CHAPTER 1

1. INTRODUCTION AND LITERATURE REVIEW

1.1 Environmental Health

Environmental health, as a sub-field of public health, evaluates and modifies the effects of human activity on environmental quality and thus on human health [4]. Environmental threats to human health are many, being divided into "traditional hazards" associated with lack of development, and "modern hazards" associated with unsustainable development [5].

There is a wide range of traditional hazards related to poverty and "insufficient" development, including: lack of access to safe drinking water; inadequate basic sanitation; indoor air pollution from cooking and heating using coal or biomass fuel as well as inadequate solid waste disposal. Modern hazards include:

- “water pollution from populated areas, industry and intensive agriculture;
- urban air pollution from motor cars, coal power stations and industry;
- climate change;
- stratospheric ozone depletion and
- transboundary pollution” [5].

The environmental health hazard pathway is indicated in Figure 1 [6].

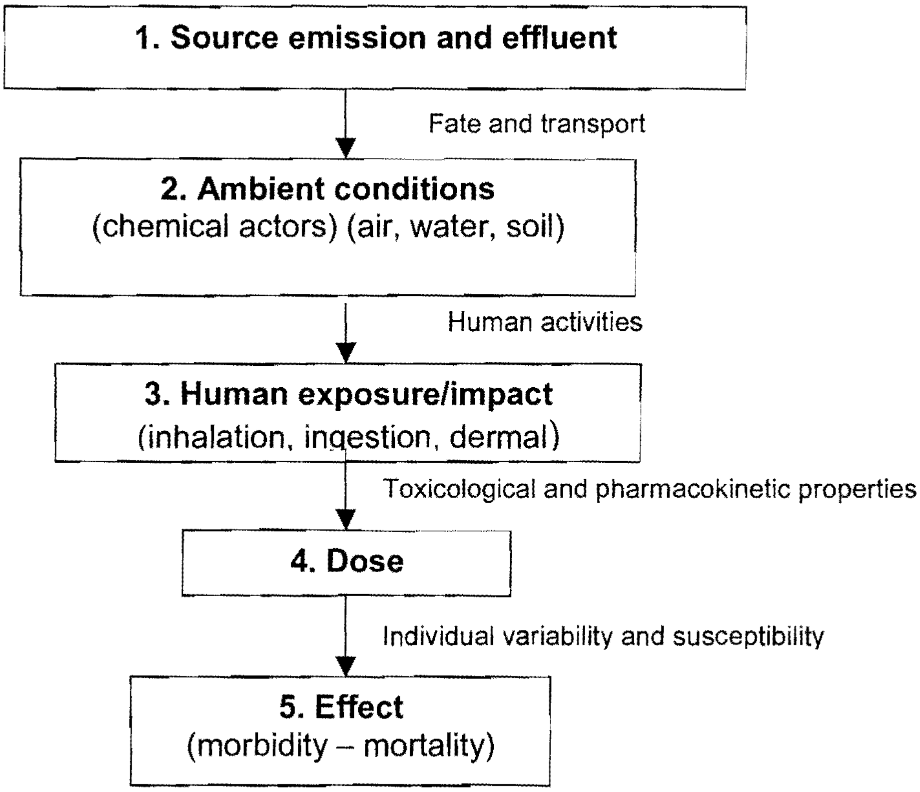

Figure 1. Environmental health hazard pathway [6]

1.2 Health Risk Assessment framework

A central function of environmental health is determining the risk associated with a particular environmental agent or mixture of agents and acting on this information to reduce or eliminate such risk [4, 6].

The concept of science-based risk assessment has been divided into four basic components:

- hazard identification;
- dose-response assessment (often including toxicological studies);
- exposure assessment and
- risk characterization.

The resulting risk is the chance or probability of adverse health effects in those who are exposed [4, 7].

In order to realistically assess and prioritise risks, accurate estimates of both exposure and toxicity are necessary. Most resources have focused on toxicity only. This has resulted in a lack of knowledge about important exposure mechanisms and routes for many agents, which are a major source of uncertainty in many risk assessments [4].

The Health Risk Assessment framework is indicated in Figure 2.

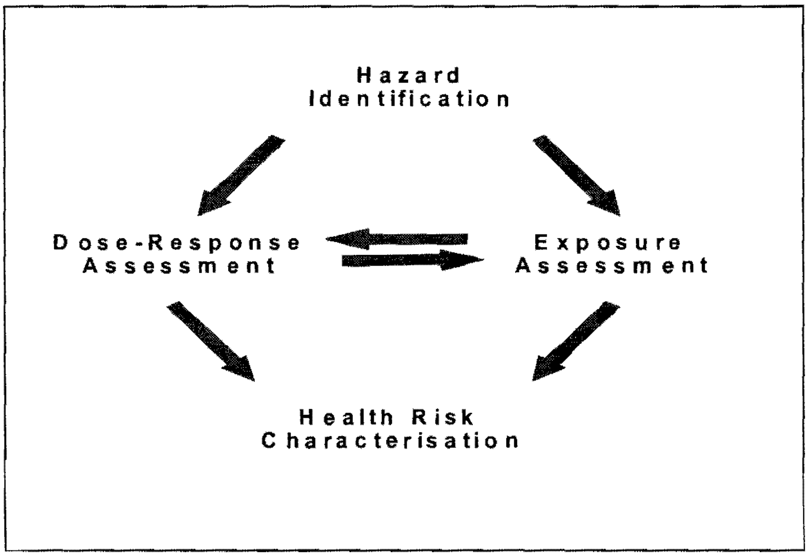

Figure 2. **Health Risk Assessment framework [8].**

1.3 Exposure assessment

During day-to-day activities everyone comes into contact with environmental pollutants through breathing air, drinking water, consumption of food, and encounters with soil or dust. This contact between people and pollutants requires the simultaneous occurrence of two events: (i) the presence of a pollutant in an environmental medium, and (ii) contact between a person and the specific medium. The National Association of Sciences defines exposure to a chemical contaminant as "an event consisting of a contact at a visible external boundary, such as the skin, nose, and throat, between a human and the environment at a specific concentration and for a specific interval of time; the units to express exposure are concentration multiplied by time" [9, 10, 11, 12, 13, 14].

Four basic characteristics are important when describing exposure to an environmental chemical:

(i) Route - exposures may occur via inhalation, ingestion, or absorption;
(ii) Magnitude - the pollutant concentration;
(iii) Duration - the duration of exposure and
(iv) Frequency - the rate at which exposure occurs.

Although concentration is the most commonly reported parameter, exposure data are more useful when expressed as a concentration over a specified time period [14].

Exposure is a key element in the chain of events that begins with the release of pollutants into the environment, and leads to environmentally induced disease or injury, via concentration of the pollutant in one or more environmental media and internal or delivered dose [14, 15].

If there is no exposure, no effects or disease can be expected [10, 7]. This chain of events as shown in Fig. 1 forms the conceptual basis for understanding and evaluating environmental health [9].

Exposure is not necessarily a stable parameter and may display variation over time [16]. Inadequate characterization of exposure tends to bias the results of environmental health studies and may confound causal associations [16]. Accurate assessment of exposure is therefore a crucial element of every study of health effects related to various environmental factors [17].

In recent decades there has been a significant increase in the number and diversity of chemical toxicants to which humans are exposed. Traditional exposure studies focused on occupational exposures, which generally occur at higher levels than community exposures. Serious adverse health effects may, however result from lower exposures as well. Besides agent-specific characteristics, serious health effects at low dose can be due to prolonged, continuous exposure (compared to intermittent exposures in the occupational setting), and due to specific susceptibility of the population involved, such as children whose physical development places them at special risk [15].

1.3.1 Variability and uncertainty in environmental exposure assessment

There is both uncertainty and variability associated with the measurement of exposure. Variability is an inherent characteristic of populations and of physical and biological processes.

1.3.3.1 Variability

Variability can result from the nature and intensity of exposure, the susceptibility to pollutants that may be related to age, lifestyle, genetic background, gender or ethnicity. In addition to human variability, exposures may also vary due to temporal and spatial factors associated with the emissions source, such as wind speed, wind direction, thermal and biological influences [16].

1.3.3.2 Uncertainty

Uncertainty, on the other hand, represents lack of knowledge about the true value of an exposure estimate. Imprecise measurement techniques, sampling error, use of models, and use of assumptions to bridge data gaps all contribute to uncertainty [16]. Uncertainty can be reduced through further studies or improved techniques.

1.3.2 Exposure pathways

Detection of a chemical in measurable quantities in a medium does not necessarily indicate exposure. For an exposure pathway to be complete, a mechanism for transfer of the chemical from the medium to the receptor is necessary. Pollutants can move along different pathways from the emission or source to people [17].

Figure 3 provides a generic overview of the major pathways by which people come into contact with environmental pollutants [6].

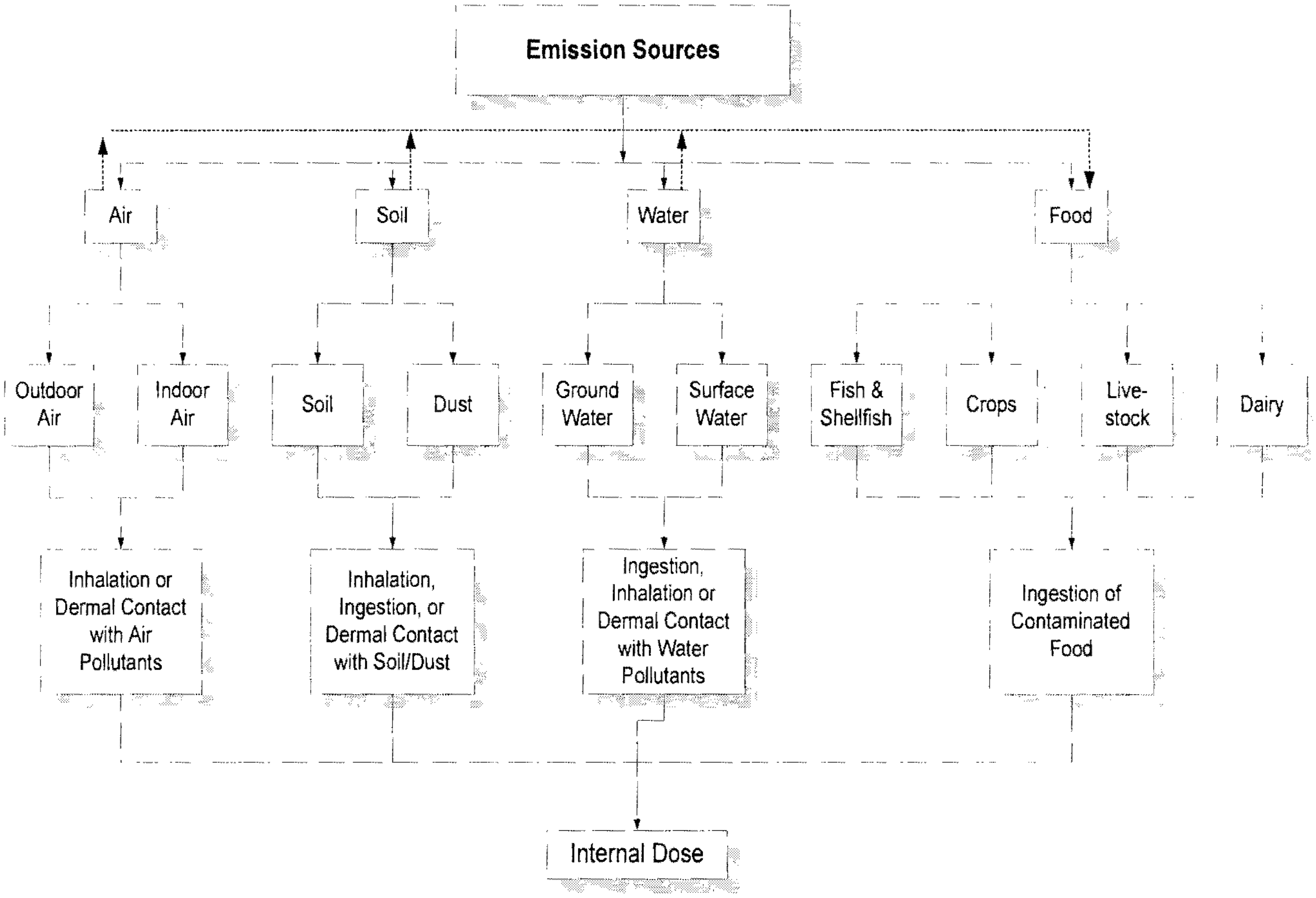

Figure 3. General environmental exposure pathways [6]

These pathways have traditionally been examined individually. Figure 3, however, indicates that multiple pathways can contribute to ultimate exposure and internal dose for a single pollutant. For example, children can be exposed to lead by drinking water, by breathing indoor and outdoor air, by eating paint, house dust, soil, and food - all of which contribute to increased blood lead levels. This reality of multiple, simultaneous exposure pathways and the need to account for it in exposure assessments is the basis for the concept of "total human exposure". Assessment of "total human exposure" estimates exposure through all relevant pathways of environmental exposures experienced by individuals. This should provide a more realistic understanding of exposure patterns [9].

Ideally, all exposure assessments would be based on data reflecting all media and all pathways. In reality, the costs and, in some cases, the technical feasibility limits the ability to achieve this. Therefore, it is most important to focus on those pathways that lead to the highest exposure in individuals or the population of concern. For example, when considering exposure to gaseous pollutants, inhalation is normally the most important pathway [20]. Other routes of exposure should only be investigated once this main pathway has been measured.

1.3.3 Factors influencing exposure of individuals to pollutants

Similar exposures to a pollutant may lead to different health outcomes in different populations as a result of a variety of conditions, including nutrition, ethnic, climatic or geographic conditions, the type of pollutant mixture, or temporal patterns in exposure [21]. For a given exposure, the resultant dose will depend on host characteristics including age, gender, metabolism, breathing rates and activity patterns [13, 22].

Children are a specially vulnerable group with respect to air pollution exposure because of their stage in physical development, their higher rates of metabolism, and their higher exertion levels [16, 23, 24, 25]. Children's exposures to environmental contaminants could be expected to be different, and often higher from those in adults [26, 20]. They drink more water, eat more food and breathe more air per kilogram body weight than adults. Differences in exposure are therefore partly due to differences in physiologic function and surface-to-volume ratio. However, differences in the behaviour of children, particularly the way in which they interact with their environment, may also affect the magnitude of exposure to contaminants [20]. Childhood diseases associated with these reasons for increased exposure include birth defects, asthma, leukaemia, and learning disabilities [20, 27, 28].

1.3.3.1 Characteristics of children of relevance to environmental exposure assessment

Both physiological and behavioural characteristics have an effect on children's exposure to environmental contaminants. These characteristics are a function of age, sex, race/ethnicity, and socio-economic status (SES)[26]. Children's activities and physiological status change substantially from birth to maturity. All of these characteristics make it difficult to categorise children and collect data on their exposure. Children should not be treated as one group, and differences in physiology and activity patterns compared to other children and to adults should be considered when conducting research on environmental exposure [20].

Not much data are available on the magnitude of children's exposure to most environmental toxicants, except for exposure to lead and to environmental tobacco smoke (ETS). Information on the nature of their unique susceptibility to these toxicants is even less available. To rectify these gaps in information, exposure assessment tools and strategies specifically suited to measure exposure in children need to be developed, validated, and refined [18].

Physiological development

The ratio of surface area to body weight is larger in children than in adults, with the surface-area-to-body-weight ratio for newborn infants being more than twice as high as that for adults. This ratio decreases by approximately one-third within the first year of life and reaches adult values around 17 years of age. The high ratio results in a relatively high loss of body heat to the environment, necessitating a higher rate of metabolism to maintain body temperature. In addition, children need extra metabolic energy for growth and development. These two factors are the most important reason for the greater needs for food and oxygen per kg body weight in children compared to adults. The higher breathing rate and food consumption rate required to meet these physiological demands will result in relatively higher exposures to environmental contaminants in air and food in children compared to adults in the same environment [26, 29].

The absorbed dose is influenced by age-dependent barrier properties of the skin, the respiratory tract lining, and the gastrointestinal tract lining. The permeability of the skin is highest at birth and decreases in the first year to such an extent that the skin of a one year old is similar in terms of permeability to that of an adult. In addition, a subcutaneous fat layer develops at approximately 2-3 months in infants and persists through the early toddler period. This layer can act as a sink for lipophylic chemicals absorbed through the skin. Changes in the permeability of the lung epithelial cells during childhood have not been reported. However, the alveoli continue to develop until adolescence, increasing the surface area for absorption so that the same exposure might lead to a higher absorbed dose as a child ages [26]. The period required for complete development of the human lung extends over the first 6-8 years of life. The developmental events occurring during this period are the continuation of events that begin before birth and include cytodifferentiation of epithelial and interstitial cell populations, morphogenesis and reorganisation of the gas exchange area, and the development of the respiratory mucosal immune system [30]. The developing lung may be seriously affected by exposure to environmental agents. This can be illustrated by studies of the effects of environmental tobacco smoke on pulmonary function in children. It has been shown that the forced expiratory flow rates (FEV_1) of children exposed to environmental tobacco smoke (ETS) are measurably lower than children with no exposure [29].

