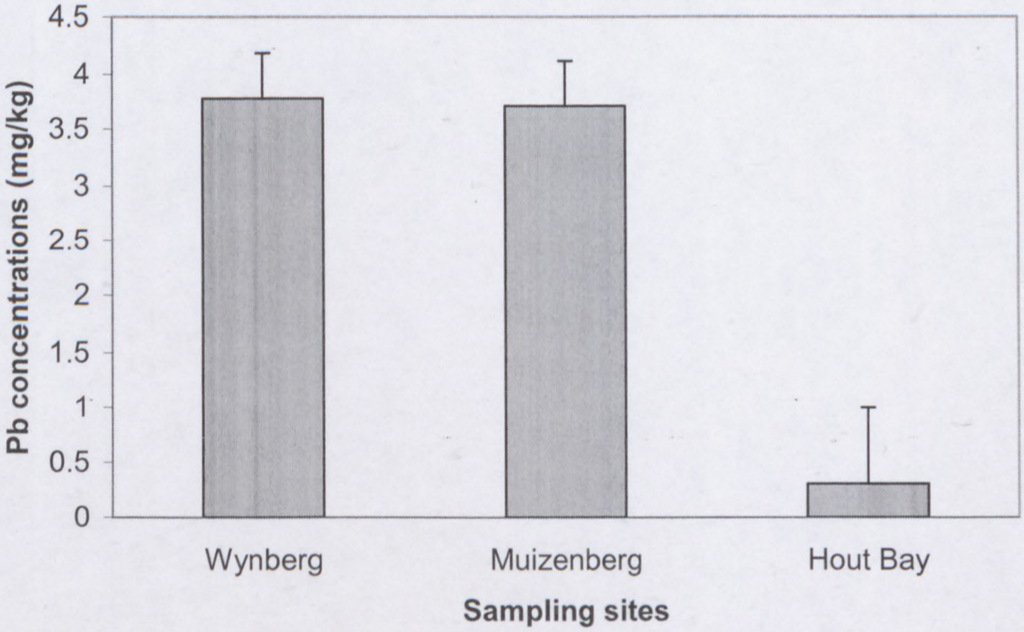

Figure 22: Mean lead concentrations (±SD) (mg/kg) in the sandpit soil samples of sampling sites in the South Peninsula. (n=5)

The lead concentrations in the sandpit soil of the Tygerberg area are illustrated in Figure 23 and shown in Table 6. The Bonteheuwel site had no sandpit and was therefore excluded from the analysis. Statistical comparisons of lead concentrations found in the sandpit soils showed no statistical differences between the sampling sites ($p>0.05$). Lead was only detected at the Bellville site (0.378 ±0.612 mg/kg).

