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LEAD POLLUTION ALONG MAJOR ROADS IN MAURITIUS

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MAURITIUS RESEARCH COUNCIL

Address:

Level 6, Ebène Heights,
34, Cybercity,
Ebène 72201,
Mauritius.

Telephone: (230) 465 1235
Fax: (230) 465 1239
Email: mrc@intnet.mu
Website: www.mrc.org.mu

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LEAD POLLUTION ALONG MAJOR ROADS IN MAURITIUS

Dr Robert CHOONG KWET YIVE
Dr Henri LI KAM WAH

Department of Chemistry
Faculty of Science
University of Mauritius

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ABSTRACT

The project deals with the determination of lead in soil samples collected near roads in Mauritius.

Roads with different traffic densities (High Traffic Density, HTD; Average Traffic Density, ATD; Low Traffic Density, LTD) found in rural, sub-urban and urban areas were selected for the study.

A total of 733 soil samples have been collected, dried, sieved, digested using microwave technique and analysed for lead by atomic absorption spectrometry.

The lead content obtained in the different soil samples ranged from 0 ppm (road near Trou aux Cerfs region) to 3012 ppm (alongside the M1 motorway between Réduit and Caudan).

Typically roads having a LTD, ATD and HTD have a mean lead soil content of less than 250 ppm, 400 ppm and greater than 500 ppm respectively. The results clearly indicate that vehicular exhaust is the main source of lead pollution near roads in Mauritius.

The most polluted soil samples were collected near the Réduit/Caudan segment of the M1 motorway (mean lead level > 800 ppm).

Lead soil levels alongside roads in Beau-Bassin/Rose-Hill, Quatre-Bornes and Curepipe varied from 18 ppm to 1299 ppm. Curepipe was found to the least polluted (mean 159 ppm) whereas Quatre-Bornes and Beau-Bassin/Rose-Hill had similar soil lead content (mean of 283 and 290 ppm respectively).

The mean soil lead level was found to increase with time alongside the M1 motorway.

Climatic conditions and topography of the land were found to influence greatly the deposition of lead particulate matter near the roads.

LIST OF ABBREVIATIONS

ADT	Average daily traffic
ATD	Average traffic density
ATSDR	Agency for Toxic Substances and Disease Registry
CDC	Centre for Diseases Control
EP	Erythrocyte protoporphyrin
EPA	Environmental Protection Agency
HTD	High traffic density
NTA	National Transport Authority
Pb	Lead
PbB	Lead blood
SETW	South East Trade Winds

CHAPTER ONE

INTRODUCTION

LEAD POLLUTION ALONG MAJOR ROADS IN MAURITIUS

1. INTRODUCTION

1.1 AIM OF PROJECT

The study deals with lead pollution in roadside soil in Mauritius. The main objectives of the study are:

(i) to determine the level of lead pollution in roadside soils along motorways, in towns and in some rural areas,

(ii) to monitor this pollution with time,

(iii) to investigate whether there is any correlation between lead content in soil and traffic density, wind direction and other factors, and finally

(iv) to compare the lead content values obtained with those reported in the literature in other parts of the world.

1.2 GENERAL INTRODUCTION

Lead (Pb) is a naturally occurring element that has been used almost since the beginning of civilisation. It occurs in the earth's crust with an average abundance of 16 parts per million (ppm), primarily as galena (PbS). Because of the many industrial activities that have brought about its wide distribution, lead has the distinction of being ubiquitous in the environment today. All humans have lead in their bodies, primarily as a result of exposure to man-made sources. Despite the success of the reduction measures implemented since the mid-1970s in industrialised countries, low-level exposure to lead continues to threaten the health of vulnerable groups, such as young children.

1.3 LEAD USE IN THE WORLD

Lead is one of the most widely used non-ferrous metal after aluminium and copper and is a vital material in everyday life. It is mined and smelted in both developed and developing countries. An increasing proportion of the supply of the metal (over 50%) is being met by recycling. Consumption is predominantly in industrialised countries but is increasing rapidly in the developing countries.

The principal consumption of lead is in lead-acid batteries, which are used in vehicles, and in leaded gasoline as well as in industrial batteries found in computers and fork lift trucks. Lead is also used in remote access power systems and load levelling systems as well as in compounds in the glass and plastics industries and for radiation shielding.

1.4 SOURCES OF LEAD POLLUTION

During the last 100 years, lead was added to many products including paint, gasoline, water pipes and health care supplies. About 330 million tons of lead were mined in U.S.A. for these purposes. Even though lead's use is now restricted and regulated because of known health risks, the heavy metal is still mined and added to products.

Because lead does not dissipate, biodegrade or decay, most of the lead ever produced remains in soil and dust. The odourless, colourless, tasteless metal so widely present in homes, yards, and workplaces can only be detected through chemical analysis. The two biggest contributions of lead to the environment are leaded paint and leaded gasoline. In U.S.A., use of leaded paint peaked in the 1920s but gradually fell off. At its zenith in the 1970s and before its use was restricted in 1986 in U.S.A., leaded gasoline spewed up to 250,000 tons of lead per year into the environment[1]. Leaded paint continues to cause most of the severe lead poisoning in children in the United States[1]. It has the highest concentration of lead per unit weight and is the most widespread of the various sources, being found in approximately 21 million pre-1940 homes. Dust and soil lead-derived from flaking, weathering, and chalking paint plus airborne lead fallout and waste disposal over the years, are the major proximate sources of potential lead exposure. Lead in drinking water is intermediate but highly significant as an exposure source for both children and the foetuses of pregnant women. Lead in food also contributes to exposure of children and foetuses.