After birth, the gastric pH is relatively high, and only reaches adult levels of acidity after several months of age. Gastric pH affects absorption by changing the ionisation state of chemicals. Absorption and permeability in the gut are also regulated to provide nutritional intake appropriate for age. For example, calcium absorption in children is much higher than in adults, probably to satisfy growth needs. The same mechanism used to actively absorb calcium is also responsible for the absorption of similar positive ions such as lead. It has been estimated that an adult will absorb only 10% of ingested lead, compared to 50% ingested by a 1-2 year old child [26, 29].

The tissue distribution of chemicals also varies with the developmental stages of a child. It has been shown from animal models that more lead is retained in the infant animal brain than in the adult. Lead also accumulates faster in children's bones. This accumulation rate doubles from infancy to the late teen years [29].

Kidney function is yet another mechanism that is influenced by development. Glomerular filtration rate at birth is only a fraction of normal adult values. It increases to adult values by about one year of age. The ability to concentrate urine only reaches adult levels at around 16 months of age. Finally, children also differ from adults because their organs are still growing and differentiating, and exposure to environmental pollutants may disrupt both of these processes resulting in different pathology than in adults [29].

Behavioural development

Children's behaviour and the way children interact with the environment influences the magnitude of their exposure to contaminants [26, 29].

The way in which infants and toddlers move (i.e. crawling, using hands) is different from the way in which adults move, and this places them at significant risk for exposure to contaminants in the air and on residential surfaces that may not be as important for older children and adults. As the motor function of children develops, they will spend less time playing on the floor and touching other potentially contaminated surfaces [26].

It can be problematic to use developmental milestones as often used by paediatricians, and other health and education workers, as indicators of exposure in children because there is great variation between the time of first achieving a milestone and the time of performing the same activities regularly, and between different children reaching the same milestones. Developmental milestones may, nevertheless, provide a useful basis for categorizing children in exposure studies in the absence of more precise criteria [26].

Children's "mouthing" behaviour, with its potential for contacting and moving contaminants from objects and surfaces in the environment, needs to be characterized and quantified. An infant will put almost all objects in their environment into their mouths during the first two years of life as a means of exploring their environment, while young children transport objects by using their mouth as a third hand. Teething, which includes biting and chewing of fingers and objects, is also an important stimulus for mouthing activities and usually starts between 4 and 7 months of age. Mouthing activities will vary from child to child resulting in a highly variable impact on exposure [26].

The breathing zone for a child is much closer to the floor than that of an adult and the exact zone depends on the mobility and height of the child leading to different exposures from those of adults in the same spaces. Within these zones, for example, heavier chemicals such as large respirable particulates settle out and radon accumulates rendering a child more susceptible to these pollutants [29, 26, 31].

<u>Physical activity</u>

Exposure to contaminants is also a function of the following aspects of physical activity:

(i) The type of physical activity, such as playing games or watching television

(ii) The location of the physical activity, such as outdoors, at school or in the living room, but also temporal location of activity

(iii) The intensity of the child's activity level while engaged in physical activity [26].

Different activities result in different exposures by different pathways. The location where a child is engaged in physical activity determines the exposure media that are contacted, while the intensity of the child's activity level determines the contact rate with those media. Differences in duration and frequency of periods spent in particular locations lead to different exposures and risks to children. This varies with age and developmental stage. Seasonal and geographic differences in activity patterns, and differences in the use of indoor and outdoor spaces may result in additional variation in exposure among children of similar developmental stages [26].

Studies conducted in the Vaal Triangle indicated that South African children spend up to 20% more time outdoors than children in the United States of America. This can have important consequences for their total exposure to industrial and other forms of pollution [32, 33].

Diet and eating habits

Children's diets are very different from those of adults. Young children and infants eat more fruit and milk products in proportion to their body size than adults [29]. Some infants and toddlers may go through phases where only a few preferred foods are eaten for long periods of time, potentially modifying the dietary exposure of young children to environmental contaminants, such as, pesticide residues in fruit, compared to adults [26].

The way in which children handle food while eating may also influence their exposure to environmental contaminants. Small children may sit on the floor to eat and often pick up and eat foods that have fallen on the ground. They also eat most of the food with their hands rather than with utensils. Exposure to environmental pollutants will be higher when children handle and eat foods that have come into contact with the floor or other contaminated surfaces[26].

Gender

The location in which children spend their time may also be influenced by gender, especially in older school-aged children. Boys in this group are more likely than girls to play outdoors, and are more likely to be involved in energetic activities, whereas girls are more likely to sit and go for walks. Thus, when assessing exposure for school-aged children, gender differences in activity level and activity type need to be considered. There are insufficient data to indicate whether there are gender differences in the activity levels of infants and toddlers. It would be useful for exposure modelling to know at what age the gender differences emerge as well as the extent to which these influence exposure [26].

Health outcomes may also differ by gender. There are gender-related differences in rates of growth and in maximum lung size, with girls achieving this earlier than boys. Girls may therefore be more affected by air pollutants than boys, or at least the maximum effects of pollution may be seen at different ages [26].

Socio-economic status (SES)

The SES of the child is likely to affect the child's exposure to environmental contaminants. Although there is evidence to suggest that low-income groups tend to be more exposed to many environmental pollutants than the general population, data to characterize the relationship between SES, ethnicity/race, age and exposure are insufficient [26].

Environmental factors that may be influenced by SES include:

(i) Residence - whether it is an urban, suburban or rural area;

(ii) Proximity to source of pollution, such as distance from a toxic release inventory site;

(iii) Housing, including the age, condition and type;

(iv) Activity patterns, including hygiene, housekeeping, activity level, child care; and

(v) Diet and drinking water supply [26].

Although data are available on the influence of housing, location and SES on environmental exposure and adverse health outcomes in adults and children, there is not an abundance of data on the relationship of these influences on children's activities and potential contact with the environment. Proximity to parks and play areas and the floor on which children live in a block of flats may influence where young children play and the amount of time urban children play outside [26].

Race or ethnicity

No difference in the behaviours of children of different races has been found in day-care centres in the USA. This does not mean that differences that are culturally or economically driven might not exist when the children are at home or away from the day-care setting [26]. In South Africa, however, race is likely to influence whether or not children attend day-care centres, and also the type and quality of centres.

Physical location

Children's physical location changes during their development. The newborn is usually near the mother or held by the mother, leading to very similar exposures to those experienced by the mother. The newborn often spends more time in one environment for long periods of time, rather than in several different environments. Infants and toddlers are often put on floor surfaces. They will therefore be more exposed to chemicals associated with these surfaces. Children in these stages may therefore experience continuous exposure to noxious agents because they are not able to move from their environment [29].

Infants in urban areas seem to be at increased risk of mortality due to ambient air pollution, and both rural and urban children develop asthma and acute respiratory infections (ARI) as a result of exposure to indoor and outdoor air pollution [5].

School-aged children spend a significant part of their time at school, which can be very different from their home environment. Schools are often built on land that is relatively unattractive for economic reasons. These sites may be near highways, under power lines, or on old industrial sites [29].

Adolescents begin to have greater autonomy in determining their own physical environments, often misjudging or ignoring the risks to themselves. Many adolescents may also be placing themselves in hazardous occupational environments resulting from activities such as part time jobs [29].

Vehicular congestion found in a city along with the tall buildings restricts airflow and thereby provides increased opportunity for contamination through respiration. Air pollutants that are found near busy roads as a product of traffic exhaust, such as NO_2 and particulate matter, have been shown to be associated with respiratory illnesses in children [34]. Airborne contaminants fall to the ground, where children sit and play, leading to higher levels of exposure. In addition, the application of pesticides occurs in urban areas for pest control in homes, gardens, schools, and golf courses [35]. The health effects of airborne pollutants are mostly caused by personal exposure in indoor micro-environments, rather than by levels of pollution in ambient air [36]. A ‘micro-environment’ is a physical three-dimensional space with a well-characterised, relatively homogenous pollutant concentration level over a specified period of time [37]. There is consistent evidence that indoor air pollution increases the risk of chronic obstructive pulmonary disease and of acute respiratory infections in childhood, one of the most important causes of death among children under 5 years of age in developing countries [12, 38, 39].

In summary, environmental exposure in children is substantially different from exposure in adults who occupy the same environmental space, and this should be taken into consideration when attempting to measure the health effects of pollution in children. Yet, specific exposure data for children are not readily available.

1.3.4 Pollutants of concern for children

Most children, even in South Africa live in urban and peri-urban environments facing urban problems such as traffic, smog, industrial plants, and older housing. Chemical releases from incinerators, factories and support services, such as dry cleaning, also contribute to the ambient mixture of toxins to which children can be exposed daily. Environmental pollutants associated with urbanization can easily impact on the growth and development of children [26, 40].

Chemicals that pose hazards to children based on their potential for high exposure in children or, because children have unique susceptibilities to them, are especially important. Criteria that can be used to determine whether air pollutants are of major concern for children's health include:

- Presence in residential or school air;
- Presence in soil and dust in and around residences and schools; and
- Presence in tissues of children [20].

On this basis, the following pollutants, associated with indoor and outdoor air pollution are of great importance: solvents, pesticides, lead, mercury, polychlorinated biphenyls (PCBs) and other heavy metals [23, 26]. Only a few have been adequately studied. These are listed in Table 1, together with their pathways of exposure.

Table 1. Pollutants of concern for children and pathways of exposure

Pollutant	Likely sources	Health effects/target organ	Most important pathways of exposure [a]		
			Inhalation	Ingestion	Dermal absorption
Particulate matter (PM2.5 and PM10)	Combustion processes, re-condensed organic and metal vapours and acid aerosols [80]	Acute: increases in asthma attacks and bronchitis Chronic: increased risk of chronic respiratory disease, cardio-respiratory mortality [52]	1	1-3 (depending on pollutant adsorbed to particle)	NA
Lead	Lead dust, lead-based paint, contaminated soil [33]	Neurotoxicant in children [18]	2 (25-40% through inhalation)[33]	1	3 (rare)
Pesticides	Insecticides, pesticides at home, work [16, 51]	Many	1	2	1
NO_2, SO_2, O_3	Motor vehicles, power plants [51]	Respiratory [51]	1	NA	NA

NA Not applicable
a 1-3 indicates the relative importance of the specific pathways for exposure in children; 1=most significant, 3=least significant

The effects on health of particulate matter and lead exposure in children are particularly relevant in this study, therefore these two pollutants are discussed in more detail below.

1.3.4.1 Particulate Matter

Airborne particulate matter is a complex mixture of pollutants released from many sources, the most important of which are industries, motor vehicles, residential wood burning, and construction and demolition. Airborne particulate matter is usually found in a range of sizes. Particulate matter is generally thought to provide a good indicator of the health damaging potential of air pollution, and there are well-established techniques for measuring it, with levels expressed as the weight of the particles in micrograms per cubic metre of air sample, written as ug/m^3 [41, 42, 43, 80].

Coarse particulates ($PM_{2.5-10}$) are mostly produced by mechanical processes, such as wear and tear on motor vehicles, industrial processes, fugitive dust from roads and industries, as well as cooking and resuspension of particles resulting from cleaning or from people's movements. Fine particulates ($PM_{2.5}$) originate from combustion processes, re-condensed organic and metal vapours and acid aerosols. Combustion particles are generally below 1 micron (µm) in aerodynamic diameter [44, 80]. Manmade sources are usually concentrated in urban areas where populations are concentrated. Particulate matter can be classified as aerosols, fog, fumes, mist, smog or smoke, depending on its physical state and origin [45]. Particulate matter in the air may deposit on and cause damage to plants, metal surfaces, fabrics and buildings. It may enter soil and surface water as a result of wet or dry deposition and thus contaminate the soil and water, depending on the chemicals adsorbed to the particles.[44].

The personal exposures to particulate matter have rarely been studied in children. Studies among adults indicate a poor correlation between outdoor concentrations of particle mass and personal exposure. The use of outdoor concentrations of PM_{10} as a proxy measure for personal exposures can, therefore, misclassify personal exposure and result in an attenuation of exposure-response relationships [46]. Most personal exposure studies have related daily variations in outdoor concentrations to daily variations of health end points. At present only limited information is available on the correlation within one subject between personal and outdoor concentrations of PM_{10} [44].

Table 2 outlines the advantages and disadvantages of measuring different sizes of particulate matter over different periods of time.

Table 2. Measurement of particulate matter: Usefulness of site and duration of measurements

	TSP	RSP	PM2.5
Monitoring over an 8-hour period			
Advantages	More readily detected by available equipment over shorter exposure periods*	More health relevant – respirable and penetrate deeper into lungs; more relevant for estimating lead exposure	Most health relevant – very fine particulates, penetrating very deep into lungs – absorbed into blood stream – most relevant fraction for lead exposure assessment
Disadvantages/ limitations	Contains particles that are both respirable (< 10 µm) and not respirable (> 10 µm)	Limited by available equipment* Low probability of detecting measurable amounts in clean ambient environment over short periods (eg 8 hours)	Available equipment* not able to detect enough in clean ambient environment Applicable equipment not available
Monitoring over a 24-hour period (or 2 consecutive 8-hour periods)			
Advantages	Readily detected by available* equipment	High probability of detecting sufficient particulate matter	High probability of detecting sufficient particulate matter
Disadvantages/ limitations	* May dilute peak exposure data * Logistical – will have to return to day-care centre * Available monitoring equipment cannot monitor continuously for a period longer than 12 hours before recharging – will have to use alternative monitoring equipment		

TSP: Total suspended particulates
RSP: (Respirable Particulate Matter) Particulates with an aerodynamic diameter of less than 7 µm
PM2.5: Particulates with an aerodynamic diameter of less than 2.5 µm (fine particulate matter)
* Available equipment: Gillian monitoring pumps

Health effects of PM

Exposure to indoor air pollution, especially to particulates, resulting from the combustion of biomass such as wood, crop residues, dung and charcoal has been implicated as a cause of respiratory and eye diseases, including conjunctivitis and possibly cataracts, and blindness [47]. Exposure to coarse particles is primarily associated with the aggravation of respiratory conditions, such as asthma. Particles with diameters below 10 µm, and particularly those of less than 2.5 µm in diameter, can penetrate deeply into the lungs and appear to have the greatest potential for damaging health [12, 48, 49]. Fine particles are most closely associated with such health effects as increased hospital admissions and emergency room visits for heart and lung disease, increased respiratory symptoms and disease, decreased lung function, and even premature death [5, 51].

In considering susceptibility to PM, the following characteristics are most relevant for assessing potential health effects:

(i) Particulate size;
(ii) Chemical components in particulate matter;
(iii) Biological components in PM such as pollen, spores, viruses, or bacteria; and
(iv) Anthropogenic PM components

Epidemiological identification of adverse health effects associated with increased PM levels has resulted in greater attention being given to susceptible subpopulations such as asthmatics, children, and persons with cardiopulmonary disease [50]. Children are especially sensitive to particulate matter, which may cause respiratory disease and aggravate asthma. Exposure of the mother to particulate matter early in pregnancy has also been implicated in adversely affecting foetal growth [40, 51]. There is a mounting body of evidence that there is an association between urban particulate air pollution (specifically fine airborne particles) and overall morbidity and mortality [5,16,52,53,54,55,56,57]. Research has also shown that children, who breathe smoggier air, have lower lung function growth than children who breathe cleaner air [58].

1.3.4.2 Heavy metals such as lead (Pb)

Of all the pollutants to which exposure occurs via multiple pathways, lead is probably the best known and most studied. Lead, a heavy metal, is found in air, soil, and water and it can be inhaled, ingested or absorbed. Environmental sources of lead include leaded petrol, stationary sources such as smelters, uncontrolled burning of waste, burning of solid waste or biomass for cooking purposes, refuse incineration and environmental residues from previous motor vehicle emissions. All the above leads to deposition in dust, soil, food and water [74, 69, 59].

Potential sources of lead in buildings and schools include lead contained in roof materials and in paint on the surfaces of buildings [60]. Children aged between 1 and 5 years, and foetuses are the most sensitive to the adverse health effects of lead [33, 51, 61, 62]. Individual exposures to lead as well as the uptake efficiencies of individuals vary significantly. Control of human lead intake requires attention at all potential sources [70].

Lead emissions from motor vehicles

The average particle size of lead particulate matter emitted from motor vehicles is slightly less than 1 µm; and ranges from 0.1-10 µm. Almost half the lead emitted in exhaust fumes is less than 0.25 µm in size, while approximately 90% is completely respirable [63]. Motor vehicle fuel consists of many different compounds of lead that can be emitted into the atmosphere [62, 63, 64].