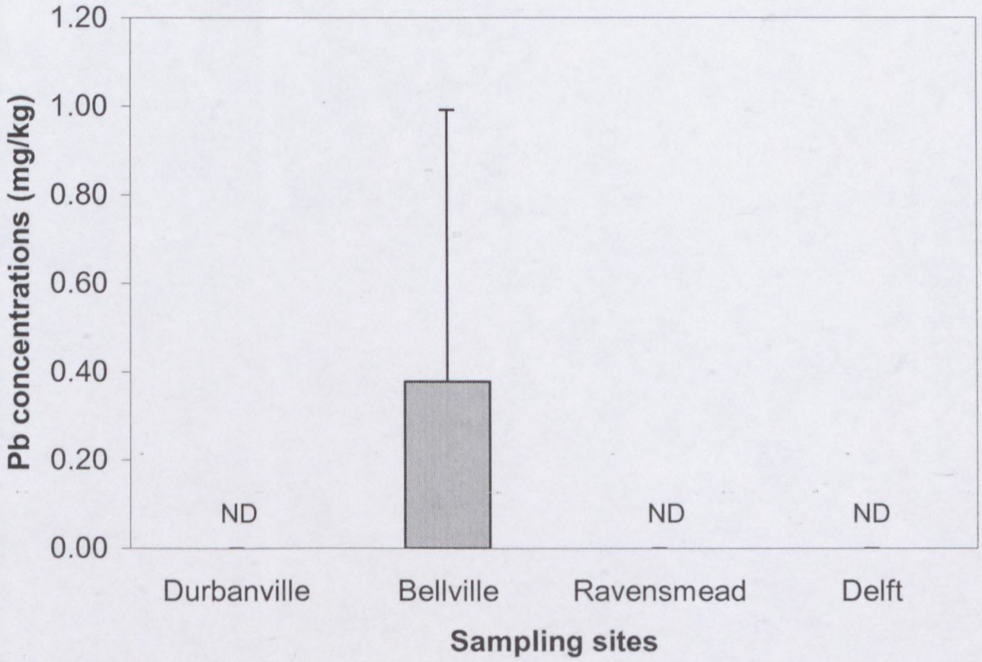

Figure 23: Mean lead concentrations (±SD) (mg/kg) in the sandpit soil samples of sampling sites in Tygerberg. (n=5) No sandpit at Bonteheuwel site. ND = not detected.

3.3.3. Comparisons of lead concentrations in the natural soil vs sandpit soil of the same sampling site

In the Blaauwberg administration area the lead concentrations measured in the natural soil differed significantly from sandpit soil lead at the Milnerton site ($p<0.05$). In the Cape Town area the lead concentrations differed significantly ($p<0.05$) at all the sampling sites when natural soil and sandpit soil were compared at the same site. The Gugulethu site had no sandpit and could therefore not be included in this analysis. The natural soil versus sandpit soil comparisons of lead concentrations in the Helderberg area revealed significant differences at all sites ($p<0.05$), except at the Somerset-West 2 site ($p>0.05$). Due to the absence of a sandpit, the Gordons Bay site was excluded form this analysis. The natural soil versus sandpit soil comparisons of lead concentrations in the Oostenberg area showed significant differences at all sites ($p<0.05$), except at the Brackenfell 2 and Kraaifontein sites ($p>0.05$). The natural soil versus sandpit soil comparisons of lead concentrations in the South Peninsula area revealed significant differences at the Wynberg and Hout Bay sites ($p<0.05$), but no difference was found at the Muizenberg site ($p>0.05$). The natural soil versus sandpit soil comparisons of lead concentrations in the Tygerberg area revealed significant differences at all sites ($p<0.05$), except at the Ravensmead site ($p>0.05$). Due to the absence of a sandpit, Bonteheuwel was excluded from this analysis (Table 6).

3.3.4. Comparisons between the administration areas in terms of lead concentrations

The combined mean lead concentrations of natural soil calculated for the different administration areas are shown in Table 7 and Figure 24. The Cape Town administration area had the highest combined mean natural soil lead concentrations of 147.124 ±254.749 mg/kg. The Cape Town and Helderberg administration areas had statistically significantly higher combined mean natural soil lead concentrations than the Tygerberg administration area ($p<0.05$). None of the other comparisons showed differences ($p>0.05$).

The combined mean lead concentrations of sandpit soil calculated for the different administration areas are shown in Table 7 and Figure 25. The sandpit soil lead concentrations measured in the Cape Town area were statistically significantly higher than those of Tygerberg ($p<0.05$). None of the other comparisons showed differences ($p>0.05$) (Table 7; Figure 25).

Table 7: Combined mean lead concentrations (±SD) (mg/kg) found in natural and sandpit soil in each of the administration areas of the City of Cape Town. ND = not detected.

Sampling area	n	Lead concentrations (mg/kg)	
		Natural soil	Sandpit soil
Blaauwberg	15	6.904 (±7.135)	3.529 (±1.767)
Cape Town	30	147.124 (±254.749)	13.168 (±13.025)
Helderberg	25	22.555 (±11.512)	3.047 (±2.627)
Oostenberg	25	8.647 (±6.724)	2.208 (±1.768)
South Peninsula	15	10.101 (±4.977)	2.599 (±1.985)
Tygerberg	25	3.136 (±3.149)	0.094 (±0.189)