Individuals may be exposed to lead through several sources. When evaluating a site, a health assessor should be aware of multiple sources of lead exposure and the additive nature of the risks. An important source of lead exposure in older homes is contact with interior or exterior surfaces that have been painted with lead-based paints. Some individuals may be exposed to lead from occupational or hobby sources or from other less-common sources, such as the use of lead-glazed pottery, stained glass-working, and target practice in poorly ventilated indoor firing ranges.

1.4.1 Gasoline

Automobile emissions have been an important source of lead exposure for urban residents, particularly in areas with congested traffic. In developed countries where unleaded gasoline is available, although inhalation of lead from gasoline is no longer considered a public health problem, the lead from dust in automobile emissions before the advent of unleaded gasoline has been deposited in the soil. For example, in U.S.A., although lead emissions from gasoline have largely been eliminated, an estimated 4-5 million metric tons of lead previously used in gasoline remain in dust and soil[2]. Children playing near roads and freeways may come in contact with contaminated soil.

However, in developing countries, vehicular emission is still a threat to human as in most of these countries including Mauritius, only leaded gasoline is available. Lead is added to gasoline as organic tetraalkyllead or ethyltrimethyllead. Lead content of petrol differs in many countries. For example, the lead content of petrol in Delhi, London and Sydney are respectively 1.8, 0.15 and 0.3 g $litre^{-1}$ in 1997[3].

It has been found[4] that, assuming an average vehicle fuel consumption of 0.10 litre km^{-1} and an average lead content of fuel of 0.7 g $litre^{-1}$, a vehicle at a speed of 80-100 km/h exhausts an average of 0.04 g Pb/km of distance along a highway.

Lead-containing particles from car exhausts are mainly spread upwards. Lead emitted by automobiles accumulates primarily within 50 m of the roadway and within the upper 0-5 cm depth of soil. It has been recorded that while some 25% of vehicle emitted lead is coarse grained and thus deposited close to the road, the remaining 75% is fine and may remain airborne and contaminate areas more remote from the point of emission[5].

Concentrations of lead in air vary from 0.0001 $\mu g/m^3$ (in remote areas of the world) up to about 5 $\mu g/m^3$ in city areas with heavy traffic[6]. Lead concentrations in excess of 10 $\mu g/m^3$ have been measured in places such as closed car parks, inside vehicles or on busy urban motorways[6]. About 90% of airborne lead is thought to be derived from emissions from engines and the level of lead in air is found to decrease as the concentration of tetra-alkyl lead added to petrol is reduced.

In most cases, indoor concentrations are substantially lower than the corresponding outdoor values. Indoor/outdoor ratios of 0.6 to 0.8 have been reported for airborne lead[7]. For the majority of urban and rural residents, airborne lead averages to less than 0.5 $\mu g/m^3$.

Evidence suggests that the removal of lead additives from gasoline is an effective preventive action that can be taken to reduce city children's exposure to lead. The best evidence for the effect of removing lead additives from gasoline is a reduction in the mean blood-lead level of the children in the U.S.A. from 15 μg/dL to about 6-7 μg/dL.

1.4.2 Paint

In developed countries, the lead content of paint was not regulated until the mid seventies. Many older structures, residential and commercial, have leaded paint that is peeling, flaking, and chipping. Lead-based paint has been responsible for a substantial proportion of cases of severe lead poisoning in children. Basic lead carbonate, $2PbCO_3.Pb(OH)_2$, was used in many parts of the world in white paint both on the exterior and interior of houses. In such paint, lead may constitute 5-40% of the final dried solids. Lead acetate, lead oxide and lead chromate are also used in paints and varnishes. Children can ingest loose paint as a result of pica (compulsive eating of non-food items) and through mouthing of items contaminated with lead from paint, dust and soil. Some countries have had regulations prohibiting the use of lead-containing paints since about 1900, e.g. Germany, France and Sweden[8]. In the U.S.A., the Lead Poisoning Prevention Act of 1971 limited the acceptable lead concentration in residential paint to 1%. In 1977 this legislation was amended to reduce the acceptable level to 0.06%[8].

However, in Mauritius lead compounds are still being used in the manufacture of paint. Yellow and red paints contain 1-3% of lead, whilst industrialised paints contain more than 3% of lead.

1.4.3 Food & Water

Between 1976 and 1991, one of the top three major sources of lead exposure in the general population of U.S.A. was from soldered cans[1]. Lead leached from the lead solder, used to hold the can together, into the food and was consumed by anyone who ate the product. Particularly acidic foods can dissolve lead from the lead solder in the side seam of the can. Lead levels in canned and fresh fruits and vegetables were compared and a 6- to 28-fold higher level in the canned products[8] was observed. In 1980, 47% of food and soft drinks cans were lead soldered.