Most of the lead (90%) found in the atmosphere of a city is from motor vehicles. Studies have shown that there is a relationship between (i) traffic volume, (ii) proximity to the highway, (iii) engine acceleration versus constant speed, (iv) wind direction and the amount of lead in the air [64, 65, 66, 67, 68, 69]. The atmospheric “residence time” of lead is dependent on the size and weight of particles as well as on meteorological conditions. Most airborne lead derived from traffic falls within 100 m of the road. This area is also referred to as the near exposure zone. Fallout levels decrease exponentially with distance from the road [33]. Lead emitted into the atmosphere has a lifetime of around 7-30 days and may therefore be subject to long-range transport [64].

Table 3 provides information on traffic density and lead concentration in the air in Cape Town in 1996, when no unleaded petrol was available.

Table 3. Traffic density and atmospheric lead in Cape Town in 1996 [64]

Density of traffic (vehicles/day)	Lead content in air (µg/m^3)
>20 000	2.1
18 000	1.3
8 000	1.3
1 000	0.9
250	0.4-0.7

The decrease of lead in petrol has resulted in a marked reduction in the atmospheric levels in many countries [70]. No studies have been found to document the impact of the introduction of lead-free petrol on air levels of lead in South Africa.

Fate and transport of lead

Atmospheric lead falls as either wet or dry deposition. Lead is relatively immobile in soil. It enters the soil as lead sulphate, or is converted to this compound, which is relatively soluble and could leach through soil if not transformed. Soils with a pH greater or equal to 5 and with at least 5% organic matter retain atmospheric lead in the upper 2-5 cm of the undisturbed soil. Urban areas tend to have higher concentrations of heavy metal contaminants, including lead, than rural areas due to the greater amounts of atmospheric deposition [62].

Human exposure to lead

Human exposure to lead arises from the following main sources:

(i) Inhalation of airborne particles. Adults inhale about 20 m^3 of air daily. Therefore, if an urban lead concentration of 0.1 $\mu g/m^3$ is assumed, intake is 2 µg/day. As the efficiency of lead absorbance is about 70%, it can be estimated that an average adult has in intake of 1.4 µg per day. Cigarette smoking also exposes an individual to lead.

(ii) Ingestion of lead through food. The concentrations of lead will vary between different types of food and even between different batches of the same food. Absorption of dietary lead is much higher in young children than in adults [70].

(iii) Drinking water and beverages. Concentrations of lead in drinking water vary greatly, due to the presence or absence of lead in the household plumbing system. Gastrointestinal absorption of lead from water and other beverages is very dependent upon food intake. Absorption of lead is delayed after meals [63].

(iv) Ingestion of lead-rich surface dust by children through hand-mouth activity. Many studies have indicated that surface dust and soil are very important lead pathways for children and infants [63, 71]. Lanphear and Roghmann found that dust lead loadings ($\mu g/m^2$) were more predictive of children's blood lead levels than dust lead concentrations (µg/g) [60].

Although decreasing in many developed countries, lead exposure remains a major public health issue in cities and industrialized areas in developing countries [5]. It is estimated that about 80-90% of lead in urban air in these areas is derived from leaded petrol. However, research shows that only 25-40% of total human exposure is through inhalation of lead-contaminated dust. The major pathway is ingestion [33]. The relative importance of the inhalation and ingestion exposure routes differs between children and adults. Adults absorb

15-70% of inhaled lead compared to only 2-17% in children. However, children inhale a greater volume of air in relation to body size and can therefore build up a relatively larger dosage. In the case of ingestion, children absorb up to 50% of lead ingested while the figure for adults is 10% [72, 73]. A study has indicated that the highest average blood lead levels were found in 5-year old children because this age group tends to play for longer periods in contaminated environments [74]. It has also been recorded that there is a higher incidence of lead-related poisoning during the warmer months [61]. No reason was provided for this.

No childhood blood surveillance programme is in place in South Africa, although a number of epidemiological studies involving the determination of blood lead levels have been undertaken in various parts of the country over the last 15 years [75].

1.4 Methods of estimating exposure of children to pollutants with specific reference to lead

Actual exposure of children to pollutants can be measured either directly through personal monitoring or indirectly by combining information on pollutant concentrations with information on their activity patterns in each micro-environment where the children spend time. Information on these activity patterns is useful for understanding the relationship between levels of pollution and behaviour [76, 12].

1.4.1 Direct measurement of exposure

Direct exposure assessment measures contact with a chemical in a medium over a specific period of time, often using more than one personal monitoring technique, including:

(i) Micro-environmental samplers, such as passive samplers that measure average concentrations of airborne lead over a period of time;

(ii) Personal monitors, such as active samplers worn by volunteers that measure real-time concentrations of airborne lead; or

(iii) Biological measurements in human tissues, such as determination of blood lead concentration [9, 77].

1.4.1.1 Micro-environmental samplers

Micro-environmental samplers such as passive badges uses a lightweight, relatively tamper-resistant monitor that can be used on children. Problems may arise when using these and other personal monitors in pre-school children, as it might be difficult to explain the implications of tampering with the equipment to young children. Personal NO_2 measurements with diffusion samplers have been used among pre-school children, although rejection of a large amount of sample tubes can be expected when used on small children [13, 26, 36, 78].

1.4.1.2 Personal monitoring

Personal air exposure monitors are devices that are worn on the person and that can therefore measure an individual's total exposure[14]. Although these monitors do not measure resulting body burden, they do estimate the intensity of an individual's total exposure to airborne agents better than fixed-site area monitors. Personal air monitors have been found to be acceptable to subjects from 7 to 85 years of age. Monitoring backpacks that can be worn successfully by children of all ages have, however, not been developed yet. Personal monitoring is therefore seldom done for infants or pre-school children [18, 26, 13, 78, 79].

1.4.1.3 *Biological monitoring*

There has been great interest in the development of biologic markers for exposure because of the difficulty of obtaining accurate and unbiased exposure information from study subjects using samplers and because of difficulties in estimating the actual dose that exposure can produce. Biologic markers generally give a quantitative, or at least semi-quantitative, estimate of dose [13]. Some biological markers may provide an estimate of cumulative exposure, for example bone lead, mercury or cocaine in hair. However, most biological markers can assess only relatively recent exposure [13]. Biological monitoring is best done in combination with other modes of exposure assessment, including exposure questionnaires or monitoring in air, water or soil [18, 80]. Table 4 outlines the different biomarkers that can be used in assessing lead exposure together with their advantages and disadvantages.

Table 4. Different indicators of lead exposure

Exposure indicators	Uses/Advantages	Disadvantages
Blood	- Reflects acute exposure (within 3-6 wks) [81] - Through all routes of exposure	- Ethics – obtaining consent - Traumatic experience for pre-school child - Contamination potential - HIV risk for both those who take samples and do analysis - Does not provide indication of long-term exposure - Does not differentiate between routes of exposure - Influenced by extraneous factors, such as variation in analytical methodology [82] - Special EDTA blood containers
Hair or nails	- Provides information regarding tissue storage and long-term exposure (1-3 months) [82] - All routes of exposure - No special procedure for storage	- Ethics – obtaining consent - Does not provide information on acute exposure - Analysis very expensive - Does not differentiate between routes of exposure - Only minute amounts excreted - Inconsistent laboratory results
Urine	- Total excretion of lead over 24-hours [83]	- Ethics – obtaining consent - Only minor amounts excreted - Concentration varies widely throughout the day [83] - Does not differentiate between routes of exposure - Must be kept at 4 °C

1.4.2 Indirect measurement of exposure

Indirect measurement estimates exposure by combining information on concentrations of chemicals in the environment with information about the timing and nature of individual contact with the chemical. In using this approach the actual exposure for the individual is not measured but instead an 'average exposure' is assigned based on observations of activities in which the person engages. This approach relies on validated models of exposure that were developed using direct measurements [84]. The specific information needed to conduct an indirect assessment depends on the specific routes of exposure for the contaminant [21, 26, 76, 77].

Information on the following exposure factors is required to be able to undertake an indirect assessment of exposure:

(i) Contaminant concentrations in the exposure media in the environment where the individual spends time;
(ii) Activity patterns which, amongst others determine contact rates of the individual with the exposure media;
(iii) Contaminant transfer efficiency from the contaminated medium to the portal of entry; and
(iv) Contaminant uptake rate(s) [26].

The major advantages of the indirect method are lower costs and ease of use. The indirect approach also poses less of a burden on the respondent. A major disadvantage is that it is vulnerable to systematic measurement error in the predicted exposures because the micro-environmental concentration data required are not available and, therefore, might need to be borrowed from other sources. The data-intensive nature of the indirect approach, especially the need for a detailed assessment of human activity patterns, makes validation of this approach difficult [76, 77].

As there is generally a lack of exposure data for children and because the models used for adults are unlikely to be valid for children, the indirect approach is not as reliable for children as it is for adults [18]. It is difficult to develop and verify exposure factors such as contaminant uptake rates and transfer rates for young children because they cannot intentionally be exposed to contaminants and, therefore, controlled laboratory studies on children cannot be conducted. Using adult surrogates for these studies introduces errors, because adults do not behave like young children and therefore cannot mimic their contact activities. It is also difficult to collect personal air, blood, urine and duplicate-diet samples from children.

It is difficult to accurately record the activity patterns of children. Direct observation, which may include videotaping, is considered to be the most accurate way to record a child's activities, but this is relevant only for dermal absorption and ingestion, not for respiratory exposure. Children are also involved in a wider range of contact activities than adults, and therefore a much wider distribution of activities should be considered for recording. To develop realistic estimates of children's exposures to environmental contaminants it is essential to understand and quantify children's activity patterns [26].

To complicate matters even further, it needs to be understood that an important difference between exposure in adults and children is the variability that age-specific development introduces to exposure. Finally, even if an age-specific model of exposure is available for a "typical child" at a certain age, the model will be inaccurate for individuals who are delayed or advanced in their physical or mental development [26].

1.4.2.1 Questionnaires

Questionnaires are the least expensive method of obtaining either retrospective or prospective information on the exposure to environmental pollutants of large populations, and this has been the method most commonly used for exposure assessment in epidemiological studies [85]. In environmental epidemiological studies, questionnaires may be the method of choice for assessing exposure because no other source of exposure information is available. They may be used alone or in combination with other types of exposure assessments.

Problems associated with the use of questionnaires include the fact that there may be large differences in the understanding of the questions between the designer of the questionnaires and the study participants. There may also be a lack of content validity because the questionnaire does not cover all sources of exposure. The validity of exposure data obtained by questionnaires can, in principle, be addressed by comparing these with data obtained from biological monitoring, personal exposure monitoring, other monitoring procedures, time-activity data, or from historical records of exposure [86, 21]. When used for young children, questionnaires introduce another potential source of error related to proxy reporting and recall bias [85].

1.4.2.2 Time-activity patterns

Temporal characteristics of exposure, including duration, time of occurrence and repetition is important in estimating an exposure-response relationship. Among the methods that can provide exposure estimates with sufficient time resolution are methods that combine measurements of pollutant concentrations in micro-environments with measurements of patterns of time-activities of individuals [31]. These methods are usually called ‘time-activity’ studies or studies of ‘time-activity patterns’ (TAPs) [21]. Recording TAPs involves getting information on 1) where individuals spend their time and 2) what their activity level is in each instance. This information, coupled with measurements of average air pollutant levels in the different micro-environments where individuals spend their time, provides a better estimate of their air pollution exposure compared to exposure assessments using fixed site monitors [87].

Time-activity patterns may act as a modifier of the relationship between the available exposure and the 'true' exposure of the individuals under study. The 'true exposure' can be derived from the equation:

$$E = \sum C(i) * t(i),$$

where E = exposure of an individual, C(i) = concentration in micro-environment i, t(i) = time spent by the individual in micro-environment i [88].

Time-activity patterns can be measured by time-activity diaries (TADs) or data logging instruments. In TADs, participants register where they have spent their time and how they have spent it. TADs provide ongoing records of the micro-environments in which the study participants engage in daily activities. Additional questionnaires can provide information on additional characteristics about the micro-environments such as the type of appliances used in the home. The rationale for TADs to estimate human exposure to air pollution, is to quantify the time spent in activities that provide opportunities for exposure [10]. These activities may include personal, cultural, geographical and socio-economic factors that can affect the duration and frequency of exposure for individuals or for populations [7].

The potential of TADs

The interest in TAPs, in combination with TADs, as measures of the level of exposure to indoor and outdoor pollutants, has increased in recent years [87]. It is cheap, easily multiplied, very flexible, provides a permanent record and can be designed for direct computer reading. TAPs also provide important information when exposure is assessed indirectly from pollution dispersion modelling or from other sources of micro-environmental data [89].

TADs are useful for obtaining exposure information for children. TAD information can be provided by parents over the course of a study period, especially when the children are very young [18]. Although the idea of asking children to keep diaries may seem unrealistic, the concept of tracking activities will not be foreign to most primary school children as they are taught to complete numerous exercises that require listing activities over various periods of time. Even so, care should be taken to ensure that the diaries fit the comprehension level of the age group under consideration [77, 91].

TADs allow only for a rather rough time and location resolution. Completion of TADs is also demanding and invades privacy. The precision of data obtained from TADs is variable because of varying levels of care, precision and understanding of subjects. Data validation is therefore difficult and subjective [11, 85]. If applied for long periods of time, TADs requires high motivation from subjects which poses real limits on study designs. Methods of time-activity monitoring by active or passive electronic instruments have been developed to overcome some of these limits by making the data entry easier and more accurate, or by removing individual judgment from data entry [90].

A child's exposure is influenced to a great extent by the micro-environment in which the child is located. The activity in a particular micro-environment can be described by what the child is doing, such as watching television, eating, playing games, or crawling around on the floor. This type of information has been used since the early 1980s to assess inhalation exposure. However, in recent years it has become obvious that general activity descriptions do not provide enough information on the specific contacts with exposure media that occur within a micro-environment to estimate dermal and non-dietary ingestion exposure [91]. To become more specific, activity levels have been divided into three to five levels, in previous studies, ranging from low to high activity [37, 87, 92, 93].

In further response to the need for more detailed information, a distinction can be made between macro- and micro-activity information. The former has been described above. Micro-activities, on the other hand, are detailed actions occurring within a general activity, e.g. hand-to-surface and hand-to-mouth behaviour [26].

Activity pattern data requirements are determined by means of algorithms used to estimate exposure by inhalation, dermal contact, and ingestion. These algorithms for combining the environmental monitoring data with the exposure factors to estimate an exposure or a dose may be used to guide the type of data collected to assess children's exposures [26].

Inhalation exposure assessment

Inhalation exposure can be estimated for each of the micro-environments in which a child spends time and each macro-activity that would result in a different inhalation rate while performing that activity. Exposure over a 24-hr period would then be the sum of all of the micro-environmental/macro-activity ($_{me/ma}$) exposures [26].

For each individual micro-environmental/macro-activity ($_{me/ma}$), inhalation exposure over a 24-hr period ($E_{me/ma}$) is defined as:

$$\mathbf{E_{me/ma} = T_{me/ma} * C_{ame} * IR_{ma}} \qquad \text{where}$$

$T_{me/ma}$ = the time spent in that me/ma over a 24-hr period (hrs/24 hrs); C_{ame} = the pollutant concentration measured in the micro-environment ($\mu g/m^3$); and IR_{ma} = the child's respiration rate representing the activity level for that macro-activity (m^3/hr) [26].

To apply the above formula, data are required on the amount of time the child spends in each me/ma over a 24-hr period and on the child's inhalation rate for each me/ma. Inhalation rates are normally estimated based on age and weight of the child and on the macro-activity. Macro-activity data can be obtained by means of a variety of survey techniques, including time-budget diaries or recall telephone surveys [26].

Estimates of exposure using the equation are most accurate when fairly specific micro-environments are used. The better exposure levels in different micro-environments are known, the more accurate assessment of exposure using the indirect approach will be [77].

Findings of a study by Levy *et al.* imply that personal exposure can depend on activity patterns and that micro-environmental concentration information can improve the accuracy of personal exposure estimates [94]. Ezzati *et al.* indicated that ignoring the spatial distribution of pollution and the role of activity patterns on exposure could not only result in inaccurate estimates of exposure but also - and possibly more importantly - could bias the relative exposure levels for different demographic groups [47].

Literature about children's activities, from the fields of child development and psychology, tends to focus on social development and peer interactions of infants, toddlers, and pre-school children. Detailed reports on how children act on, or move about in, their physical space are seldom provided. Two general approaches to gathering micro-activity data have been used: i) real-time hand recording, in which trained observers watch an individual and write down the relevant information on a score sheet; and ii) videotaping, in which trained videographers videotape an individual after which the data of interest are extracted by hand or by computerized software. Several studies have used the videotaping approach to quantify children's micro-activity data [26, 95].