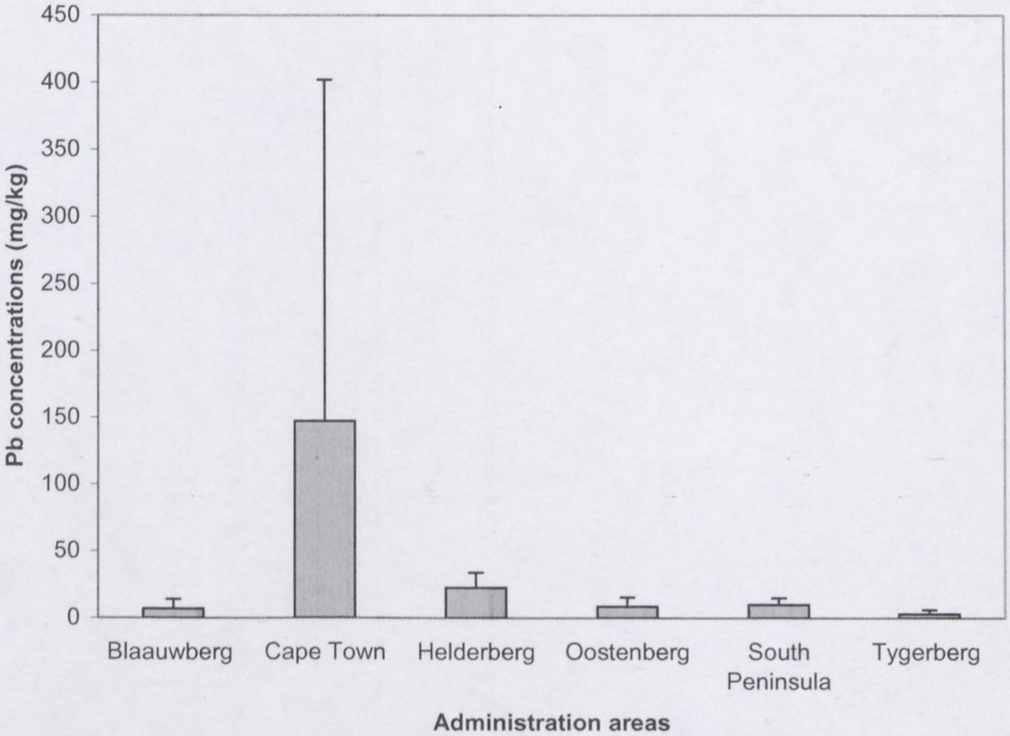

Figure 24: Comparison of combined mean lead concentrations (±SD) (mg/kg) in the natural soil of different administration areas of the City of Cape Town.