Water from leaded pipes, soldered plumbing or water coolers is another potential source of lead exposure. Elevated levels of lead in water arise principally from industrial discharges, highway runoff and weathering processes. Lead in water occurs in either dissolved or particulate form. With time the particulate lead will be associated with the sediment. The natural lead level in the ocean has been determined to be 0.02 μg/L at 2000-4000 m depth[6]. The lead concentration at the surface was 0.07 μg/L. Surface water samples in the United States had lead concentrations in the range 1-55 μg/L. In household tap water, elevated lead levels usually arise from lead soldered plumbing materials.

1.4.4 Consumer products

Since ancient times, lead has been used in cosmetic preparations, particularly hair dyes, face powders and eye colourings. Lead acetate is used to darken the hair. Certain cosmetics from the Indian sub-continent, such as khols and surmas, which are applied to the eyes including those of children and infants, contain lead. They may contain up to 83% of lead[8]. It is also reported that several types of lead-based hair colouring products contained lead acetate levels between 2300 and 6000 micrograms of lead per gram[1]. After their use, hands, faucets, combs and other articles were coated with dangerous amounts of lead that could be transferred from surfaces and ingested by anyone who comes into contact with them.

Other sources of lead exposure in children may be brightly coloured magazine pages, artist paint pigments, lead dust in shooting galleries and some herbal "medications". Burning of battery casings has caused fatal and nonfatal cases of lead poisoning[9].

In 1985, 43 cases of lead poisoning were reported from Israel, due to lead contamination of flour[10]. Freshly ground flour contained large amounts of lead originating from lead fillings employed to fasten the housing of the drive-shafts to the millstones. Systematic screening of stone mills in the surrounding villages showed significant lead contamination of flour in 33 mills.

1.4.5 Others[1]

- Contaminated cooking utensils
- Ethnic medicines
- Lead batteries
- Mines and smelters
- Primary batteries, wet & dry
- Valve & pipe fittings
- Pottery & ceramics
- Automobile parts & accessories

- Home remedies
- Chemical preparations
- Industrial machinery

1.5 LEAD IN SOIL AND DUST

Soil is contaminated by lead from various sources. Lead particles are deposited in the soil from flaking lead paint, from incinerators (and similar sources), and from motor vehicles that use leaded gasoline. Waste disposal is also a factor. Urban environments in general have received higher depositions of lead from vehicular emissions than rural areas[2].

Wide variations in soil lead levels have been reported, ranging from less than 100 ppm to well over 11,000 ppm. Natural levels of lead in surface soils are usually below 50 ppm. Soils adjacent to houses with exterior lead-based paints may have lead levels of >10,000 ppm[8].

Depending on the uniformity of lead distribution at a site, a single soil sample may significantly overestimate or underestimate the average lead concentration at a site. Evidence for the non-uniformity of lead distribution in urban soils was demonstrated in a study[8] which examined soil lead concentrations in urban Baltimore gardens. Soil lead concentrations varied more than 10-fold within a single garden.

Atmosphere lead is retained in the upper 2-5 centimetres of undisturbed soil, where it is bound to organic components of the soil. Soils that are disturbed or turned may be contaminated down to far greater depths. The downward movement of lead in the profiles of highly contaminated soils could be attributed to leaching as soluble chelated complexes with organic matter, transfer of soil particles by earthworms and other faunal organisms or transfer by plant roots.

Roadside soils may contain atmospheric lead from 30 to 2000 ppm in excess of natural levels within 25 metres from the road. There is no doubt that deposition of a petroldriven lead aerosol gives rise to elevated lead concentrations in surface dust or topsoil adjacent to busy major roads. Lead accumulation is dependent on several factors[11] including: length of exposure time, local topography, vegetation cover, soil type, average daily traffic (ADT), direction of prevailing wind and type of driving, whether freeway or city. Extensive stop-start vehicle movement conditions result in a significant consumption of fuel and thereby enhanced lead emission into the environment. In addition, considerable amounts of lead may be washed from the roadway by storm-water runoff[11].

Despite the abundant literature on roadside lead, little is known concerning long term rates of lead accumulation in soil. It has been shown[11], based on lead deposition in beakers placed at 1.5 m above ground and 15 m downwind of a freeway (ADT = 70 000), that deposition of lead after 22 days amounted to an estimated 70 ppm per year.

Lead in dust and soil is a source of lead exposure that is probably highly significant for children. Preschool-age children and foetuses are usually the most vulnerable segments of the population for exposures to lead. This increased vulnerability results from a combination of factors[2]:

- the developing nervous system of the foetus or neonate has increased susceptibility to the neurotoxic effects of lead;
- young children are more likely to play in dirt and to place their hands and other objects in their mouths, thereby increasing the opportunity for soil ingestion (pica - eating of dirt and other food items - is more likely to occur in children),
- the efficiency of lead absorption from the gastrointestinal tract is greater in children than in adults, and
- nutritional deficiencies of iron and calcium, which are prevalent in children, may facilitate lead absorption and exacerbate the toxic effects of lead.

Among children, those in the 2-3 year old age range may be most at risk for exposure to lead-contaminated soil or dust, and studies[2] have confirmed that children in this age group had the highest blood lead concentrations.

High concentrations, up to 50 000 ppm have been found in dust at certain sites such as car parks and garage forecourts[12].