Ultimately, the use of personal continuously recording monitors in combination with TADs seems to be the most accurate method to assess individual exposure. However, the use of personal monitors is often restrained by time and cost considerations and by lack of individual compliance. Even in cases where personal monitors are used, these assess the level, as a time-weighted average, of one specific pollutant near the face of the individual. The actual dose, however, also depends on the person's activity. Therefore, the time activity pattern information is still useful [87, 96]. This study will rely on a combination of stationary monitors, TADs and questionnaires.

CHAPTER 2

2. AIMS AND OBJECTIVES

2.1 Rationale behind the study

Traditional approaches to risk assessment focus almost exclusively on adults. Children are considered only incidentally, and are often treated as 'small adults'. However, children are particularly sensitive to exposure to environmental contaminants due to their developing immune, neurological, and skeletal systems, as well as to differences in their metabolism, behaviour, physical characteristics, and activity patterns, all of which may put children at different, and often higher risk than adults. The development of child-specific methods to risk assessment is essential for the development of child-protective public policies [16].

Child-centred approaches to risk assessment can only be developed by collecting and analysing data based on children's exposure rather than by extrapolating from adult data. Simple, inexpensive and valid exposure measures need to be developed that can be used widely for monitoring and evaluation of exposure [43]. The direct approach of measuring exposure, involving personal or biological monitoring, is very difficult to implement in the case of small children. Furthermore, short-term exposure estimates from stationary samplers may correlate poorly with data from personal exposure monitoring [46, 97]. Children's activity patterns have a major influence on the degree of exposure, given certain pollution. Not much is known about the impact of micro-environments on exposure of pre-school children, especially in South Africa. Even in the developed world, child-specific estimates of exposure are only now being validated and standardized although research in this field has been ongoing for more than a decade.

Lead pollution of air and soil are of potential concern in areas where leaded fuel is still used. Given the lack of data on time-activity patterns of children in South Africa in relation to lead exposure, this study was initiated to assess lead exposure in pre-school children by the use of a combination of "time activity patterns" and micro-environmental lead concentration data in air and soil. For the purposes of this study, it was assumed that the spatial variability of the exposure indicator, i.e. lead was low throughout the areas under consideration [57].

2.2. Objectives of the study

The objective of this study was to assess the exposure of 5-year old children attending pre-schools in Pretoria to lead as a result of their pre-school attendance. In addition, this study intended to measure the distribution of exposure to lead at different locations. It was hypothesized that there are differences in exposure between children attending pre-school facilities in townships and children in pre-schools in upper and middle class suburbs. For this investigation, exposure distributions and determinants were explored for an upper and middle class area - Pretoria East - and for one historically disadvantaged area - Soshanguve.

The specific objectives of this study were therefore:

- To estimate the exposure to lead of children attending pre-school facilities in two different socio-economic areas in Pretoria, namely Pretoria East and Soshanguve, by means of the assessment of activity patterns of children, and of measurement of pollutant concentrations in air and soil in the pre-schools selected.

- To determine the association between exposure resulting from inhalation of airborne lead and the following factors:

  - The site of the pre-school, specifically the proximity to roads and traffic and characteristics of the building;
  - The socio-economic status of the school within an area
  - The number of children attending the pre-school

- To make recommendations on ways to determine child-specific exposure parameters for use in future health risk assessments in South Africa

- To subsequently make recommendations to the Departments of Education and of Health on relevant findings from this study.

2.3 Relevance of the study

Section 24 of the Constitution of South Africa states that 'Everyone has the right to an environment that is not harmful to their health and well-being' [98]. As children are considered to be a vulnerable sub-population, the health and health care of children has specific emphasis in the Constitution. This study is, therefore, consonant with the priorities set by the Constitution.

Secondly, this study will help to provide more accurate ways to assess exposure to pollutants in young children. Current available data for South Africa on children's activities are insufficient to adequately assess exposure to environmental contaminants. Only a few studies address this issue directly or indirectly [99, 100, 101, 102, 103, 104]. As a result, standardized exposure quantification measures as developed by the United States Environmental Protection Agency (USEPA) are the only measures currently available in South Africa for conducting exposure assessments [105]. Given the major differences between South African and the United States of America, the development of locally derived pollution estimates will increase the accuracy of environmental exposure studies in children in the future.

A third area of relevance is the fact that improved knowledge and understanding of exposure of pre-school children to lead may result in the following:

- Assist policy makers with information concerning conditions at pre-school facilities, as well as to where future pre-school facilities are sited.
- Provide indications where preventive strategies can reduce exposure of children to pollutants.
- Assist in creating a better understanding of the methods for collecting information on health and exposure factors in pre-school children.

The final point of relevance is the fact that this study will benefit the author by fulfilling the requirements for obtaining the degree Master of Science in Community Health.

CHAPTER 3

3. POPULATION AND METHODS

3.1 Study design

A descriptive cross-sectional study was done.

3.1.1 Study population

This study was conducted at pre-school facilities in two areas of Pretoria during July 2001.

Lists of pre-school facilities in Soshanguve and Pretoria East that are registered with the Department of Welfare, the Department of Health, the Society for Pre-School Education and Care, and with the Department of Environmental Health of the Northern Pretoria Metropolitan Substructure (NPMS) were obtained. In Pretoria East, the telephone directory was used to increase the number of eligible schools and identified schools were asked to add names of pre-schools not on the list.

The following pre-schools were included in the study:

- Schools situated in Soshanguve (see section 3.1.3 for borders);
- Schools situated in the East of Pretoria (see section 3.1.3 for borders);
- Schools that accommodated children of at least 5 years of age, as this age group is most susceptible to lead exposure because of being able to move around independently resulting in access to both indoor and outdoor micro-environments;

- Schools that accommodated more than 20 children of whom more than 4 are 5-years of age;
- Schools that were in operation for at least 8 hours per day to allow better measurement of pollutant concentrations.

Pre-schools that operate as “after-school care” or as “mornings-only” facilities were excluded.

Within the selected pre-schools, the following children were selected for the study:

Included were:

- 5-year old children without any physical disability that could inhibit the child from normal movement, as judged by the teacher.

Excluded were:

- Children who, according to the teacher, had an acute disease on the day of the survey that could hamper their movement. If this had resulted in there being less than four 5-year children at the crèche, however, the sick child would be selected but the field workers would note this in their observations.
- Children who only attended the pre-school for less than 6 hours.

3.1.2 Sample selection and sample size

A list of all eligible pre-school facilities was drawn up for each of the two areas. In order to simplify the sampling process, two-stage sampling was conducted. The first level involved selecting the pre-schools and the second level the selection of children in these schools.

The number of pre-schools to be included in the sample was calculated in order to achieve reasonable precision in the estimates of the mean pollution level.

The number of units required is estimated from the formula:

$$N = \frac{1.96 * \sigma}{L}$$

Where σ is the between-facility standard deviation and L is the required precision [106].

A sample size of 30 pre-schools in each area allows the mean to be estimated to within ± 0.7σ (95% confidence limits). Unfortunately it proved impossible to obtain a reliable estimate of σ before carrying out the study.

At the second level 4 children were selected at each pre-school. Four was the maximum number that could be interviewed and observed given the logistical/financial constraints of the study.

Selection of preschools in Soshanguve:

A simple random sample of 38 pre-schools, generated from a random table, was taken of pre-school facilities from the list of 168 pre-school facilities in the Soshanguve area (Figure 4 in Appendix Q). Preschool facilities had to be visited with an environmental health officer as no contact details were available. It was therefore also not possible to determine beforehand whether all the pre-schools fitted the required inclusion and exclusion criteria. During the visits it was found that some schools on the list did not exist anymore (n=6), or could not be found (n=5), or did not fit the selection criteria (n=9), leaving 18 pre-schools to be included from this first sample list. A second random sample of 22 pre-schools was subsequently drawn from the total list. From these, 8 were not included because they did not fit the selection criteria, leaving 14 to be included in the study. This added up to a total of 32. Pre-schools were visited the day before they were surveyed to confirm their participation. During these visits, 2 pre-schools were omitted from the list of 32 as they were found to be too small. The total number of pre-schools studied in Soshanguve is, therefore, 30. It is difficult to calculate a response rate, given the difficulty in judging eligibility of pre-schools on the list. For purposes of this study, however, the response rate for Soshanguve is calculated as 30/30 or 100%.

Selection of pre-schools in Pretoria East

In the Pretoria East area it was possible to contact pre-school facilities before the study to decide whether they fitted the inclusion criteria. Sixty-three schools, which represented all of the known pre-schools within the borders of the study area were contacted at the first level (Figure 4 in Appendix Q). From these schools 36 were excluded because they could not be traced (n=13), or they did not fit the inclusion criteria (n=15) or did not want to participate in the study (n=8). After the final selection of 27 schools, 2 pulled out and 1 was found to be too small. Only 24 pre-schools eventually participated in the study. The response rate in Pretoria East was, therefore, (34-10)/34 or 70.6%.

Table 5 indicates the number of these facilities that were visited each day in each area.

In both areas, at the second level, 4 children were selected at each school. This was undertaken by drawing a sub-sample of children from each of the pre-school facilities. The teacher was requested, in advance where possible, to draw up a numbered list of names of eligible children and a list of randomly drawn numbers was then used to select four children. It was, however not always possible to select children in a random fashion as they arrived at different times and it was not always evident to the teacher at what time children would arrive. It also happened that some of the selected children arrived very late. In these cases, children fitting the inclusion criteria were selected as they arrived as indicated by the teacher. These selected children were then observed as required.

The names of the pre-schools taking part in the study is presented in Appendix A.

3.1.3 Study area

For purposes of this study, the following boundaries were selected for the two areas under consideration:

Soshanguve

- North west – Mabopane
- West – Ga Rankua and De Wildt
- South – Rosslyn and Akasia
- East – Wonderboom Farms

Pretoria East

- North – La Montagne
- East – Faerie Glen
- West – Menlo Park
- South – northern part of Moreleta Park

Meteorology

As Pretoria falls within a summer rainfall area, winter was selected as a "worst case" for determination of inhalation exposure to lead. Temperatures in winter typically range from between about 2° and 19°C in June-July [3]. Winter winds in Pretoria are predominantly from the north-east with other relatively strong and frequent winds blowing from the north-west, north-north-west, west and west-south-west. Calm conditions occur about 50% of the time during winter [107].

The high occurrence of low wind and calm conditions in Pretoria in winter has implications for pollutant dispersion throughout the city. On average, unstable conditions only occur from about 11am to about 2 pm during both summer and winter. When winds have been light and skies clear during the night, an inversion forms, which is eroded during the day from the surface upwards. Neutral atmospheric stability generally prevails during the peak traffic hours of 7-9 am and 4-7 pm [107]. The potential impact of inversions was not taken into consideration in this study.

Temperatures and prevailing wind directions (monitoring stations at Irene and at the Weather Service) were requested for each sampling day.

The positions of the pre-schools were captured as geographic coordinates using GPSA Geographic Positioning System (GPS). A map indicating the spatial distribution of the two areas is presented in Appendix B.

3.2 Procedures, measurements and measurement tools

As lead is present in the atmosphere as small particles, most of which are respirable, the best method to measure airborne lead is the measurement of lead in $PM_{2.5}$. As the instruments needed to measure $PM_{2.5}$ were not available for this study because of financial constraints, other measures were employed. The next best method is the measurement of RSP (respirable suspended particles) over an 8-hour period. A disadvantage is that the detection of lead in RSP is low, especially in 'cleaner' environments, that is, where there are fewer RSP generating sources such as waste burning, bio-fuel burning or motor vehicle emissions. Extension of the monitoring periods could then be required. A third method, measurement of TSP (total suspended particles) could be used. However, a major disadvantage in terms of evaluating health effects of inhalation exposure, is that TSP consists of particulates that are mostly not respirable. TSP measurement can, however be used for comparison purposes. The option to monitor TSP over two consecutive days rather than over an 8-hour period at the same pre-school was not considered as this would have reduced the power of the study as only half the number of pre-schools could have been studied.

Finally, biomarkers can also be used for measuring lead exposure. In the case of lead exposure, blood would be the biomarker of choice [26]. It was decided not to collect blood samples in this study as it would have been difficult to obtain samples from young children. Consent from parents would also need to be obtained for an invasive procedure such as drawing blood [108].

For purposes of this study, the following measurements were done, employing students from the Technikon Gauteng North as fieldworkers:

(i) Physical measurements
  - Lead levels in TSP (indoors and outdoors) and RSP (only outdoors)
  - Lead levels in surface dust and surface soil

(ii) Observational measurements
  - Time-activity diaries
  - Questionnaires
  - Traffic counts

3.2.1 Physical measurements

3.2.1.1 Measurement of pollutant concentrations in air

Instrumentsand preparation procedure for sampling of TSP and RSP

The following battery-operated personal samplers were used for stationary monitoring of children's exposure:

- Gil Air Constant Flow Air Sampling System by Gilian® Instrument Corp and
- Gil Air5 Tri-Mode Air Samplers by Gilian® Instrument Corp.

The samplers operated at the calibrated flow rate of 1.9 L/min as this is the optimum rate for detecting RSP [2, 109]. Only one Gilibrator was available for calibration purposes and it was therefore only possible to undertake calibration at the end of each day. Each personal sampler was therefore calibrated by checking the flow rates at the end of each day and if necessary, adjusting the flow rate to 1.9 L/min using the volume displacement method (soap bubble method) as the primary standard. Pumps were subsequently charged and then used the next day. Flow rates were checked visually at the start of the monitoring period and at intervals during the day. A Gilibrator Primary Flow Calibrator (control unit PN D-800268) from Gilian® Instrument Corp., with a range of 20 cc to 6 litres/minute was used for calibration.

Mixed cellulose ester filters, with a 37 mm diameter and a 0.8 µm pore size (Millipore, www.millipore.com/inform) were fitted onto the samplers by a qualified laboratory technician. Filters were acclimatized in a dessicator to eliminate possible effects of fluctuations of temperature and humidity, at least 12 hours prior to weighing, and allowed to stabilize for 2 hours before weighing, according to standard procedures of the South African Chamber of Mines adapted from the National Institute for Occupational Safety and Health (NIOSH) [110]. After pre-exposure weighing, filters were placed in a three-piece 37 mm styrene acrylonitrile filter cassette and the plug left on to protect them against environmental conditions.

For RSP monitoring, a SX-37 teflon cyclone that conforms to MRE 113A was placed onto the filters, for capturing respirable particulates. Cyclones used in South Africa are manufactured to comply with the internationally accepted 'Johannesburg curve', that is, the cyclone has a cut-off point at 7 µm (PM_7) [2].

Monitoring procedure

Monitoring of TSP (indoors and outdoors) and RSP (outdoors) were conducted in order to determine the levels of lead associated with these particulates. RSP was only measured outdoors as levels were too low to be detectable indoors. Monitoring was conducted over a 10-hour exposure period, or as close as possible to 10 hours, as follows:

Two personal samplers per school (one inside and one outside) were placed at the average breathing height of a 5-year old child, about one metre high at a place where they spend most of their time, with filters facing downwards. Sampling occurred at a known flow rate of 1.9 L/min for as close as possible to 10 hours. The time and volume of air drawn through the pump was recorded.

The following criteria applied in deciding where to monitor inside the pre-school:

- The position of windows and doors that may have an effect on airflow through the room. Positions of windows and doors close to the monitor were recorded. Where possible, sampling was done at least 3 m away from internal ventilation units like windows, air conditioners or vents for heating/air conditioning [112]. This was not always possible as some of the rooms were fairly small.
- Samplers were, where possible, not placed directly adjacent to a wall or other flow-obstructing object [111]. Again this was sometimes difficult to achieve, as rooms were sometimes small and crowded.
- Sampling was done at the location where the 5-year olds spent the majority of their time [112].
- Samplers were not placed immediately adjacent to a potential source, such as a stove, heat vent etc[111].

Outside samplers were placed according to the following criteria:

- Monitoring was conducted in an area where children play most of the time, according to their teacher [112].
- Samplers were positioned as close as possible to the fence where traffic counts were taken, in an area where children would be expected to spend at least some time during the day.
- Samplers were placed in a location where the probability of the sampler being run over by children was low.

Inside and outside monitors were placed on a laboratory stool and attached to a retort stand where appropriate.

An example of the monitoring information sheet used by field workers (including the guidelines for positioning) is indicated in Appendix C.

Samples were transported in the filter holders in which they were sampled, with the plugs in position [113].

3.2.1.2 Surface soil lead measurements (outdoors)

Determination of surface dust and surface soil lead levels were done to provide an indication of the surface dust and soil to which children may be exposed via ingestion through hand-mouth contact, although the concern about exposure from this route is greater for children who are still in the mouthing stage. It is not expected that 5-year olds have high rates of mouthing [114], but the observers noted this activity on the time-activity diaries.

Field workers used US EPA method 3050B for surface soil sampling outdoors [115]. A number of field samples were taken at the playground of each pre-school, depending on the surface area of the playground. One sample was taken for more or less every 10 m^2. Where possible at least one sample was taken near the outdoor air sampler, and at least one sample from the sandpit, if one was present. If no soil was present on the playground, surface dust measurements were taken outdoors as well. A spoon, cleaned with alcohol, was used to take the sample after which the soil was placed in a bag which was then sealed and marked.