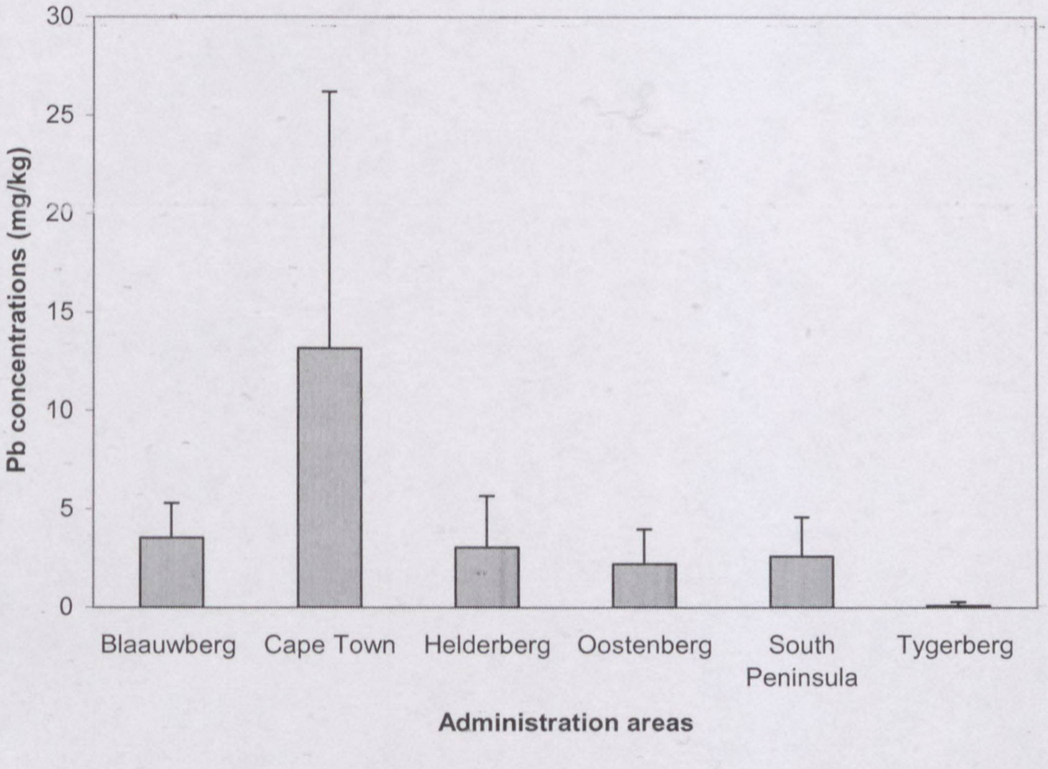

Figure 25: Comparison of combined mean lead concentrations (±SD) (mg/kg) in the sandpit soil of different administration areas of the City of Cape Town.

Chapter 4

DISCUSSION

4.1. CONTAMINATION AND POTENTIAL TOXICITY OF CADMIUM AND LEAD IN SOIL

4.1.1 Soil pH and moisture

The soil is a primary recipient, intended or otherwise, of many of the waste products and chemicals humans produce. Furthermore, once these materials enter the soil they become part of a cycle which affects all forms of life, including man. Soil is only a part of the biological cycle relative to metals. At the same time, soils are the ultimate depositories of large quantities of these compounds (Brady, 1974). According to Spurgeon et al. (2006) the uptake and toxicity of chemicals such as metals, are not only controlled by total concentrations in the soil but also by the soil conditions.

Generally, the soil in the present study was found to be sandy. The low moisture content (Table 3) found could be due to the sandy nature of the soil because of the high drainage capacity of sandy soil. In the present study the pH of the soil tended to be moderately alkaline (Table 2). Soil pH controls many speciation and precipitation reactions that could influence the bioavailability of a metal contaminant (Tomson et al., 2003). High pH values are generally in turn associated with lower toxicity of metal contaminants (Allen, 2002). It is also known that a reduction in soil pH can increase the mobilization of metals, whereas the reverse is true for pH increases (Spurgeon et al., 2006). Bradham et al. (2006) found that soil pH was the most important soil property affecting the bioaccumulation of lead in earthworms. Janssen et al. (1997) found that cadmium uptake by earthworms seemed to be more affected by pH than in the case of lead indicating that different metals react differently to pH changes in the soil. The high pH value in the present study may be an indication that metals are less available for uptake by children but more moisture in the soil, e.g. after rainfall, could lower the pH and increase bioavailability.

4.1.2. Comparison of sampling sites per administration area

4.1.2.1. Blaauwberg area

The Canadian soil quality guidelines indicate that lead concentrations in residential/parkland areas should not exceed 140 mg/kg, and cadmium concentrations should be less than 10 mg/kg (CCME, 1999). No such guidelines exist for South African soils.

Cadmium was only detected in the natural soil at the Atlantis site (0.038 ±0.084 mg/kg) in the Blaauwberg area, and is according to the Canadian soil quality guidelines (CCME, 1999) environmentally acceptable.

Cadmium was not detected in the sandpit soil at any of the other sites in the Blaauwberg area. This may be a result of the sandpit soil being regularly replaced. Furthermore, it is possible that no significant sources of cadmium contamination were present in the surrounding areas of these sampling sites.

Lead concentrations in the natural soil samples of the sampling site at Milnerton were the highest in the Blaauwberg area (14.687 ±5.100 mg/kg). The same site had the lowest concentrations in sandpit soil of 1.488 ±2.038 mg/kg. Lead concentrations found in the sandpit soil of the Table View site were the highest (4.589 ±8.287 mg/kg). Compared to the Canadian soil quality guidelines (CCME, 1999) the concentrations for both metals in the Blaauwberg area were well below the recommended guidelines. In the Blaauwberg administration area relatively low lead concentrations were found. This could be due to pre-school facilities being some distance from industrial activity, which is normally, together with roads, major sources of metal pollution (Hopkin, 1989).

4.1.2.2. Cape Town area

Cadmium concentrations found in the natural soil at the Kloofnek site (2.150 ±0.150 mg/kg) were statistically significantly higher than all other sampling sites in the Cape Town administration area. In the sandpit soil cadmium was not detected at Pinelands, Kloofnek and Mowbray and this may be because the sandpit soils which are used as children's playgrounds are regularly replaced with fresh soil. As a result they are free of metals. None of the cadmium concentrations measured in soil in the Cape Town administration area exceeded the CCME (1999) guidelines.