Several investigations[2] have shown a highly significant correlation between lead blood levels and lead concentrations in dust and soil. In general, lead in dust and soil at levels of 500 and 1000 ppm begins to affect children's lead blood levels. Generally, blood lead levels rise 3-7 μg/dL for every 1000 ppm increase in soil or dust lead concentration.

Many governments[2] have issued guidelines for lead in soil. In U.S.A., Canada and England, the recommended soil lead standard for residential land use is 500 ppm. For sandy soil or soil having a low content of organic matter, the recommended standard is lower (375 ppm).

Researchers[2] have also calculated "acceptable" levels of lead in soil and dust:

- To protect pica children, a lead soil standard should be below 100-150 ppm.
- To keep lead blood levels below 10μg/dL (the acceptable limit set by the Centre for Diseases Control of U.S.A.), the standard should be less than 150 ppm.

On the other hand, after assessing the risks from lead content of street dust, Duggan and Williams[13] estimated that the highest tolerable lead content was 300 ppm.

The lead content in samples of house dust categorized into fractions by particle size collected in Cincinnati, Ohio (Table 1) was determined. The study[2] shows that lead concentration is generally independent of particle size and that the bulk of the dust particles are concentrated in the smaller size ranges. Note that 77% of the lead was present in particles smaller than 149 μm. This distribution of lead in small particles would maximize intestinal absorption.

Table 1: Normal house dust by particle size and lead content[2]

Size range (μm)	Weight % of fractionated dust	μgPb/g of dust fraction	% Pb in unfractionated dust
< 44	18	1440	21
44-149	58	1180	56
149-177	4.5	1330	4.9
177-246	2.7	1040	2.3
246-392	6.1	1110	5.6
392-833	11	1090	9.6
Unfractionated dust	100	1214	100

1.6 ENVIRONMENTAL FATE OF LEAD

1.6.1 Air

In anti-knock fluids, 1,2-dihaloethanes are used as scavengers of decomposition products from the lead alkyls. The oxides resulting from combustion of the lead alkyls are thus able to form mixed halides. The principal chemical forms of the metal emitted from car exhausts[2] are therefore lead bromochloride (PbBrCl) and the alpha and beta forms of ammonium chloride lead bromochloride ($2PbBrCl.NH_4Cl$ and $PbBrCl.2NH_4Cl$) together with trace amounts of mixed oxide ($PbO.PbBrCl.H_2O$) and sulphate ($PbSO_4$). Degradation of these particles leads to halogen loss and conversion to oxide and/or carbonate.

1.6.2 Water

Lead has a tendency to form compounds of low solubility with the major anions found in natural water (Table 2). In the natural environment, the divalent form (Pb^{2+}) is the stable ionic species of lead. Hydroxide, carbonate, sulphide, and, more rarely, sulphate may act as solubility controls in precipitating lead from water. A significant fraction of lead carried by river water is expected to be in an undissolved form. This can consist of colloidal particles or larger undissolved particles of lead carbonate, lead oxide, lead hydroxide, or other lead compounds incorporated in other components of surface particulate matter from runoff. The ratio of lead in suspended solids to lead in dissolved form has been found to vary from 4:1 in rural streams to 27:1 in urban streams[2].

Table 2: Solubility of lead and lead compounds[2]

Element / Compound	Solubility	
	Water	*Organic solvents*
Lead	Insoluble	Insoluble
Lead Acetate	221g/100ml at 50°C	Soluble in glycerol, very slight in alcohol.
Lead Chloride	0.99g/100ml at 20°C	Insoluble in alcohol
Lead Chromate	0.2mg/L	Insoluble in acetic acid
Lead Nitrate	37.65-56.5g/100ml at 0°C	1 g in 2,500 ml absolute alcohol 1 g in 75 ml absolute methanol
Lead Oxide	0.001g/100ml at 20°C (Litharge) 0.0023g/100ml at 23°C (Massicot)	Soluble in alkali chlorides Soluble in alkali (Massicot)
Lead Sulfate	42.5mg/L at 25°C	Insoluble in alcohol

1.6.3 Soil

Paint and automobile emissions are major contributors to soil lead contamination. The accumulation of lead in soil is primarily a function of the rate of deposition from the atmosphere. The fate of lead in soil is affected by the specific or exchange adsorption at mineral interfaces, the precipitation of sparingly soluble solid phases, and the formation of relatively stable organo-metal complexes or chelates with the organic matter in soil[2].

Evidence exists that atmospheric lead enters the soil as lead sulphate or is converted rapidly to lead sulphate at the soil surface. Lead sulphate is relatively soluble, and thus could leach through the soil if it were not transformed. In soils with pH ≥ 5 and with at least 5% organic matter, atmospheric lead is retained in the upper 2-5 cm of undisturbed soil[2]. Lead may mobilise from soil when lead-bearing soil particles run off to surface waters during heavy rains. Lead may also mobilise from soil to atmosphere by downwind transport of smaller lead-containing soil particles entrained in the prevailing wind[2]. This latter process may be important in contributing to the atmospheric burden of lead around some lead-smelting and other sites that contain elevated levels of lead in soil.