3.2.1.3 Surface dust lead measurements (mainly indoors)

Field workers used The National Institute for Occupational Safety and Health (NIOSH) method 9100 to collect surface-wipe samples [116]. Samples were taken in the room where the 5-year olds spent most of their time. Where possible, at least one sample was taken from a windowsill, at least one from an object such as a bookshelf or a table and at least one from the floor (if uncarpeted). Where possible, sampling was done before cleaning of the room on the particular day.

An example of the recording sheets including instructions to field workers is included as Appendix D.

3.2.2 Observational measurements

3.2.2.1 Time-activity diaries

Time-activity diaries were kept by the field workers to determine activity levels and time spent by children in different micro-environments. A time-activity diary was filled in for each of the 4 children selected. Each child was assigned a different colour badge to simplify the observation process. Observations started as soon as possible after the child arrived. Personal information about the child was requested from the teacher. The time-activity diary was subsequently filled in during the day, indicating location and type of activity for every 15-minute period of the day. Information that was recorded included:

- Time spent indoors and outdoors respectively
- Type of activities during 15-minute time periods (eg running, playing etc)
- Exertion level during these periods (indicated as high/medium/low).

Types of activities included in each level are indicated in Appendix E.

An example of the time-activity diary template is included as Appendix F.

3.2.2.2 Questionnaires

A questionnaire was developed to determine the factors associated with exposure at a pre-school facility, as well as additional information that may distinguish different types of areas and pre-school facilities from one another and provide information on possible confounding factors. Questionnaires were administered by field workers to the principal or teacher in charge and one other member of staff where possible. An example of the questionnaire that was administered is included as Appendix G.

3.2.2.3 Determination of traffic counts over the exposure period

As traffic counts were not available from the Traffic Department for the majority of streets, traffic counts were conducted over three 15-minute periods during the day, using hand-held counters. The criteria for selecting the relevant street were as follows:

1) Selecting the street closest to the facility or
2) If a busier street was visible and within walking distance of the pre-school, this street was selected.

The distribution of the types of vehicles was also recorded where possible.

3.2.3 Analyses of environmental samples

3.2.3.1 Gravimetric determination of particulate matter concentrations

After exposure, the lid and plugs were put back on the cassette, the cassette removed from the pump and sent to the Air Quality laboratory at the CSIR for analysis. Gravimetric analyses to determine concentrations of total suspended particulate matter (TSP) or respirable suspended particulate matter RSP (in µg/m^3) were performed at the laboratory, using a 5 decimal micro-balance (Mettler

HK60), capable of weighing up to at least 0.01 mg. The procedure is described in detail in the document: 'Standard operating procedures for the gravimetric analysis method, CSIR STEP report' [117].

3.2.3.2 Determination of lead content of particulate matter

After gravimetric analyses, filters were analysed for lead. Filter preparation for lead analysis (which consists of digesting the filter in HNO_3) was performed according to NIOSH Method 7105 [118]. Analyses of samples were conducted by Perkin Elmer ELAN 6000 Inductive Coupled Plasma-Mass Spectrometry (ICP-MS) by a recognised laboratory (Council for Geoscience in Pretoria). Instrumental conditions for the ICP-MS are indicated in Appendix H.

3.2.3.3 Determination of lead in surface soil and dust

Surface soil

US EPA method 3050B was used for surface soil digestions [115].

Different amounts of soil were collected at the different schools, depending on the size and the characteristics of the school. Not all samples were analysed. Prioritisation of samples for analyses was done as follows:

1) Samples taken in playground near air sampler
2) Samples from the sandpit
3) Samples taken from one or two other locations on the playground, depending on the overall number of samples that were taken.

Between two and four samples per school were analysed.

Surface dust

NIOSH method 7105 was used to digest surface-wipe samples [118]. The recommended digestion method for analyses by ICP (NIOSH method 7300) was not used, as the laboratory was not fitted with the appropriate scrubbers to remove hydrogen perchlorate ($HClO_4$). Personal communication with the analyst at Geosciences indicated however, that the former method was sufficient [119].

Between two and four samples per school were analysed.

3.2.4 Quality assurance

The twenty environmental health students from Technikon Gauteng North in Soshanguve, employed as field workers, included third year and BTech (Bachelor of Technology) students.

3.2.4.1 Sampling and observations

Field workers conducted physical sampling of lead in air and soil, as well as the observational sampling, which included traffic counts, questionnaire administration and the recording of time-activity-patterns. The principal researcher, prior to the fieldwork, trained the field personnel. Training was conducted over three sessions. During the first session the theory was discussed. The following two sessions were used for demonstration and hands-on training. The procedure was as follows:

- The aim of the study was discussed to ensure that they understood why the study was being undertaken.
- Administration of the questionnaires was practiced by undertaking role-playing and administering the questionnaire to at least one person outside their group after which problems and unclear questions were discussed.
- Recording of time-activity diaries was practiced by undertaking role-playing among one another, after which problems and obstacles were discussed.
- Handling of air samplers was demonstrated and students had the opportunity to obtain hands-on experience in using these.
- Methods of taking surface soil samples outdoors and surface

dust indoors were demonstrated and students had the opportunity for hands-on training in these.

- Manual traffic counters were demonstrated and students had the opportunity to do traffic counts with these outside the gate of the Technikon.
- A trouble-shooting list was also drawn up in the process.

A detailed work plan for each activity was included at the start of each given activity (see Appendices D-G). This work plan explained each procedure step-by-step, including trouble-shooting issues. Care was taken to ensure that each team of field workers (3/team) had a working cell phone with them to ensure contact with the researchers in case of unexpected problems.

Dust samples were taken, with equipment that had been cleaned prior to and after use, according to the methodology as specified in the relevant methods (Appendix D).

3.2.4.2 Analyses

- The air quality laboratory staff were trained and adhered to quality procedures as specified in the Air Quality Laboratory Quality Manual (see Appendix I).
- Digestion of filters, soil samples and dust wipes were conducted inside a fume cupboard, using an appropriate methodology [113]. Lead levels of samples were determined by LJ Jordaan at the Council for Geoscience according to their laboratory quality procedures.
- Calibration certificates are available for the following instruments:
  - Gilibrator
  - Mass balance.
- 10% field and laboratory blanks were taken for quality assurance. During air sampling, 2 filters for every 10 samples taken were prepared in exactly the same way as the samples

but no air was drawn through them. One filter was taken to the field (field blank) while the second remained in the laboratory (laboratory blank). These results were taken into account during the calculations.

3.2.4.3 Validation of questionnaire

Accuracy of questionnaires was evaluated by interviewing more than one person at a school, if possible. This was used during data entry to check whether discrepancies in responses existed.

3.3 Pilot study

Different pilot studies that were conducted by the principal researcher before the actual study were the following:

- At the outset, children were observed at local pre-school facilities, and staff from pre-school facilities interviewed to establish the time that children typically spend at a pre-school, including the time indoors versus outdoors and the type of activities that they engaged in. This provided an indication of the types of questions that may need to be asked.
- Personal samplers were subsequently placed at indoor and outdoor locations at the CSIR (where concentrations were expected to be low, representing a best case scenario) over a period representative of a one-day (10-hour) exposure period for children. These filters were analysed for RSP, TSP and lead to establish whether this period was sufficient to detect concentrations above the detection limit and whether it would be feasible to detect RSP indoors. It was found that the 10-hour period was sufficient for detecting TSP indoors and outdoors; RSP was detected outdoors but not indoors.
- Colleagues evaluated the time-activity diary and questionnaire and their comments were incorporated.

- The time-activity diary was tested on a number of children during visits to pre-schools to test their validity and ease of use. This was mainly done by observing the children to evaluate whether the diary was suitably structured for easy use by the field workers. Relevance of definitions of activities was also evaluated at the same time. Changes were subsequently made to simplify the time-activity-diary.
- The questionnaire was also administered to a number of teachers at different pre-schools to test its comprehensibility after which the structures of some of the questions were adjusted for clarity.

The flow diagram outlining the execution of the study is indicated in Appendix J.

3.4 Ethics

Permission for this study was obtained from the Ethics committee of the University of Pretoria. Letters were then sent to the Department of Education to obtain permission for the study (Appendix K). The Department, however, indicated that they were not in a position to grant permission, as they did not deal with pre-school facilities. The Department of Health (Environmental Health) was also approached but indicated that they were also not the correct body. Eventually The City Council of Pretoria Health Services Department indicated that they could provide us with a letter stating that they were aware of the study and were supporting it (Appendix L). Informed consent was subsequently obtained from the principals of the pre-schools by providing them with letters explaining the rationale behind the study and asking for their support (Appendix M). Some pre-schools in Pretoria East were visited while faxes were sent to others. Letters were delivered personally to pre-schools in Soshanguve and consent acquired by telephone where possible. Follow-up visits were made where no telephonic contact was available. As no personal data were collected from children and no personal contact was necessary, informed consent was not needed for each child taking part in the study. Letters to the parents were issued to teachers, providing background information on the study. These letters were written in English and subsequently translated into Afrikaans and Tswana. A copy of this letter is included in Appendix N.

All parties involved were assured of confidentiality. No names (of schools or individuals) were therefore used in the analyses, although they were recorded on the questionnaires. The pre-school (questionnaire) number was used as unique identifier.

3.5 Data analysis

3.5.1 Data capturing and cleaning

Data capturing was conducted in Epi Info 6.04d [120]. One questionnaire file was created from both the questionnaire and time-activity diary. The way the questionnaire was structured including the variable names are displayed in Appendix O. Missing data were sourced by contacting pre-schools where possible. Data cleaning was achieved by duplicate entry of data, the first set of data being entered by the principal researcher and the second set by one of the students who assisted in the fieldwork. The Validation command in Epi Info was subsequently run and errors corrected.

3.5.2 Preparation for data analysis

A bio statistician was consulted during sample selection and again during data analysis. Preliminary descriptive statistics were done in Epi Info 6.04d after which the questionnaire data were converted to a Stata 6 file [121].

As data from time-activity diaries consisted of four observations per pre-school, the dataset, reflecting variables at **pre-school level**, was reshaped to create a dataset that would allow for appropriate analyses of variables at **individual** or child level. Analyses were performed in both datasets.

In order to answer the research question and address the objectives of the study, it was necessary to create new variables.

3.5.3 Creation of applicable variables

3.5.3.1 Exposure variable

The research question dealt with exposure of children at pre-schools to lead. Inhalation exposure was determined by a combination of time-activity data and concentrations of lead in air. Time-activity data were used to determine the ratio of time spent indoors and outdoors for a few typical children attending the pre-school. The purpose of the data collection was not to calculate the specific exposure for those children; the personal exposure calculation is rather a way to "adjust" the indoor and outdoor concentrations for estimating population exposures.

The exposure variable (estimating inhalation exposure to lead) was therefore created in both the 'pre-school' and 'individual level' datasets, using data on time-activity patterns and lead concentrations in air:

Total inhalation exposure over the exposure period =

$$(C_{in} * T_{in}/T_{observed}) * T_{\text{spent at pre-school}} + (C_{out} * T_{out}/T_{observed}) * T_{\text{spent at pre-school}}$$

Where $\mathbf{T_{in}}$ and $\mathbf{T_{out}}$ = observed time spent indoors and outdoors over the exposure period; $\mathbf{T_{observed}}$ = total time that the child was observed on the day of the survey; which is the sum of T_{in} and T_{out}; $\mathbf{T}_{\text{spent at pre-school}}$ = time that each child actually spent at the pre-school on the day of the survey; **C** = the lead air concentration measured in the specific micro-environment (µg/m^3).

The final exposure variable used for further statistical analyses represented inhalation exposure of 5-year olds attending the pre-school for 6 hours or more on the day of the survey.

Individual level dataset:

In this dataset individual observations were compared. Inhalation exposure was therefore calculated for each 5-year old child (attending for 6 hours and more) at each pre-school to be compared to other parameters that were derived for each individual in the time-activity diary, such as gender, weight and activity level.

Pre-school level data set

Comparisons were made at pre-school level. A mean observation variable for each pre-school was therefore created in order to compare mean inhalation exposure of 5-year olds attending 6 hours and more to other pre-school variables as specified in the objectives of the study. If all four children at a pre-school were eligible for inclusion, the mean exposure consists of the average of four observations. If only one child was eligible for inclusion, the mean exposure consists of the exposure of the one child.

3.5.3.2 Distance of pre-school to the road where traffic counts were taken

This variable was potentially created from one of two variables in order to measure the distance of the pre-school from the road where traffic counts were taken:

- the distance of the closest street to the fence of the pre-school or
- the distance of the street from the pre-school if a different street was used for traffic counts (see Appendix P for generation of variables).

3.5.3.3 Location of the pre-school

The following assumptions were made to classify pre-schools as either busy or quiet:

A pre-school was classified as 'busy' if:

- The distance from the road to the fence of the pre-school was less than 60 m and the total number of motor vehicles during the three measuring periods was more than 200.
- The distance from the road to the fence of the pre-school was less than 100 m with the total number of vehicles being more than 600.

This was defined by (i) the total traffic counts during the day as well as (ii) the distance of the pre-school from the road where traffic counts were taken. In all other cases a pre-school was classified as being next to a quiet road (Appendix P - generation of variables).

3.5.3.4 Average lead in surface dust and surface soil

A few surface dust and soil samples were taken at each pre-school. Variables were created to reflect the average lead concentrations in soil and surface dust respectively at each location (see Appendix P).

3.5.3.5 Surface area/child indoors and outdoors

Variables were created to determine the number of 5-year olds per surface area, indoors and outdoors respectively. These newly defined variables consisted of the following variables: surface area of the rooms occupied by 5-y olds indoors, as well as the surface area of the outdoor playground where 5-years played most of the time. The inverse of this variable was also created to reflect the surface area/child outdoors and indoors respectively (see Appendix P).

3.6 Limitations of the study

Various factors, including costs and time-constraints limited the scope of this research project.

- It was envisaged that at least one pre-school facility be visited before the main study to provide hands-on training. This was, however not feasible because the closest pre-school facility to the Technikon was not suitable and transport was a problem.

- The ideal would have been to undertake sampling on at least 3 representative days but resource constraints only allowed for measurement over one day. The study, however, only considered exposure on one typical weekday during winter. Factors, such as, the day in the school's weekly or monthly schedule in which the monitoring falls, unplanned events, weather conditions on the day, and changes in activities for that day because of monitoring, may therefore have distorted the spatial and temporal extent of the target population's activities.

- It was not always possible to monitor for 10 consecutive hours due to the following problems:
    - Some schools started later than originally indicated.

  - Traffic was sometimes a constraint in getting to pre-schools in time in the mornings.
  - In Soshanguve locations had to be found by means of a GPS. This proved difficult, especially at the start of the study.
  - In a few cases schools closed earlier than originally indicated. In these cases monitoring was done for as long as possible.

- Monitors ran for more than 10 hours for 15% of cases, for more than 9 hours for 87% of the cases and for more than 8 hours for 95% of the time.

- Only one Gilibrator was available for calibration purposes and it was therefore only possible to undertake calibration at the end of each day, although calibration should ideally be done directly before use (after charging) and after use (before recharging)

- Only inhalation exposure was determined in this thesis. The concentration of lead in soil and surface dust was used as an indicator of ingested exposure. Only a few samples were taken from soil and surface dust at each school. Time-activity patterns for this pathway was however not determined. Although it was attempted to select sites that are comparable across schools, the lead content of these samples may under or over-represent the actual exposure of children as it might have been taken from an area with either an accumulation of lead or no lead.
- The following limitations were associated with surface soil and dust measurements:
  - Some students in Soshanguve did not initially measure the surface area of surface dust samples when not using the template for taking samples from window sills (3 occasions) and the floor (1 occasion) as these areas

    were sometimes too small for the template. These measurements therefore had to be discarded.
    - During digestions of surface soil samples about 17% of all samples caused small explosions while being heated, resulting in some content being lost in the process.

- Time-activity patterns and lead concentrations were determined on typical weekdays at pre-school facilities. Exposure at home and in other micro-environments were not considered.

- As a result of resource constraints, one field worker normally observed 2 children. In Pretoria East it was sometimes reported to be problematic as children in this area had more micro-environment options. Some of the detail of observations may have been lost in these instances.

- It was not always possible to select children in a random fashion. In this particular study, children fitting the inclusion criteria were selected as they arrived as indicated by the teacher. Children who arrived earlier may have come from similar types of households in comparison to those who arrived later, which may potentially have biased results from the questionnaire. A related sampling problem was that for logistical reasons no 'sampling proportionate to size' could be done. While it is possible to calculate weighted average exposures, the sampling of 4 children per pre-school irrespective of pre-school size will lead to a reduction in accuracy of estimates.