Lead concentrations in the natural soil of the Kloofnek site were high with a mean concentration of 661.687 ±106.127 mg/kg. Such high concentrations, according to the Canadian soil quality guidelines (CCME, 1999), pose a threat to the environment and its surroundings because these concentrations are much higher than the guideline of 140 mg/kg. In a study by Kachur et al. (2003) high concentrations of lead were found in soil samples collected from school areas and playgrounds in Russia. Lead concentrations of an average of 550 mg/kg, with a maximum of 1350 mg/kg were measured.

Mean lead concentrations of sandpit soil in Mitchells Plain were 32.292 ±21.979 mg/kg, which were the highest in the Cape Town administration area. These concentrations are high relative to other sandpit soil lead levels measured in this study. It could be that the sandpit soil of the Mitchells Plain site is not regularly replaced, causing lead to accumulate over time in the soil. The fact that children normally play in the sandpits, means that the risk of exposure of children, at this site, to lead contamination is higher than at the other sampling sites.

As in the case of cadmium, Kloofnek had the highest mean concentrations of lead in the natural soil. Higher levels of metal concentration are usually associated with local industrial/urban activities (Jackson, 1978; McFarlane et al., 1979; Smith, 1987). Kloofnek is situated on the slopes of Table Mountain, and is surrounded by mountains in the form of a sickle. The prevailing wind in summer is the south-eastern, while the north-west wind is dominant in winter. This could provide one of the possible reasons for the higher concentrations at Kloofnek, because Table Mountain could act as a wind barrier causing metal containing air to swirl around and eventually settle on soil in this area. Another contributing factor may be the fact that Kloofnek is in the city itself, with more concentrated human activities, such as traffic.

4.1.2.3. Helderberg area

Mean cadmium concentrations in natural soil of the Strand 2 and Somerset-West 2 sites had the highest concentrations of 0.201 ±0.014 mg/kg and 0.196 ±0.009 mg/kg), respectively. Cadmium concentrations in natural soil at the Helderberg sites were low compared to the CCME (1999) guidelines for cadmium in residential/parkland soil. This is probably due to the fact that these sites are far from sources of cadmium contamination. Cadmium was not detected in sandpit soil.

The highest mean lead concentrations in natural soils in the Helderberg were 34.334 ±33.239 mg/kg and 31.695 ±8.000 mg/kg at Somerset-West 1 and Somerset-West 2, respectively.

Lead concentrations in the sandpit soils of the Strand 1 sampling site were the highest for Helderberg (5.927 ±3.467 mg/kg). It can be noted that the highest natural soil and highest sandpit soil lead concentrations in this study were not found at the same site. This could be due to the fact that the sandpit soil is brought in from other areas, and that it is replaced more regularly at some sites than at others.

According to the Canadian soil quality guidelines (CCME, 1999) the concentrations of both metals in the Helderberg administration area are environmentally acceptable as they fall below the recommended guidelines.

4.1.2.4. Oostenberg area

In natural soil, mean cadmium concentrations were at very low levels of 0.034 ±0.019 mg/kg at Brackenfell 2, with the highest mean concentration being only 1.744 ±3.607 mg/kg, found at the Kraaifontein site.

Sandpit soil results indicated that cadmium concentrations were very low with the Brackenfell 1 sampling site the highest with 0.148 ±0.311 mg/kg, while the rest were equal or below 0.1 mg/kg. There were no significant differences in sandpit soil cadmium concentrations between the different Oostenberg sites.

The mean lead concentration in the natural soil was 20.540 ±2.144 mg/kg at the Kuilsriver site, which was the highest natural soil lead concentration measured for Oostenberg. This could probably be due to a smelting works situated in the Kuilsriver area. Smelting works are known to be significant contributors to metal pollution (Gummow et al., 1991). Soil concentrations found close to a smelting works in the Oostenberg area, revealed lead to be ranging between 45 and 105 mg/kg (Unpublished data).