The downward movement of lead from soil by leaching is very slow under most natural conditions[2]. The conditions that induce leaching are the presence of lead in soil at concentrations that either approach or exceed the sorption capacity of the soil, the presence in the soil of materials that are capable of forming soluble chelates with lead, and a decrease in the pH of the leaching solution (e.g. acid rain)[2].

1.7 BIOLOGICAL FATE OF INORGANIC LEAD IN HUMAN BODY

Inorganic lead is not metabolised but is directly absorbed, distributed, and excreted. Once in the blood, lead is distributed primarily among three compartments - blood, soft tissue (kidney, bone marrow, liver and brain), and mineralising tissue (bones and teeth)[8]. Mineralising tissue contains about 95% of the total body burden of lead in adults. Some of the lead absorbed is excreted through the kidneys or intestines.

In blood, 99% of the lead is associated with erythrocytes; the remaining 1% is in the plasma and is available for transport to the tissues. In single-exposure studies[8] with adults, lead has a half-life in blood of approximately 25 days; in soft tissue, about 40 days; and in the non-labile portion of bone, more than 25 years. In bone, there is both a labile component, which readily exchanges lead with the blood, and an inert pool. Lead in the inert pool poses a special risk because it is a potential endogenous source of lead. Because of these mobile lead stores, a person's blood lead level can take several months or sometimes years to drop significantly, even after complete removal from the source of lead exposure. Throughout a lifetime, lead is mobilised back into the bloodstream in times of stress, chronic disease or pregnancy/lactation (a hazardous exposure source for unborn foetuses).

Even though single exposures are hazardous, it is chronic exposure that poses the biggest threat. Constant, long-term exposure from both the external environment and total body burden (all lead circulating or stored in a body) can cause adverse health effects.

1.8 TOXICITY OF LEAD

Lead is a highly toxic metal to which humans are exposed in the normal circumstances of life. It is noteworthy that in U.S.A., the Environmental Protection Agency (EPA) and the Agency for Toxic Substances and Disease Registry (ATSDR) have ranked Lead as the number one priority hazardous substance[2].

The most commonly used biomarkers of lead exposure are the lead blood (PbB) concentration and the blood erythrocyte protoporphyrin (EP) concentration. The EP test has poor sensitivity and specificity below a PbB level of 25 μg/dL. The Centre for Diseases Control (CDC), the federal agency responsible for tracking diseases in U.S.A., recommends PbB concentration as the screening test of choice[2].

Increasing knowledge of the noxious effects of the metal even at low concentrations has led to the lowering of Pb toxicity units from Pb blood levels of 1.21 μmol/L in the 1970's to 0.48 μmol/L (10μg/dL)[14]. Furthermore, recent data suggest that blood Pb concentrations of about 0.38 μmol/L may be associated with decreased cognitive function in postmenopausal women[15]. Anything above 20 μg/dL of lead in blood is dangerously toxic and demands hospitalised medical treatment, which can include chelation therapy (a substance is injected into the blood where it attracts and binds lead and carries it from the body)[16].

Exposure to low doses of lead is particularly harmful to children whose neurological development may be persistently and irreversibly affected. Adults absorb approximately 5-15% of ingested lead and retain less than 5%. On the contrary, children absorb about 50% of ingested lead. Diverse harmful effects have also been described in later age groups such as arterial hypertension, kidney involvement, endocrine haematologic and immune system disorders, and the metal has even been related to the onset of neoplasias (abnormal growth of tissues). The most severe effects of lead toxicity include low intelligence quotients (IQ), memory loss, poor motor skills, hand-eye-coordination, reading disabilities and poor calcium utilisation. A very insidious effect of lead is its ability to replace calcium in bones and remain there to form a semi-permanent reservoir for long-term release well after the initial absorption. The only efficacious method of avoiding these toxic effects is to control the population's exposure to lead by eradicating its sources, which may not always be obvious (home paint, lead pipes, ceramics, vehicular emission, etc.). When a young pre-school child is lead poisoned, this can have catastrophic effects on his entire future. People who were exposed to low doses of lead as children still have measurable deficits as young adults and the effects are not just expressed in psychometric testing, but in measures of real life function like graduating from high school and learning disabilities.

Table 3 summarises the various symptoms[16] arising from lead poisoning.

Table 3: Symptoms of lead poisoning

Mild Toxicity 35-50 μg/dL in children > 40-60 μg/dL in adults	Moderate Toxicity	Severe Toxicity 70 μg/dL in children > 100 μg/dL in adults
• Muscle (pain, tingling, pricking, burning) • Mild fatigue • Irritability • Lethargy • Occasional abdominal discomfort	• Joint pain • General fatigue • Difficulty concentrating • Muscular exhaustibility • Tremor • Headache • Diffuse abdominal pain • Vomiting • Weight loss • Constipation	• Partial or complete paralysis • Brain disfunction (seizures, unconsciousness, coma, death) • Lead line (blue-black) on gum tissue • Severe abdominal cramps

1.9 LEAD IN MAURITIUS

Unlike U.S.A. and the other developed countries that have minimised or banned the use of leaded petrol, Mauritius and many developing countries still use leaded petrol. Lead emissions from vehicular exhausts are thus of great concern due to the health risk associated with exposure to environment lead. In Mauritius the other sources of lead pollution are mainly from paint and batteries. Assuming an annual consumption of 100 million litres of gasoline and an average lead concentration of 0.4g/L, about 40 tons of lead are emitted as a result of vehicular emissions, with all the implications on people's health. Also, a recent study of lead alongside some roadways in Mauritius, showed lead level of up to 1150 ppm along a motorway section[17]. Table 4 shows the annual consumption of leaded petrol from 1985-1998.