- Generalisation of results from this study to all pre-school children attending day-care facilities may be limited, as the sample of children does not reflect the ethnic or socio-economic diversity of all pre-school children in South Africa.

- This study can not be generalised to all pre-school children as children who do not attend pre-school facilities may have different behavioural or activity patterns from those who do.

- This study was also conducted on normal developing children, so comparisons with children with developmental disabilities, who may follow alternative patterns of development, may be limited.

- Traffic counts, as well as recording of the type of traffic, were often conducted by one person. In cases where the traffic was busy, it could have been possible that the observer tried to do all things and did not focus enough on the main objective, i.e. the counting of traffic. This may have introduced measurement error, which may partly explain some of the anomalous findings with regard to the association between airborne lead and traffic density.

- Questionnaires were all in English and administered by field workers (most of whose first language is Sotho) to teachers at pre-schools where the language medium was either primarily Afrikaans or Sotho. This limitation was, however, discussed with the field workers beforehand and it was ensured that where necessary Sotho words were used where the potential for confusion was deemed high.

- This study did not develop, validate or refine new measuring tools.

CHAPTER 4

4. RESULTS

Results were divided into three sections. The first section (Section 4.1) considered the descriptive statistics and compared parameters relating to exposure between Soshanguve and Pretoria East. The second section (Section 4.2) explored variability of inhalation exposure, mostly at individual or child level, while the third part (Section 4.3) investigated factors contributing to inhalation lead exposure at pre-school level by fitting multiple regression models. The potentially important factors were identified by means of Analysis of Variance, after which stepwise regression models were fitted to confirm these and obtain parameter estimates.

The first section of the results deals mostly with descriptive results.

4.1 Descriptive epidemiology

4.1.1 Demographic information

4.1.1.1 Distribution of pre-schools

Thirty of the pre-schools (56%) in the study were from the Soshanguve area, while 24 (44%) were from the Eastern suburbs of Pretoria. Of these pre-schools, 42 (77.8%) were from areas defined as formal areas, while the remaining 12 (22.2%) came from areas classified as informal areas. It was found to be less problematic to recruit pre-schools in Soshanguve to take part in the study, which was one of the reasons why the sample size from Soshanguve was larger than Pretoria East.

4.1.1.2 *Distribution of children and teachers at pre-schools by area*

The distribution of children and teachers are indicated in Table 6 (Appendix Q). The average number of children attending pre-schools in Soshanguve was less than half of that in Pretoria East, although variation in the number of children in Pretoria East pre-schools was also significantly larger (standard deviation was almost three times as high). The mean number of 5-year olds attending on the survey day as a percentage of the total number of 5-year olds was 81 and 89% for the two areas respectively (standard deviation similar). The gender distribution of children observed was almost equal (Table 7 - Appendix Q). Body weight of observed children were only available for 18% of all observed children in Soshanguve and 42% in Pretoria East. The mean weight in Soshanguve was 18.1 kg, compared with 20.0 kg in Pretoria East. The SD was similar (Table 8 - Appendix Q).

The mean number of teachers in Pretoria East was more than twice of that in Soshanguve. The mean numbers of (5-year old) teachers were similar for the two areas (Table 6 - Appendix Q). There was no significant difference in the ratio of children to teacher between the two areas.

4.1.1.3 *Smoking status of teachers*

Smoking did not seem to be an issue in either of the areas as it was only indicated twice per area that teachers at the school smoked, and never in the presence of children. The question was asked in as neutral as possible way but it cannot be ruled out that the response may be misrepresented. No visual signs of smoking by teachers were observed by field workers, although student teachers and the gardener were found to be smoking in one instance.

4.1.1.4 Monthly pre-school fees in the two areas

The monthly fees for attending pre-schools were used as an indicator of socio-economic status. The average fees were significantly lower in Soshanguve ($p<0.001$). The maximum fee in Soshanguve was R90 per month, which was much lower than the minimum fee of R350 in Pretoria East.

4.1.2 Fuels and fuel use

Sixty eight percent of all pre-schools indicated a preference for one type of fuel for cooking. Of these, 38% of the pre-schools were from Soshanguve. Of the pre-schools where only one fuel type is used, electricity is used most frequently (75%), followed by paraffin (18.9%) (Table 9 – Appendix Q). Electricity is used by all of the schools in Pretoria East, whereas in Soshanguve, paraffin is used at half of the schools. In those cases where more than one type of fuel was used, gas and electricity were used in Pretoria East, while a combination of fuels was used in Soshanguve, with electricity and coal being used the most frequently.

Stoves were mainly used for cooking in both areas; in Soshanguve a primus stove and mbawula, or combinations of these were also used (Table 10 – Appendix Q).

About half of the pre-schools in Pretoria East (13) used an energy source for heating rooms, as compared with only 27% (or 8) of pre-schools in Soshanguve. Of these about 35% in Soshanguve used one type of energy source. It was found, however that appliances used for cooking in Soshanguve often provided some heat, especially when there were no proper walls between rooms. Types of energy sources used for heating were mostly electricity, although paraffin, charcoal and anthracite were also used in Soshanguve (Table 11 Appendix Q).

4.1.3 Building characteristics and structure

4.1.3.1 Windows and doors

At 49 of the pre-schools (92%), either all or some doors were open. Of these, all doors were open at 17 (57%) schools in Soshanguve, as compared with 7 (29%) in Pretoria East. All windows were open at 6 (20%) pre-schools in Soshanguve and 5 (21%) pre-schools in Pretoria East, while none were open in 7 (23%) pre-schools in Soshanguve as compared with 3 (13%) pre-schools in Pretoria East. At most schools it was indicated that certain windows are normally open: 57 and 66% respectively in Soshanguve and Pretoria East. If it was indicated that certain windows were open, these were furthest from the road 45% of the time (16 cases).

4.1.3.2 Floor and building characteristics

Indoor floor materials consisted mostly of cement (63%) and carpet (all schools) in Soshanguve areas and mostly of carpet and tiles (92 and 88% respectively) in Pretoria East. In Soshanguve 57% of respondents indicated that the pre-school building contained corrugated iron in the structure, while in Pretoria East almost all buildings were constructed mainly of bricks: 67% had painted bricks and 58% face brick (Table 12 – Appendix Q).

Removal of the paint of a building on the premises by sanding had occurred recently, that is, during the last 3 months in 11 (20.4%) cases. Of these, 3 were in Soshanguve while 8 were in the Pretoria East area.

4.1.4 Play areas indoors and outdoors

At 80% of facilities in Soshanguve 5-year old children played mainly in one room when indoors. In Pretoria East 46% of the schools indicated that 5-year old children played mainly in one room, while 42% indicated two rooms (Table 13 – Appendix Q).

The mean indoor room area occupied by 5-year olds in Soshanguve was less than half of that measured in Pretoria East. The surface area/5-year old child was slightly higher in Pretoria East as compared to Soshanguve (4.2 m^2 vs 3.3 m^2), with the variability in Pretoria East also higher than in Soshanguve (standard deviation of 4.4 vs 2.4) (Table 14 – Appendix Q).

The mean playground area was significantly larger in Pretoria East ($p=0.004$), with the variation in the latter also significantly higher than in Soshanguve (standard deviation twice as high). The mean playground area/child in Soshanguve was somewhat less than that in Pretoria East (42.7 m^2, as compared to 48.7 m^2). This was calculated based on the assumption that all children at the pre-school play on the playground at the same time. The variation in Soshanguve was also higher (SD=56.9 vs 40.8) (Table 14 – Appendix Q).

Most respondents in Soshanguve indicated that the playground material consisted mainly of sand (40%). In Pretoria East, most responses indicated that the main playground material was lawn (24%) (Table 15 – Appendix Q).

In Soshanguve, 67% of the pre-schools had at least one sandpit, as compared with 92% in Pretoria East. In Soshanguve 40% of sandpits were cleaned at least monthly as compared with 14% in Pretoria East. One pre-school in Soshanguve and 4 in Pretoria East indicated that they either cleaned the sandpits with salt or sterilized them by treating them with a sanitizer.

4.1.5 Cleaning practices indoors and outdoors

Cleaning practices were fairly similar in both areas. Indoor cleaning was undertaken daily at 93% of schools in Soshanguve and in all cases in Pretoria East. The rest of the schools in Soshanguve indicated that the schools are cleaned weekly. Cleaning in Soshanguve was mostly done with a broom, water and soap whereas in Pretoria East a vacuum cleaner and other electrical equipment were also used.

Cleaning outdoors was done daily in 80% of the pre-schools in Soshanguve, as compared with 50% in Pretoria East. Cleaning was done at least weekly in both areas. The main method of cleaning was indicated as sprinkling water and sweeping with a broom. In Pretoria East the same method is being used, although just as often the method of choice was just sweeping with a broom.

4.1.6 Other sources of pollution around pre-schools

Six (11%) schools indicated the existence of small industrial activities near the pre-school, including a petrol station, a scrap yard, panel beaters, a coal depot and spray painting business. Five of these were in Soshanguve.

Three respondents indicated the presence of other sources of pollution, excluding dusty streets near the pre-school. These were waste burning, a restaurant, and a veld fire.

4.1.7 Traffic and road parameters

Ninety percent of the pre-schools in Soshanguve are bordered by non-tarred roads, as compared with 4% of pre-schools in Pretoria East (Table 16a – Appendix Q). Forty seven percent of schools in Soshanguve were situated visibly near a stop street/traffic light, as compared with 71% in Pretoria East. Pre-schools were classified as being situated next to a busy road in 30% of all cases, of which 13 were in Pretoria East. Total motor vehicle counts in Soshanguve over the three counting periods were also on average significantly lower than in Pretoria East. The mean traffic count in Soshanguve was 66 about 7 times lower, as compared with 421 in Pretoria East ($p<0.001$) (Table 16b – Appendix Q).

4.1.8 Meteorological conditions on the day of the survey

A larger number of respondents in Soshanguve, as opposed to those in Pretoria East, indicated that the wind blew on the day of the survey (Table 17 – Appendix Q). When the wind did blow, about half of the respondents in each area indicated that it blew the whole day. About the same percentage of respondents from both areas indicated that the day of the survey was cold. It should be noted that these responses may have been highly subjective. Also, responses represent meteorological conditions over a period of 2 weeks.

Temperatures varied as the study was done over a period of 2 weeks, with a mean of 11.5°C over the survey period. Temperatures for Pretoria varied between 9 °C, the lowest 24-h minimum and 24°C being the highest 24-h maximum (Figure 5 – Appendix Q). The prevailing wind direction during July 2001 was from the east and north east (Figure 6 – Appendix Q) These temperatures and wind directions provide an indication of the conditions on the day of the survey but were not area-specific.

4.1.9 Time-activity patterns and exposure parameters

4.1.9.1 Parameters used to assess exposure

Micro-environmental parameters

Results refer to parameters determined for 5-year olds attending the pre-school for 6 hours and more on the day of the survey.

The mean time spent indoors was significantly higher in Soshanguve as compared to Pretoria East (p=0.03). (see Table 18 – Appendix Q for related parameters). The time spent indoors versus outdoors in the 2 areas is indicated in Figure 7.

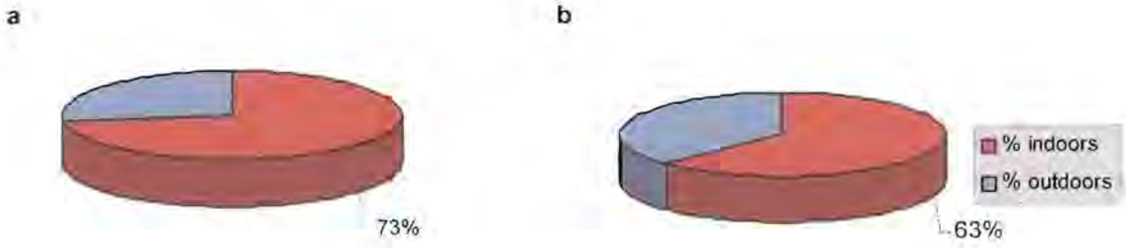

Figure 7. **Mean duration of time spent indoors and outdoors at pre-schools in (a) Soshanguve and (b) Pretoria East**

Pollutant concentrations

The means of the following pollutant concentrations used to determine exposure were significantly different in the 2 areas (Table 19 – Appendix Q):

- Lead concentrations in outdoor air associated with TSP were significantly less in Soshanguve (p=0.015)
- Surface dust lead loading on window sills was significantly more in Soshanguve (p=0.004)
- Surface dust loading on objects such as book cases was significantly more in Soshanguve (p=0.04)
- Overall surface dust average lead loading was significantly higher in Soshanguve (p=0.005)
- Lead concentrations in sandpits were significantly higher in Soshanguve (p<0.001)
- Lead concentrations in playground areas were found to be significantly higher in Soshanguve (p=0.003)
- Overall average lead concentrations in the soil were also significantly higher in Soshanguve (p=0.010)

As a result of the low particulate concentrations, results of particulate RSP measurements were not reliable and it was not possible to determine the proportion of lead in particulate matter.

Lead concentrations in the air were subsequently combined with micro-environmental data (indoors and outdoors) to estimate the inhalation exposure to lead in air.

4.1.9.2 Determination of inhalation exposure to lead in air at pre-schools

The differences in mean exposure to lead in the air between the 2 areas are indicated below (see Table 20 – Appendix Q):

- No significant difference in indoor exposure was found between the 2 areas (p=0.694)
- Outdoor exposure was significantly lower in Soshanguve (p<0.001) (Figure 8).

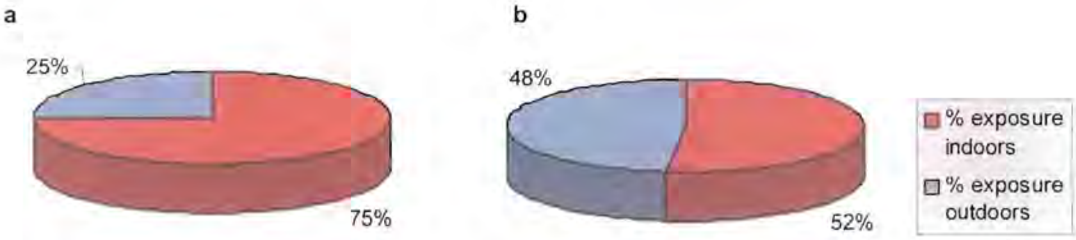

Figure 8. Comparison of indoor versus outdoor exposure to lead in the air in (a) Soshanguve and (b) Pretoria East

- Total exposure on the survey day was significantly lower in Soshanguve (p<0.001)

A box and whisker plot of average/mean exposure at pre-schools illustrates that the distribution of lead exposure was more skew in Soshanguve. The median exposure was lower in Soshanguve, as compared to Pretoria East. It also illustrates that the extent of exposure was broader in Pretoria East (Figure 9 – Appendix Q).

The frequency distribution of average/mean exposure in the two areas also indicates that more children in Pretoria East were exposed at higher levels as compared to Soshanguve (Figure 10).

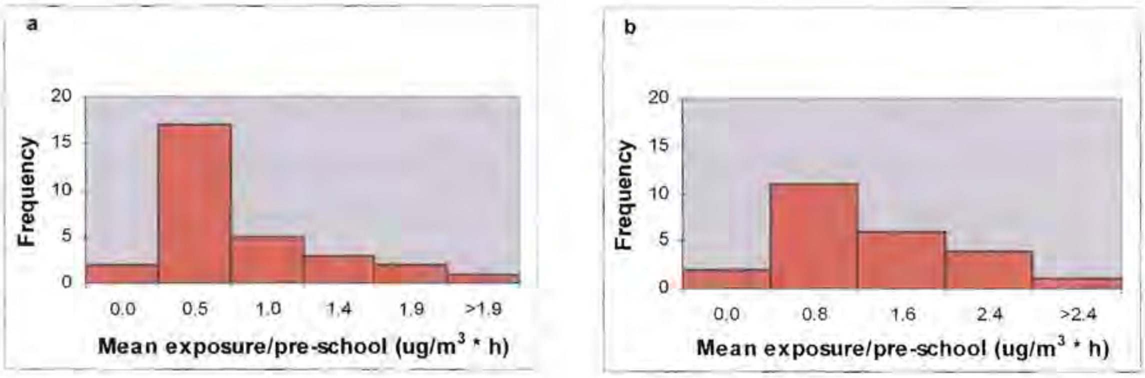

Figure 10. Frequency distribution of exposure of 5-olds attending for more than 6 h on survey day in (a) Soshanguve and (b) Pretoria East

The association between mean exposure and mean temperature on the survey day could not be determined as there were only 10 observations. A scatter plot indicating the changes in both mean exposure and mean temperature is presented in Figure 11 (Appendix Q).

4.2 Analysis of Variance at individual and pre-school level

This section deals with differences and statistical associations at individual and pre-school level, as was appropriate. The Stata data outputs are given in Appendix R.