Mean concentrations of lead in sandpit soil were found to be higher at the Brackenfell 2 and Kuilsriver sampling sites with means of 4.053 ±0.293 mg/kg and 3.606 ±0.221 mg/kg as compared to Kraaifontein, Brackenfell 1 and Blue Downs (Table 6). It could therefore be concluded that elevated lead concentrations found at some sites in the Oostenberg administration area could be due to the contribution of the smelting works, especially in the case of the Kuilsriver site.

4.1.2.5. South Peninsula area

Cadmium was only detected in the natural soil at the Hout Bay site and in sandpit soil at the Wynberg site. However, the concentrations were very low (0 to 0.388 mg/kg) as compared to the Canadian Soil Quality Guidelines, which indicates a maximum acceptable concentration of 10 mg/kg. This is an indication that the South Peninsula administration area does not have significant sources that could contaminate the soil with cadmium .

Mean lead concentrations in the natural soil were the highest at the Wynberg sampling site (15.457 ±2.756 mg/kg), which differed significantly from all other sampling sites of the South Peninsula administration area. In sandpit soil lead was detected at all the sites, with Wynberg and Muizenberg having the higher mean lead concentrations. As in the case of cadmium, it seems that there are not major sources of lead contamination close to the South Peninsula sampling sites. Compared to the Canadian soil quality guidelines (CCME, 1999) the concentrations of both metals in the South Peninsula administration area fall below the recommended guidelines.

4.1.2.6. Tygerberg area

Cadmium was not detected in natural soil and sandpit soil at any of the sampling sites of the Tygerberg administration area.

At the Delft sampling site mean lead concentration (7.342 ±2.824 mg/kg) in the natural soil were the highest for the Tygerberg area. Lead concentrations in the sandpit soil were very low at the Bellville site. Compared to the Canadian soil quality guidelines (CCME, 1999) the concentrations of both metals in the Tygerberg administration area are environmentally acceptable as they fall below the recommended guideline of 10 mg/kg Cd and 140 mg/kg Pb.

From the concentrations measured at sampling sites in this administration area, it can be deduced that pre-school facilities selected for this study were not significantly influenced by possible sources of cadmium and lead pollution, such as heavy traffic or industries. This could be due to sampling sites being away from contamination sources to such a degree that these sites are not influenced by those sources.

4.1.3 General sources of pollution in the CCT

Studies of metal pollutants in the environment have indicated that many areas near urban complexes or major road systems contain very high concentrations of metals (Harrison & Laxen, 1984). Soils in such areas are polluted with a wide range of metals, such as lead, cadmium, and other metal pollutants. It is essential to realise that the soil is a source of metals and also a sink for metal contaminants. The atmosphere is also an important transport medium for metals from various sources (Alloway, 1995a), which could be some distance away from the site of contamination.

In the City of Cape Town (CCT), it has been reported that vehicle numbers have increased by 80% over the past 20 years. The public transportation system in South Africa is weak, with a heavy reliance on road-based modes. On average, vehicles in South Africa are older than in developed countries and, consequently, associated with higher levels of pollutant emissions. During recent decades rapid and unplanned urbanisation has been under way in South Africa. Most urban populations rely heavily on motor vehicles and vehicle-related pollution has been an increasing concern in recent years (Harper et al., 2003).

Air pollution in the CCT is trapped by inversion layers. This is a situation in the atmosphere where temperature increases with height instead of decreasing, as is usually the case. Inversion layers are common in the lower part of the atmosphere during the night and also during winter when an anticyclone dominates the circulation. Air near the surface gets cooled by relatively cold ground and sinks. This cooler, denser air cannot readily mix with the warmer air above, resulting in inversion which traps pollutants near the surface (South African Weather Service, 2005). Climatic conditions often coincide with heavy traffic in the morning, causing visible levels of air pollution in the form of a white or brown haze. These emissions result from increasing vehicle usage, but also from the burning of solid fuel, oil and natural gasses for domestic production of heat, or from electricity generation in power stations (CMC, 1998).

Metals found in the natural and sandpit soils of Cape Town are also indicative of pollution from vehicles, as Cape Town is a busy area and has heavy traffic volumes. Although the South African government phased out leaded petrol by 2006 (Harper et al., 2003) a significant amount of vehicles were still running on leaded petrol when field samples were collected for this study in 2003 and 2004.