Table 4: Quantity (tons) and lead content (g/L) of petrol imported in Mauritius from 1985 to 1998*

Year	Quantity (Tons)	Lead (g/L)
1985-86	40,677	0.75-0.82
1986-87	35,073	0.70-0.82
1987-88	46,481	0.70-0.82
1988-89	54,214	0.61-0.82
1989-90	51,187	0.61-0.83
1990-91	59,989	0.18-0.83
1991-92	68,505	0.38-0.58
1992-93	65,878	0.31-0.40
1993-94	79,200	0.21-0.40
1994-95	85,143	0.001-0.40
1995-96	87,734	0.001-0.40
1996-97	89,775	0.10-0.40
1997-98	89,308	0.14-0.17

*Data obtained from the State Trading Corporation in Mauritius

From table 4, it can be observed that the concentration of lead in our petrol has decreased. But since lead does not dissipate or biodegrade, high concentration of the element will still persist for many years even after elimination of the source of contamination.

Other studies on determination of lead in Mauritius have been analysed and results obtained for these studies are summarized in table 5.

Table 5: Mean lead level in blood, water, dust and soil

COMPONENT	Mean lead concentration (ppm)
Blood[18]	0.21
Water[19]	0.045
Dust[20]	525
Soil[21]	723

1.10 STUDY OF LEAD LEVEL IN SOIL IN OTHER COUNTRIES

The determination of lead in soil has been the focus of many published results during those past 50 years in different parts of the world. The levels of lead in soil alongside streets and motorways in some countries are reported in table 6.

Table 6: Mean or range of lead levels (ppm) in soil alongside streets and motorways of some countries

Country	Place	Year	[Pb] (ppm)	Remarks
U.S.A.	Ohio[22]	1967	150	Roadside, ADT 23000
U.S.A.	South Carolina[23]	1970	1000	Main roads
New Zealand[4]		1975	160	Highway, ADT 1200
Great Britain	London[24]	1978	1796	Heavy traffic road
Egypt	Alexandria[25]	1978	239	Highway
Great Britain	Lancaster[26]	1980	296	Rural motorway
Wales	Cardiff[27]	1985	180	Traffic-less island
Greece	Athens[28]	1986	60-3650	Main roads
Great Britain	Birmingham[29]	1987	313	Main roads
Great Britain[30]		1988	298	Urban
Mexico	Mexico City[31]	1991	739-890	Avenues
U.S.A.	California[32]	1993	568	Main road
Syria	Damascus[33]	1997	826	Main roads, 2750 vehicles/hr
Singapore[34]		1997	78	Heavy traffic road
Singapore	Bishan New Town[34]	1997	33	Residential roads
India	Calcutta[35]	1999	400	Residential roads

The results cover a period of about 30 years. It is understood that the main source of pollution is vehicular exhaust. Depending on countries, different trends in the mean lead concentration have been obtained. In Damascus[33], where there are no vehicles running on unleaded fuel, the level of lead in soil was found to be quite high (826 ppm).

Studies in U.S.A. (New Orleans, Boston, Baltimore, Minneapolis and St Paul) and England (London) showed that inner city areas have more lead pollution than outlying areas[36-37].

Streetside samples in New Orleans inner city areas range from 600 to 1200 ppm of lead while soils in suburban areas contain less than 75 ppm. Soil lead levels in city areas of Minneapolis and St Paul ranged from 100 to more than 1200 ppm while outer lying suburbs ranged from 30 to 100 ppm, a 100-fold change between the two areas. The reasons postulated to account for the differences are that inner cities have historically high traffic flow and congestion, contain more leaded paint on houses and buildings, and concentrate and retain hot air and pollutants[36].

CHAPTER TWO

METHODOLOGY

2. METHODOLOGY

2.1 STUDY AREA

Roads of significantly different traffic densities were selected throughout the island to statistically represent Mauritius in this study. High, average and low traffic density roads were sampled in urban, sub-urban and rural areas from 09/01/1998 to 09/01/2000.

Soil samples alongside the following roads/streets were collected:

(a) Motorway from Plaisance to Grand-Baie

(b) St Paul-Vacoas-La Marie-Mare aux Vacoas

(c) St Jean-La Louise-Palma-Bambous-Mont Roches

(d) Avenue des Orchidées, Avenue des Capucines, Avenue des Rosiers, Avenue Labourdonnais and Bernardin de Saint Pierre St in Quatre-Bornes

(e) Vandermeersch St, Avenue Swami Sivananda, Dr Lesur St, Vuillemain St, Labourdonnais St and Marly St in Beau-Bassin/Rose-Hill

(f) Pope Hennessy St, Boulevard Victoria and Trou aux Cerfs in Curepipe.