4.2.1 Variability of inhalation exposure

A one way Analysis of Variance (ANOVA) conducted to determine the variability of inhalation exposure to lead between pre-schools indicated that the mean exposure of individuals between different pre-schools was significantly different (95% confidence level). Bartlett's test for equal variance was, however, also significant, indicating that variances within pre-schools were not equal. These results indicate that the variation in exposure at some pre-schools may be more than at others. It provides an indication that the exposure variable should be transformed to try to satisfy the assumption of homogeneity of variance. When an ANOVA analysis of the log transformed exposure variable was conducted (using individual data), the assumption of constant variance seemed to improve slightly. The chi square value was slightly reduced but still indicated no homogeneity of variance. When the test was done by area, the assumption of constant variance was still not satisfied. Log transformation did, however slightly improve normality of the data, as can be seen in graphs illustrating 1) the exposure and 2) the log transformed exposure in Soshanguve and Pretoria East respectively, with the normal curve overlaid (Figures 12 a-d – Appendix Q).

Non-parametric tests have not been used in this study as these can only investigate one factor at a time, therefore the potential effect of confounding factors could be missed. As the assumptions of constant variance have not been satisfied, the Kruskal-Wallis one way ANOVA by ranks were used to test the results found in the original ANOVA analysis. This test showed that mean ranks between the two areas differed significantly, indicating that the mean log exposure in Pretoria East was significantly higher than in Soshanguve (p=0.01).

An ANOVA to determine whether there was a difference in logexposure between the two areas using individual exposure data, indicated that the mean log exposure between the two areas was significantly different (p=0.005). Bartlett's test (p=0.023) indicated that that there was more variability in exposure between individuals in Pretoria East as compared to Soshanguve. When this test was repeated using pre-school exposure data, Bartlett's test indicated that the variance of mean log exposure was similar within areas (p=0.206).

For this reason, subsequent sections focused on **mean log exposure** at pre-school level, thereby removing one source of variability, that is, variability between children.

A multiple regression model fitted to determine the effect of the durations of different activity levels (low, medium and high) on mean log exposure indicated that the duration of high activity could be significantly associated with mean log exposure The longer the duration of high activity, the higher the mean log exposure. A regression model adjusted for area confirmed a previous result that there seemed to be a significant difference in exposure of individuals between the two areas (p=0.01). The effect of high activity, however, seems to disappear when adjusting for area (p=0.42). This is due to the confounding effect of area.

4.2.2 Gender comparisons

A box and whisker plot illustrated that the median lead exposure of boys was lower than that of girls. However, the extent of exposure was greater for girls (Figure 13 – Appendix Q).

An ANOVA done to determine whether the mean exposure differed between boys and girls indicated that there was no significant difference in exposure between boys and girls (p=0.72). Bartlett's test was not significant indicating that variance within gender was constant.

A t-test to determine whether gender affected the mean time spent by children indoors and outdoors, respectively, showed no evidence of a difference in the mean duration spent indoors or outdoors between boys and girls (p=0.42 and 0.61 respectively). There is therefore no evidence that the time that boys and girls spend indoors and outdoors is significantly different.

4.3 Factors associated with inhalation exposure at pre-school level

This section deals with the factors associated with mean inhalation exposure at pre-school level. Analysis of variance (ANOVA) was used to determine the factors that seem to be associated with the transformed variable of mean exposure (mean log exposure). Analyses were weighted according to the number of 5-year old children observed at the pre-school. Stepwise regression methods were used to choose variables to be included in the model, in addition to the variable comparing the two areas. Some factors that initially were associated with mean exposure, were not significant in the stepwise regression (p>0.05). The reason for this could be due to confounding effects with area. The exclusion process is indicated in Table 21. (The outputs of the statistical steps are included in Appendix R).

Table 21. Variables tested to find factors that seem to be associated with mean exposure

Variable name	Description of variable	Status after testing for dependence on area, using an ANOVA	Status after sw regression	Variables used in regression[a]
Anyheat	Any fuel used for heating?			
Area	Area – Soshanguve or Pretoria East	**Included in all models**	-	
Arearoom	Area of play room			
Avgtemp	Avg temp on day			
Bricks	Building material – bricks?	√	√	[b]
Carpetin	Play area indoors: carpet?	√		
Cementin	Play area indoors: cement?			
Chlpsrin	Surface area/child indoors	√	√	√
Chpsrout	Playground area/child outdoors	√	√	[b]

Variable name	Description of variable	Status after testing for dependence on area, using an ANOVA	Status after sw regression	Variables used in regression[a]
Cmntout	Play area outdoors: cement?			
Cookapp	Type of cooking apparatus	√	√	√
Cookplce	Cooking location			[a]
Coriron	Building material – corrugated iron?			
Crptout	Play area outdoors: carpet?			
Distrob	Distance of robot from pre-school	√	√	
Dooropen	Which outdoors normally open?	√		
Duratt	Duration attended	√	√	[a]
Durhigh	Duration of high activity levels	√	√	√
Durlow	Duration of low activity levels	√	√	√
Durmed	Duration of medium activity levels			
Facebrck	Building material – facebrick?	√		
Frclnout	Frequency of outside cleaning of playground	√		
Grssout	Play area outdoors: grass?			
Industry	Any small industry near pre-school?	√		
Kitsepar	Kitchen separate?	√	√	
Loctyprd	Type of road near pre-school – busy or quiet	√	√	√
Maxtemp	Max temp for day			
Mean log exposure	The mean of the logarithm of exposure	Dependent variable		
Meanpbs	Average soil Pb at pre-school			
Meanpbsd	Mean surface dust lead at pre-school			
Mintemp	Min temp for day			
Nochild	No of children at pre-school			
Nochldd	No of children attending on day	√	√	√
Normtch	No of teachers at pre-school	√	√	[b]
Nortch5d	No of teachers teaching 5-y olds on day			
Nortch5y	No of teachers normally teaching 5-y olds			
Num5y	No of 5-year olds attending	√	√	√
Num5yd	No of 5-year olds attending on survey day	√	√	[a]

Variable name	Description of variable	Status after testing for dependence on area, using an ANOVA	Status after sw regression	Variables used in regression[a]
Onecook	One type of fuel for cooking?	√	√	
Oneheat	One type of fuel used for heating?	√		
Outclean	Playground ever cleaned?			
Pay	Monthly fees	√	√	√
Pboutrsp	Pb assoc with RSP outdoors	√	√	√
Pbs1	Pb in soil near traffic			
Pbs2	Pb in soil near sandpit			
Pbs3	Pb in soil – playground	√	√	c
Pbsd1	Pb in surface dust on floor indoors			
Pbsd2	Pb in surface dust on window sill indoors	√		
Roadmat	Material of closest road			
Roomheat	Which rooms heated?	√		
Rspout	RSP concentration outdoors			
Sanding	Has the building been sanded recently?			
Sandpit	Is there a sandpit?			
Soilin	Play area indoors: soil?			
Soilout	Play area outdoors: soil?			
Srcpol	Other sources of pollution?	√	√	√
Srf5yin	No of children/m^2 indoors	√	√	√
Srf5yout	No of children/m^2 playground	√	√	√
Srfpgr	Surface area of playground			
Stoprob	Stop street or robot near pre-school?			
Strdist	Distance of closest street	√		b
Strslope	Is the street at a slope?	√	√	√
strtrffc	Different street used for traffic counts?			
Surfplay	Material of playground	√	√	√
Tchday	No of teachers on survey day			
Temp	Very cold day?			
Tilein	Play area indoors: tiles?			
Timewind	When did wind blow?	√	√	a
Totwin5y	Tot no of windows in room	√	√	√
Traftot	Total traffic over the day	√	√	√

Variable name	**Description of variable**	**Status after testing for dependence on area, using an ANOVA**	**Status after sw regression**	**Variables used in regression**[a]
Trfcnts	Traffic volume rating of road where traffic counts were taken			
Trfdist	If different road used for traffic counts, distance from pre-school	√	√	a
Tspin	TSP concentration indoors	√	√	a
Tspout	TSP concentration outdoors	√		
Uphill	Which side do vehicles go uphill?			
Wind	Windy day?			
Winopen	Which windows normally open?	√		
Winwhcop	Which windows are open	√		
Wood	Building material – wood?			

a As it was not possible to run one regression model with all the terms that were significant, these additional variables were excluded as their relevance were questionable.

b Variables that were not significant when fitting the final regression model were excluded

c Were significant, but contained too many missing variables; therefore excluded from the final regression model.

√ indicates that the variable was significant after the test

The variable indicating lead concentrations in surface soil at the playground area was significantly associated with mean log exposure. A positive association was found within each area, being significant only in the case of Pretoria East (see Appendix R). As this variable contained too many missing values, especially in Soshanguve (37% missing), it was excluded from the final regression model.

The final regression equation, taking the selected parameters into account, is as follows:

$$\begin{aligned}\text{Logexp65} = {} & -0.89\text{area1} + 0.002\text{pay} - 0.005\text{nochldd} + 0.02\text{num5y} \\ & -0.19\text{cookapp2} - 0.24\,\text{cookapp3} + 0.06\text{surfpgr2} + 0.30\text{surfpgr3} \\ & +0.43\,\text{surfpgr4} + 0.20\text{surfpgr5} + 0.13\text{surfpgr6} + 0.28\text{surfpgr7} \\ & +0.77\text{pboutrsp} + 0.25\text{strsl1} - 0.0005\text{traftot} + 0.002\text{durhigh} + 0.002\text{durlow} \\ & +0.02\text{totwin5y} - 0.75\text{loctyprd1} - 0.31\text{srf5yout} - 0.01\text{chlpsrin} + 0.34\end{aligned}$$

The results of the regression equation indicate that the mean log exposure:

- Was lower if the area was indicated as Pretoria East.
- Increased slightly as the monthly fees increased.
- Decreased slightly as the number of children present on the day increased
- Increased as the number of 5-year olds attending the pre-school increased
- Was lower when the cooking apparatus was indicated to be a primus stove (cookapp2) or mbawula (cookapp3), as compared to an electric stove
- Was higher as compared to exposure when playing on sand when the surface of the playground was indicated as:
  - Cement (surfpgr2)
  - Lawn (surfpgr3)
  - Sand and cement (surfpgr4)
  - Sand and lawn (surfpgr5)
  - Cement and lawn (surfpgr6)
  - A combination of sand and cement and lawn (surfpgr7)
- Increased if lead associated with respirable particulates outdoors increased
- Was higher if the street was indicated to be sloping
- Decreased very slightly if the total traffic increased.
- Increased if the total number of windows in rooms occupied by 5-y olds increases
- Increased slightly if the duration of high activities increased. It also increased slightly if the duration during which low activities are performed increased.
- Was lower if the location of the pre-school was indicated as being next to a quiet road as compared to a busy road
- Decreased as the number of children/m^2 outdoors increased
- Decreased as the surface area (m^2)/child indoors increased

4.4 Other statistical tests

The following tests were done on residuals of the final model. The outputs of these tests are included in Appendix R.

- Test for homogeneity of variance.
- Test for the presence of omitted variables in the model, that is, whether the model could be improved by adding extra variables.
- Normality

The results of these indicate the following:

- Plotting the residuals did not show a distinctive pattern indicating that the true relationship between the mean log exposure and the independent variables could be linear.
- The test for omitted variables indicates that there is strong evidence that there are other unmeasured confounders.
- The test for homogeneity of variance indicated constant variance, that is, similar variability for each individual.
- Removal of zero values for logexp65 improved normality of the plot. This plot did not depart radically from normality.
- The impact of exclusion of outliers was not tested as no justification was available to warrant the removal of these.

CHAPTER 5

5. DISCUSSION

Many authors have agreed that there is a critical scarcity of accurate exposure-related data for children of all ages, backgrounds and circumstances [108, 122, 123].

5.1 Exposure of children attending pre-school facilities to lead in air

The different parameters that were used to calculate exposure to lead in air, as well as their implications are discussed below. The discussion will deal with the exposure of 5-year olds who attended pre-school for 6 hours and more on the day of the survey.

5.1.1 Time spent indoors versus outdoors

The mean time spent indoors was significantly higher in Soshanguve as compared to Pretoria East. Indoor results compare fairly well with results from another study conducted in SA involving primary school children which indicated a median % of time spent indoors on a school day to be from 68% to 75% [99]. In comparison, a study in Germany on toddlers (2-3 years old) attending a nursery school indicated that they spend an average of 87.6% of their time indoors, 11% of their time outdoors and 1.2% of their time using various means of enclosed transportation [93]. It has been indicated that South African children spent up to 20% more time outdoors than children in the US [32]. Where the child plays may be more significant than the duration of playing indoors or outdoors, thus in most cases very detailed information on the level and duration of each activity type might not be necessary [124, 74].

It has been indicated that the reliability of exposure and dose model predictions depend on the accuracy of time-activity information [124]. Data on human activity patterns can help determine estimates of pollutant dose by serving as a proxy for inhalation rate [92]. The possibility that people change their behaviour due to the wearing of personal sampling equipment has been studied by comparing time activities on the day of sampling with time activities on other days. The impact was significant for adults but for children no significant differences in time activities were found [79].

The significant difference in sizes of indoor and outdoor playgrounds between the 2 areas are factors that may have contributed to the significant differences in time spent indoors and outdoors respectively in the two areas, although there did not seem to be a significant difference in the mean surface area per child between the two areas, both indoors and outdoors. Visual observations also indicated that playgrounds in Soshanguve were sometimes small, which could result in children spending more time indoors.

5.1.2 Lead concentrations in the air

Mean air lead concentrations indoors were found to be lower than outdoors, which is to be expected and consistent with findings from other studies [33].

Outdoor lead concentrations associated with TSP were significantly higher in Pretoria East as compared to Soshanguve. At the same time, significantly more pre-schools in Pretoria were situated next to busy roads, with traffic counts being significantly higher in Pretoria East. The findings of the current study therefore indicated that there was a dependency of lead concentrations on traffic density and the distance from a busy road, as measured by traffic counts, a finding which has been confirmed by other studies [63, 64, 69, 73, 125].

Romieu *et al.* indicated atmospheric lead levels exceeding the standard WHO guideline of 1.5 µg/m^3 for lead in a city in Mexico where traffic and industrial emissions were particularly high. These levels were, however, not exceeded in the current study, as a maximum concentration of 0.605 µg/m^3 was found. Estimates for major cities in the US are typically found to be between 0.1 and 0.2 µg/m^3 [126]. Fairly recent studies confirmed estimates by the USEPA indicating that industrial areas displayed the highest atmospheric lead concentrations (avg: 1.8 µg/m^3), as compared to commercial areas (avg: 0.8 µg/m^3) and rural areas (avg: 0.02-0.04 µg/m^3) [63,69]. Average atmospheric levels of 0.26 µg/m^3 have also been found in an informal settlement in KwaZulu Natal [130].

5.1.3 Exposure to lead in the air

Exposure of children to lead in the air took into account both lead concentrations and micro-environmental locations, in this case indoors and outdoors. The mean log exposure indoors indicated a similar pattern in both areas. Mean log exposure outdoors was, however, about three times as high in Pretoria East, as compared to Soshanguve. The mean log exposure between pre-schools, as well as between the two areas was also significantly higher in Pretoria East. In both areas most children were exposed to low levels of lead. It has been indicated in the literature that simple models ignoring, amongst others, the combination of spatial distribution of pollution within a home and the role of activity patterns, could underestimate exposure by 3-71% for demographic subgroups, resulting in inaccurate and biased estimates [47]. Once the micro-environmental concentrations and time-activity pattern data are representatively determined for a population, a realistic frequency distribution of exposures can be calculated for different scenarios [93].

As temperature and wind speed were not measured at the individual locations, no direct comparisons between meteorological and exposure results can be made for this study. It is however expected that these variations would have had an effect on the actual exposures. Previous studies have found that lead values generally decrease with increasing wind speed but noted that the correlation between the two factors is rather weak [127]. Studies have also indicated that seasonal cycles are experienced all over the world, with higher concentrations found in winter [128]. These may be attributed to higher occurrence of surface temperature inversions, lower wind speeds and rainfall and greater engine emissions due to more frequent cold starts in winter [69].

There was no significant difference in exposure between boys and girls, with the variation within gender being constant. A study done on primary school children indicated that boys had higher exposures than girls [78, 91]. It is, however, expected that the activities of boys will differ more from those of girls, as they grow older.

Most previous studies have estimated personal exposure to lead by means of either personal continuous monitoring, measurement of air lead concentrations or using blood lead levels as proxies for exposure to lead [36, 47, 67, 90, 127, 134]. A few have used a combination of personal monitoring, together with time-activity patterns and micro-environmental concentrations [46, 76]. This is similar to the approach used in this study. Studies have shown that personal exposures can depend on activity patterns and that micro-environmental concentration information can improve the accuracy of personal exposure estimation [94].