A source of exposure in the case of children, such as in the present study, is the ingestion of contaminated soil by mouthing fingers, palms, and other contaminated objects. The children in the present study may also be exposed to contamination by eating with dirty hands, eating food exposed to soil/dust, and inhaling and ingesting airborne dust (Harper et al., 2003). The inhalation and ingestion of airborne dust may be a major route of exposure in this study due to the strong south easterly wind and dry climate in the summer months in the Western Cape. Coupled with this is the presence of generally sandy soil that can be easily windblown in dry conditions. There are also concerns about childhood exposure to lead from peeling paint in aging buildings such as schools, especially in older townships and inner-city areas. Lead is also used in a wide range of other processes and products in South Africa, for example, ammunition, wheel balancing weights, batteries, cabling and protective clothing (Von Schirnding et al., 2001). The latter authors concluded that the inner-city environment sources of lead are ubiquitous, with elevated levels found in air, dust and paint, in the environment at large. In the present study soil could have been contaminated with cadmium and lead from contaminated dust, air or pealing paint settling on, and accumulating in the soil.

4.2. IMPLICATIONS FOR THE HEALTH OF CHILDREN

In soil, metals such as cadmium are normally found concentrated in the surface horizon, due to a combination of factors: it is the zone with the highest organic matter content and metals may be retained in this strongly adsorptive horizon (Kabata & Pendias, 1992). The problem with metals such as cadmium and lead is that they are very immobile in soil and persist a long time (Miller & Gardiner, 1998). Brady (1974) also indicated little if any downward movement of cadmium.

Children younger than five years are especially prone to cadmium and lead compared with older children (Wilhelm et al., 1994). Children playing in the soil could be exposed to lead, and other metals, sometimes even after the deposition and contamination source is removed (Berglund et al., 2000). Contaminated soil may also result in a variety of other environmental compartments being contaminated, and incidental ingestion may cause exposure to contaminants (Nason et al., 2003).

Cadmium absorbed by humans is known to accumulate in the liver, having a negative impact on human health (WHO, 1974). Oral exposure of cadmium may also affect the human immune system (Exon and Koller, 1986; ATSDR, 1993). Children are at particular risk because some of them tend to eat soil. However, the Nordberg et al. (1985) study showed that cadmium compounds are more absorbed by inhalation than by ingestion.

Although cadmium in this study was found at relatively low levels, it does not mean that it will not pose a potential threat to human health. In research done it was found that hypertension of laboratory animals was associated with prolonged low-level feeding on food contaminated with cadmium (Brady, 1974). Environmental factors also play a role in the toxicity of contaminants, such as cadmium and lead. pH is an important factor in this regard (Allen, 2002). Neutral to moderately high pH values (7.04 – 9.49) were measured in soil in the present study. However, the uptake of metals, and the influences of digestive system pH on bioavailability of metals could increase the potential toxicity (The national contaminated sites remediation program, 1996). Cadmium was previously shown to be easily absorbed by earthworms to levels that are orders of magnitude above the concentration present in soil (Rolston et al., 2003). This could also be the case in humans.

Zinc has exhibited the ability to influence the bioaccumulation of cadmium in a mixed metal exposure experiment conducted on woodlice (Odendaal and Reinecke, 2004). This means that the toxicity of cadmium can be changed by other pollutants. Seventy one percent of the metal contaminated sites in the USA reported the presence of multiple metal contaminants (Forstner, 1995). The possibility of a cocktail of metals in the present study increases the potential toxicity and risk to the children. Further field and laboratory studies are needed to investigate this complicating factor.

The range of children potentially exposed to lead in dust and soil is estimated at 5.9 million to 11.7 million children (Mahaffey, 1992). Findings of studies conducted of childhood blood lead levels in South Africa's Cape Peninsula during the late 1980's and early 1990's, showed that there has been ongoing concern for the health of large groups of urban South African children exposed to elevated environmental lead levels (Von Schirnding et al., 2001). A study done by Von Schirnding et al. (1991), demonstrated that the median blood lead level among Cape Town inner city first grade children was 16µg/dL, which is above the international action level of 10µg/dL (Center for Disease Control, 1991). Even at relatively low levels of blood lead, health effects such as neurobehavioral deficits and poor school performance have been demonstrated (Campbell & Osterhoudt, 2000). Lead exposure can also result in reduction of hemoglobin concentration in the blood (Bernard & Becker, 1988). Children of especially the Kloofnek site are at risk, due to the high lead levels found in their environment. However, chronic exposure to low levels of metals, as measured in the present study, can also cause long term toxic effects.