2.2 SAMPLING

Surface top soil, (3±1) cm deep and within 0.5 m from the road, was collected over an area of about $(10\pm2)^2$ cm^2 into coded self-sealing polyethene bottles. To obtain a statistical representation of each sample, 3 equal portions were collected at intervals of one metre apart alongside the road as shown in figure 1 and were thoroughly mixed to obtain one unbiased sample for analysis.

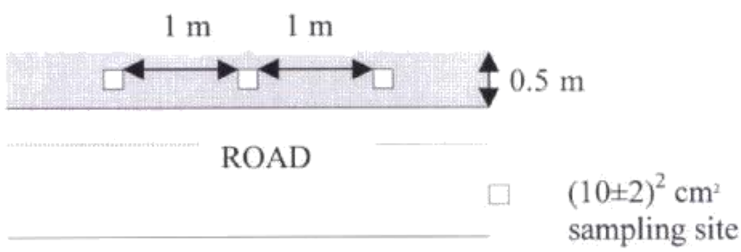

Figure 1: Statistical representation of sampling site

2.3 PROCESSING OF SAMPLES

The crude samples were dried at 40°C for 48 hrs in a drying cabinet (Unitemp) and were then ground using a mortar and a pestle. The ground samples were then passed through a sieve of 225μm mesh to remove small pebbles and dry leaves, which did not constitute the soil. The processed samples were kept in a drying cabinet at room temperature prior to analysis.

2.4 ANALYSIS

Samples (~0.5000± 0.0001g) were digested in duplicate with a mixture of analytical grade concentrated nitric acid (60%, 4mL) and analytical grade concentrated hydrofluoric acid (2mL) using a High Performance Microwave Digestor (Milestone, mls 1200mega) with MDR (Microwave Digesting Rotor) technology. The rotor was of MDR-600/10 type. The vessels were of FC 100 TFM type, with maximum capacity of 100mL and with a pressure resistance of 30 bar. The digestion process followed the automated scheme:

Time/min	5	5	10
Power/W	250	400	500

The digested samples were filtered, made up to 25±0.3 mL in a volumetric flask and analysed for lead using a 929 PU Flame Atomic Absorption Spectrometer (Unicam) with lamp details as follows: Hollow Cathode Lamp (Unicam), primary wavelength - 217.0 nm, lamp current - 10 mA, best sensitivity - 75%, best precision - 100%, flame - 0.100mg/L and with flame details as follows: flame type - air-acetylene, flame chemistry - stoichiometric, fuel flow rates – 0.9 to 1.2 L/min.

Standards were freshly prepared from 1000ppm of lead standard (Fisons). A 'blank' constituting only the water (distilled, deionised) used in the preparation of standards, was used to eliminate all effects from the water. The graph coefficient adopted for the calibration of standards was above 0.995. A 'sample blank' containing all reagents i.e. HNO_3, HF and H_2O except the sample, was used to eliminate all lead contaminants from the reagents. For internally prepared quality control, analytical lead(II)acetate was used.

CHAPTER THREE

RESULTS AND DISCUSSION

3. RESULTS AND DISCUSSION

3.1 LEAD LEVELS IN ROADSIDE SOIL IN MAURITIUS

733 samples of soil collected at different sites, over a period of two years, were processed, digested and quantitatively analysed for lead by atomic absorption spectrophotometry. The results are displayed in table 7.

Table 7: Lead levels (ppm) in roadside soil

Road	Traffic Density	Date*	N*	AM*	GM*	Range	% RSD*
Réduit/Caudan motorway	Very high	09/01/98	16	699±85	605	203-1404	49
		25/07/99	30	952±105	819	378-2634	60
		24/11/99	30	1108±123	912	178-3012	61
La Vigie/Réduit motorway	High	22/01/98	20	540±142	262	21-2717	118
		07/07/99	20	604±81	488	143-1342	60
		17/11/99	20	763±84	666	254-1490	49
Riche-Terre/Grand-Baie motorway	Average	14/01/98	42	240±40	-	0-1402	108
		25/07/99	57	445±34	388	166-1278	57
		24/11/99	57	589±41	520	171-1697	54
La Vigie/Plaisance motorway	Average	22/01/98	46	789±66	608	8-1938	57
La Vigie/Plaisance motorway	Average	07/07/99	58	314±25	251	12-921	61
(during enlargement works)		17/11/99	58	445±36	368	107-1580	62
Caudan/Riche-Terre motorway	Very high	30/09/99	24	671±67	603	307-1503	49
		09/01/00	24	901±71	837	379-1678	39
St Paul/Vacoas Road	Average	16/07/98	15	370±63	311	123-910	66
Palma-Bambous/Tamarin junction	Average	14/07/98	10	317±114	173	38-1217	114
Bambous/Tamarin junction - Mont Roches/St Patrick junction	Low	14/07/98	19	167±24	123	8-422	63
Vacoas/La Marie/Mare aux Vacoas	Low	16/07/98	20	166±25	135	34-506	68
Quatre-Bornes							
Royal Road St Jean	Average	14/07/98	9	233±34	214	123-398	44
Avenue Des Orchidées	Low	10/11/98	12	369±36	352	215-640	34
Avenue Des Capucines	Low	10/11/98	12	318±44	294	182-716	48
Avenue Des Rosiers	Low	10/11/98	12	280±31	254	81-438	38
Avenue Labourdonnais	Low	10/11/98	12	213±17	200	57-257	28
Bernardin de Saint Pierre St	Low	10/11/98	12	271±26	257	128-450	33
Beau-Bassin/Rose-Hill							
Vandermeersh Street	High	14/07/98	10	690±121	578	187-1299	55
Ave Swami Sivananda/Dr Lesur St	Low	13/11/98	26	240±20	218	95-412	43
Vuillemain Street	Low	13/11/98	10	199±35	173	73-389	55
Labourdonnais Street	Low	25/01/99	10	335±27	325	212-475	26
Marly Street	Low	25/01/99	12	102±25	79	24-333	83
Curepipe							
Pope Hennessy Street	Low	21/04/99	18	141±23	108	18-375	70
Boulevard Victoria	Low	21/04/99	7	207±28	195	111-329	36
Trou aux Cerfs	Low	21/04/99	5	60±31	-	0-167	116