5.1.3.1 Blood lead as proxy for lead exposure

Airborne lead, mainly from motor vehicles, has been indicated as an important determinant of children's blood lead levels [126]. Earlier studies have indicated that the ratio of lead in the air to lead in the blood is 1:2, implying that 1 µg/m^3 of lead in the air will result in an equivalent increase in the level of lead in the blood of children of 2 µg/dL [33]. More recent studies have indicated that an increase of 0.1

µg/m^3 in lead in the air was associated with an increase in the mean level of lead in foetal cord blood of 0.67 µg/dL [129].

A study in KwaZulu Natal found that the distance of residences from tarred roads was associated with the level of lead in the blood of children. Motor vehicle emissions accounted for most of the difference in ambient lead levels of urban versus rural areas. The study also indicated that only a small fraction (30%) of atmospheric lead emissions in the country are from motor vehicles, which is in agreement with the low atmospheric lead concentrations found in the current study [130].

5.1.3.2 Factors impacting on lead exposure in air

When the relationships between 'mean log exposure' and possible contributing factors were assessed, the following factors were found to be significantly associated with exposure to lead in the air:

Area

Mean log exposure was lower in Pretoria East, which is contrary to what was expected. This result differed from the t-test results that showed that exposure was in fact higher in Pretoria East. The latter test did, however not adjust for confounding, possibly explaining the discrepancy. Such results could be expected if the values of all other variables in the model were equal between the two areas. It is, however, highly unlikely that all these variables could be equal.

Cooking apparatus

The mean log exposure was lower when the cooking apparatus was a primus stove or mbawula, as compared to an electric stove. A possible explanation is that schools using a mbawula or primus stove, are likely to be in lower socio-economic areas, resulting in the existence of fewer motor vehicles leading to inhalation exposure to lead. It has been indicated that the burning of solid wastes for heating or cooking is associated with blood lead levels in children but could not be tested in this study as blood lead levels were not determined [130].

Monthly pre-school fees

It was indicated that, overall, mean log exposure increased slightly as the monthly fees increased. This is in agreement with the finding that exposure in Pretoria East, having higher socio-economic conditions, was higher than in Soshanguve. No evidence could be found in the literature to support this finding. A study in Mexico did find that socio-economic level and housing location were not significantly related to the level of lead in children's blood as an indicator of their exposure to lead [66].

Numbers of children on the survey day

Mean log exposure decreased slightly with an increase in the total number of children present on the day, which is contrary to what was expected. A possible explanation for this is that children may be less active when there are more children per pre-school. Another possibility may be that younger children are present in greater numbers in the pre-school, as compared to more active, older children. Mean log exposure increased as the number of 5-year olds attending the pre-school increased. As 5-year olds are expected to be more active than the smaller children, this may indicate that exposure is associated with the resuspension of dust from the activities of these children.

Mean log exposure decreased as the number of children/m^2 outdoors increased, resulting in a smaller surface area per child. It also decreased as the surface area (m^2)/child indoors increased. These results may be explained by the fact that children may spend more time indoors if the surface area outdoors is too small to accommodate all children.

Playground characteristics

The mean log exposure of the following factors, as compared to the mean log exposure when playing on sand, was higher when the surface of the playground was indicated as:

- Lawn
- Sand and cement
- Sand and lawn
- A combination of sand, cement and lawn

There were no differences between surfaces covered by sand and when the surfaces were indicated as cement or cement and lawn. These variables were not grouped optimally in the questionnaire and other interactions may have appeared or disappeared as a result.

Number of windows in rooms where 5-year old spent most of time

There was a positive association between mean log exposure and the total number of windows in rooms occupied by 5-y olds. Most schools in the current study indicated that certain windows were normally open. This practice could have affected the extent of lead concentrations detected indoors and outdoors. Previous studies have indicated that the habit of keeping windows open could obscure indoor versus outdoor differences in atmospheric lead concentrations [74, 59].

Lead measured as respirable particulate matter

The mean log exposure, that is, lead present as TSP, increased if lead concentrations measured as RSP outdoors increased. As it is expected that most lead from motor vehicles will be present in the RSP fraction, this indicates that if lead in the RSP fraction can be detected in suitable amounts, it may provide a good indication of mean log exposure [127]. Previous studies have indicated that the lead content of soil, street dust and house dust increases as particle size decreases [62].

Road and traffic parameters

Mean log exposure was higher if the street was indicated to be sloping. Of the 54% pre-schools that were situated next to a sloping road, the uphill section was closest to the school in 62% (18) of cases. The slope of the street may therefore affect the extent of exposure of these children as vehicles may use more petrol when going uphill.

Overall, mean log exposure to lead decreased very slightly if the total traffic increased, which is contrary to what was expected. Most previous studies focused on the association between lead concentrations or levels of lead in blood and traffic density and did not take time-activity patterns into consideration [66]. In this study, both mean log exposure and total traffic counts were significantly higher in Pretoria East when compared to Soshanguve, indicating that there seems to be an association between mean log exposure and traffic density. A possible explanation for the discrepancy between these two findings could have been that children spent more time indoors in areas where the traffic volumes were higher as a result of other factors such as noise stemming from traffic.

The mean log exposure was lower if the location of the pre-school was indicated as being next to a quiet road as compared to a busy road. This is consistent with findings in the literature. A study in Hong Kong has indicated that road type may be an adequate indicator of traffic condition and traffic flow [59].

Duration of different levels of activities, defined as high/medium/low

Mean log exposure increased slightly when the duration of involvement in activities classified as high increased. This is to be expected, as high activities such as running should result in a higher inhalation rate leading to an increased exposure. Mean log exposure, however also increased slightly with an increase in duration of low activities. It is currently not known why this was the case and could have been as a result of other contributing factors, which may have to be investigated further. Only 3 levels of activity were used in the current study, which may have lead to misclassification of activities. Other studies have indicated that increasing the number of classes of activity levels will increase the resolution of these parameters, resulting in more reliable relationships [93].

Although it was not the intention of the study to rank these factors in order of significance, for intervention purposes, five of these factors were selected as being the most important, on the basis of statistical testing. The variables of most practical importance were:

1) the monthly fees paid at the school;
2) whether the street was indicated to be steeply sloping;
3) total traffic volume;
4) the number of children/m^2 outdoors; and
5) the surface area (m^2)/child indoors

(lead exposure being positively associated with the first two and inversely associated with the last three variables).

Tests done after fitting the regression model indicated that mean log exposure did improve the fit of the data (Appendix R) but the distribution was still not normal, as can also be seen from the histograms in Figure 12 – Appendix Q.

5.2 Lead loadings and concentrations in soil as proxy for ingestion exposure indoors

The concentrations of lead in soil and loadings in surface dust were used as indicators of exposure to lead in soil and surface dust.

5.2.1 Lead loadings in surface dust

Mean lead loadings in surface dust indoors were in all cases found to be higher in Soshanguve than in Pretoria East, which is contrary to findings from previous studies [73]. More untarred roads and dusty playgrounds were found in Soshanguve. Loadings were significantly higher in the case of windowsills and objects such as bookcases. In a few cases loadings exceeded guidelines as established by USEPA which considers lead loadings of greater than 1000 $\mu g/m^2$ on hard floors to be unsafe. This level was exceeded in three places. All three were from windowsill samples taken in Soshanguve; the maximum loading being 1644 $\mu g/m^2$. Some researchers reported that the highest indoor lead levels were observed in dust samples from windowsills: 7.1% of the samples exceeded 2 150 $\mu g/m^2$ of lead content, while others found mean dust loadings of 210 $\mu g/m^2$ for floors and 620 $\mu g/m^2$ for window sills [60, 66].

It has been demonstrated that a major portion of interior house dust lead results from deposition of leaded petrol emissions (95% in newer houses and 50% in old houses). Also, house dust lead concentrations increase as a function of traffic density and as a function of the age of the building, which is an indication that structures act as traps for lead dust [59, 63, 133]. Information on the age of these structures was not recorded in the current study, but formal housing in Soshanguve began in about 1972, while informal housing, which includes corrugated iron structures has been around since the early 1990s [131].

Mean dust lead loadings on uncarpeted house floors in urban areas have been found to vary between 160 and 25 $\mu g/m^2$ [60]. The levels of lead in indoor dust on uncarpeted floors, furniture and windowsills were positively correlated. A positive correlation between atmospheric lead levels, furniture and windowsill dust lead has also been found [126]. Results of a study in South Durban, however, indicated that dust lead loadings were correlated with lead concentrations in dust but not with distance from the highway or with atmospheric lead deposition rates. The study concluded that sources other than motor vehicles may contribute to dust loadings [60]. This finding may contribute to explaining why surface soil and dust concentrations in the current study were found to be higher in Soshanguve although traffic counts were lower. Although Soshanguve is a markedly more dusty area than Pretoria East, a factor that may contribute to the resuspension of lead, no visible sources of lead pollution were evident in the area while conducting this research.

It has been indicated that variation in lead loading within small areas and variations in collection inherent to the sampling techniques contribute to measurement error [60].

5.2.2 Concentrations in surface soil

Average lead concentrations in surface soil (outdoors) were also found to be consistently higher in Soshanguve than in Pretoria East, with a higher variability. In order to establish whether this was the case in general, background lead levels measured in Pretoria (2001), were obtained. Mean background lead levels in the area around Soshanguve were 23 µg/g, which is about half of the mean for Pretoria East. No background concentration data were available for the Pretoria East area but a mean background of 69 µg/g has been measured around the city centre and a mean background of 43 µg/g in the area just north of the city centre.[132].

Mean concentrations in the sandpits, as well as overall lead concentrations were significantly higher in Soshanguve. The Dutch Soil investigation criteria for soil contamination of 300 µg/g soil which have been used previously to evaluate the health risk of playground soils with respect to soil metal contents, were also used in this study [71]. The maximum concentration of 103 µg/g soil, found in Soshanguve did not exceed this guideline.

No significant relationship was found between the mean soil and surface dust concentrations in the current study. Previous studies have, however found significant correlations between soils and dusts for lead [63]. Mean concentrations of lead in surface soil from playgrounds ranging between about 100 and 400 µg/g have been detected. One particular study also concluded that lead in playground dusts was probably from atmospheric deposition resulting from motor vehicle emissions [71]. Lead levels in soil at playgrounds of elementary schools ranging between 77 and 223 µg/g have also been found in Jakarta [67].

A high correlation has been found between roadside soil and traffic volume [71], while research in the US has shown a decreasing pattern of soil lead concentrations from high concentrations in the inner city, decreasing to the outer city, suburban areas and being lowest in rural areas [63].

Correlations between lead-contaminated soil and the level of lead in the blood are influenced by many factors. These include access to soil, behaviour patterns of children, presence or absence of ground cover, seasonal variation of exposure conditions, particle size and the composition of the lead compounds [62]. A study conducted in the US in the 1980s found that the concentration of lead in children's blood increased when the concentration of lead in soil increased. The age of the houses did not influence these results. Statistically significantly lower concentrations of lead in blood and soil were also found in communities with low traffic flows as compared to those with high traffic flows [63]. Although results from this study suggest that the level of lead in the blood of children in Soshanguve may be higher than that of the children in Pretoria East, the information from the current study is not sufficient to arrive at such a conclusion.

A study conducted in Johannesburg indicated that, relative to other areas such as inner city and suburban areas, children attending schools in informal settlement areas appeared to have slightly higher blood lead levels. A greater proportion of children in these informal settlements or peri-urban areas also had higher levels of lead in their blood when compared with the other two areas [104].

It should be noted that caution should be used in drawing conclusions when only one or a few soil samples from a site have been analysed as a single soil sample may significantly over or underestimate the average lead concentration at a site [62].

Pre-schools in both areas indicated that cleaning was done at least daily indoors and at least weekly outdoors. A study conducted in Philadelphia indicated that the distribution of lead on accessible surfaces in school classrooms is uniformly low, mainly due to effective cleaning procedures [133]. Other studies have, however found that the use of a broom for housekeeping increased the mean blood lead level among women by 40% as compared to women who did not use a broom as it substantially increases the concentration of suspended particulates. Sweeping the floor would, therefore offer little protection to a child [134, 130, 60].

The following factors were investigated as potential explanations of the results of higher lead loadings in surface dust and concentrations in soil:

- It may be speculated that Soshanguve is a more dusty area than Pretoria East, with more resuspended dust. This will, however have to be investigated further.
- A higher background level of lead in soil in Soshanguve was suspected. The mean background lead concentrations in the area around Soshanguve was, however, found to be lower than the mean for Pretoria East [132].
- Different cleaning practices in the two areas - dust loadings on window sills in Soshanguve are expected to be higher as these sills are often very narrow and rough and therefore cleaned seldom or never. It has been reported that lead accumulates indoors, especially on window sills, which are not cleaned as frequently as floors [126].

This study has indicated that environmental lead levels, especially in air, were generally low. This is consistent with findings from other studies [31, 66]. Lead exposure in Pretoria East, where traffic counts were on average significantly higher than in Soshanguve, was also significantly higher than in Soshanguve, which is similar to findings from other studies [64, 66, 69, 125]. In contrast to this finding, it was found that mean soil concentrations and surface dust loadings were higher in Soshanguve as compared to Pretoria.

Extrapolation of this sample to a pre-school population should, however, be done with caution, due to the following reasons:

- Exposure was calculated and, if no lead concentrations were detected indoors and outdoors, the exposure was regarded as zero.
- The results refer to exposure on a particular winters day and are affected by the meteorological conditions of the particular day.

CHAPTER 6

6. CONCLUSIONS AND RECOMMENDATIONS

This study indicated that exposure to lead particles in air was not determined by socio-economic status as such, but rather by traffic density.

The strength of the study was that it considered a wide range of factors regarded as being potentially associated with exposure to lead in air, using multi-variate analyses. This is different from approaches that consider only a few parameters at a time, thereby leaving more room for confounding. Factors to take into consideration with regard the choice of site and building of pre-schools include the following:

- Proximity of the school to busy roads and other sources of lead when new pre-schools are planned. Traffic volumes on these roads should be monitored in advance;
- Schools should not be built on a steeply sloping road;
- Cleaning procedures used at a pre-school should not use appliances that disperse dust so-as to minimize exposure to resuspended lead; and
- Reduce time outdoors if the facility is close to sources of pollution.

The following issues, emerging from this study, could be investigated in future studies:

- The impact of the distance of a pre-school to a busy road on the lead concentration in soil and air, taking meteorological conditions into account
- The reasons behind the higher concentrations of lead in soil and surface in Soshanguve when compared to Pretoria East.

- It has been stated that socio-ecological conditions in urban schools in South Africa contributed to an increased risk of dust lead exposure with factors such as (i) overcrowding of classrooms, (ii) activities, (iii) the dusty environment and (iv) infrequent washing of hands increasing the probability of hand contamination and hand-to-mouth transfer of lead [60]. This is even more of a reality in pre-school facilities where hand-mouth contact is more prevalent. The impact of these factors on exposure and eventual dosage should be investigated.

6.1 Ways to determine child-specific exposure parameters for use in health risk assessment

It has been said that research priorities need to be expanded to include children [135]. These initiatives should, wherever possible, link to opportunities provided by developmental projects [41]. In order to improve the database relating to children's exposure to lead, the issues raised above need to be quantified. The impact of activity patterns on exposure of children to lead in South Africa require further investigating in order to develop measures comparable to standardised exposure equations developed by the USEPA. In doing so, the following should be considered:

- Identification of appropriate age or developmental benchmarks for categorizing children in exposure assessments [26].
- Development of methods and equipment for monitoring children's exposure to lead and activities in these different stages [18]. Examples of these include the modification of personal monitoring equipment such as backpacks for small children. Each stage will require a different approach, depending on their mobility, socio-economic conditions in which they operate and the environment of concern. It is especially important to develop and validate methods to extract information from or about young children who are

nonverbal or who lack a well-developed sense of time about their activities and exposure [26, 108].

- This study determined exposure to air pollutants by means of inhalation and used soil concentrations as proxies for ingestion exposure. It is, however important that physical activity data for children (especially young children) required to assess exposure by all relevant routes of exposure be collected. In most countries, neither the public health agencies nor school authorities have paid much attention to the problem of indoor or outdoor dust contamination. No codes, guidelines or standard tests for heavy metal contamination in schools exist. It is therefore important to study the levels of heavy metals in the school environment, including pre-schools and to examine their relationships with external environmental factors [59].

In order to increase the validity of exposure assessment in health risk assessment, the exposures and time-activity patterns of susceptible groups such as children need to be characterised as a function of the following: age, sex, settings such as residence, school, or day care, socio-economic status, race or ethnicity, location, region, and season. Data gaps are particularly significant for very young children (younger than 4 years of age) [26, 136].

The spatial and temporal variations in environmental pollutants, including lead, have implications for air monitoring strategies and epidemiological studies focusing on the relationship of exposure to these pollutants and the health impacts on populations. It is therefore necessary to take micro variations in exposure into account when assessing exposure to environmental pollutants [125, 18, 26]. As this study only touched the surface of exposure assessment in different micro-environments for South African pre-school children, further research in this field will assist in providing the knowledge base needed to improve exposure assessments for children.