Pirkle et al. (1985) found that exposure to lead heightened the risk of high blood pressure and cardiovascular disease. Lead in the environment and its effects on people's health are a matter of great concern. The estimated number of children potentially exposed to U.S. stationary sources (e.g. smelters) is 230,000 children (Mahaffey, 1992). The children from the Kuilsriver site are at risk because of the proximity of the smelting works. Furthermore, the children from Kloofnek and Mitchells Plain are exposed to relatively high lead concentrations, creating a definite health risk.

Childhood exposure to lead is preventable, and the intellectual cost of not preventing it may be astronomical (Mahaffey, 1992). With an increasing body of evidence, developed over the years and in a wide range of settings, on the health effects of exposure to lead, even at very low levels, many countries have taken action to reduce children's environmental exposure. These actions have included, establishing national surveillance and screening programmes, developing blood lead standards or action values, developing environmental lead standards or guidelines, removing lead from petrol, pigments and paints, and establishing soil abatement and personal and environmental hygiene programmes. For the most part, however, actions to reduce environmental lead contamination, and children's exposure, have been implemented most vigorously and successfully in developed countries, and not so much in developing countries. Lead poisoning is a preventable disease but also a major international issue. In South Africa and other developing countries, childhood lead poisoning will remain a concern as long as sources remain that cause exposure. The challenge is to implement effective national and regional efforts to address specific sources of lead (Harper et al., 2003).

Chapter 5

CONCLUSION

- Cadmium is not a significant contaminant in the soils of pre-school facilities in the CCT. The Cape Town administration area was found to be the most contaminated with this metal.

- This study showed that the Cape Town administration area had the highest lead concentrations in pre-school soils in the CCT. This can be attributed to the higher density of industry and traffic activities in this area. It can be concluded that the children in this area are at a higher health risk than those from the other administration areas.

- This study showed that there were lower metal concentrations in the sandpit soil than in the natural soil. This may be due to the regular replacement of sandpit soil, especially at some of the sites.

- pH plays an important role in the bioavailability of metals. Relatively high pH values are associated with low toxicity (Allen, 2002). In this study relatively high pH values were found throughout the study area. This means that metals found in this study could be regarded as having a potentially low toxicity only as long as the soil remains dry. However, acidification of the soil could increase the bioavailability, resulting in an increased toxic potential of metals.

- There is a need for further research to determine the relationship between soil metal concentrations and blood metal levels, especially in children. The reason for this is that young children are more vulnerable (Henke, et al. 1970) and are more likely to play in soil and some of them may have a tendency to eat the soil, therefore putting them at risk of accumulating toxic levels of metals.

- Although occupational health and safety legislation, that include metal regulations, are in place in South Africa, no similar provisions exist in respect to children (Harper et al., 2003). It is clear that such a need exists to protect children from metal exposure that may be potentially toxic.

- Metals are elements,; therefore they cannot be further decomposed or oxidized. The only solutions to removing their toxic effects are:

  1) To tie these metals up into insoluble substances. Lead contaminated soils, such as at Kloofnek, can be treated by the addition of phosphate to form insoluble Pb pyromorphites (Sauvé, 2002);

  2) To remove soil to another depository;

  3) To bury soil, thereby removing them from circulation in life cycles (Miller & Gardiner, 1998).

4) However, because these methods are either costly or ineffective the use of metal-scavenging plants is also an option to investigate. Good, efficient and cost-effective solutions for metal polluted areas are not available yet and it is difficult to visualize any simple solution to this problem (Miller & Gardiner, 1998). However, for sandpit soils it would be more practical to replace the soil in these pits on a regular basis.

Previous studies have shown that the total concentration of contaminants in soil is not a good predictor of long-term bioavailability or toxicity (Tomson et al., 2003). However, the fact that they are present in the soil and in some cases at relatively high concentrations in the present study justifies further investigations as to these metals' toxicity to environmental and human health.

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