* Date of sampling, Number of samples, Arithmetic mean, Geometric mean, % Relative standard deviation

Results displayed in table 7, indicate a very wide range of lead level in soils collected alongside roads in Mauritius. The highest values are obtained alongside the M1 motorway between Réduit and Caudan and the lowest values are obtained near Plaine Champagne and Trou aux Cerfs. Lead levels in soils near roads of the major towns vary from 18 ppm to 1299 ppm. The highest values in towns are obtained in soils collected alongside the Vandermeersh street (an average of 690 ppm and a range of 187-1299 ppm) in Beau-Bassin/Rose Hill.

The mean lead level in roadside soil alongside the La Vigie/Plaisance motorway segment obtained on the 07/07/99 (314 ppm) and 17/11/99 (445 ppm) are lower than that found on the 22/01/98 (789 ppm). This is accounted by the fact that the two last samplings were carried out during the enlargement works of the motorway. These results will not be discussed further.

Since most of the coefficients of variance or % relative standard deviation values are above 50%, it can be deduced that the lead levels in soils alongside the roads are not uniform or close to one another but are instead spread over a wide range. It therefore implies that there are lots of factors, which determine the lead level at each sampling site alongside each road. Some of the factors are: topography of land, texture of soil, carriage by wind, washing away and leaching by rain, and adsorption and retention of lead particles depending on the cation exchange capacity of the soil.

3.2 DISTRIBUTION OF SOIL LEAD

Results obtained show that the soil lead values cover a range of 0-3012 ppm. Table 8 and figure 2 show the frequency distribution of lead in the 733 soil samples analysed.

Table 8: Distribution of lead content in soil (ppm)

Region	Lead content (ppm)					
	0-200	201-400	401-600	601-800	801-1000	>1000
Réduit/Caudan (N=76)	2	8	11	15	16	24
La Vigie/Réduit (N=60)	12	12	7	6	11	12
Riche-Terre/Grand-Baie (N=156)	24	66	27	17	15	7
La Vigie/Plaisance (N=162)	38	34	43	20	15	12
Caudan/Riche-Terre (N=48)	-	7	9	12	10	10
St Paul/Vacoas/ Mare-aux-Vacoas Palma/Mont-Roches (N=64)	39	17	5	-	2	1
Quatre-Bornes (N=69)	15	47	5	2	-	-
Beau-Bassin/Rose-Hill (N=68)	28	29	5	2	1	3
Curepipe (N=30)	23	7	-	-	-	-
Total (N=733)	**181**	**227**	**112**	**74**	**70**	**69**

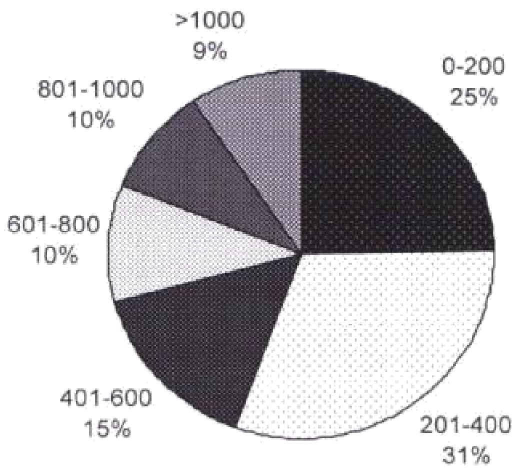

Figure 2: Distribution of lead content in soil (ppm)

Excluding soil samples collected alongside Plaisance/Grand-Baie motorway, most of the soil samples are found to have a lead content of less than 400 ppm.

In the towns, only four soil samples (all collected alongside Vandermeersch St in Beau-Bassin/Rose-Hill) have a lead content exceeding 800 ppm.

The majority of the soil samples collected alongside the Réduit/Caudan and Caudan/Riche-Terre motorway segments have lead levels exceeding 600 ppm indicating that these segments are the most polluted ones.

3.3 SOIL LEAD LEVELS ALONGSIDE THE RÉDUIT/CAUDAN, RÉDUIT/LA VIGIE, CAUDAN/RICHE-TERRE AND THE RICHE-TERRE/GRAND-BAIE MOTORWAY SEGMENTS

The mean lead levels obtained in roadside soils near the Réduit/Caudan, Réduit/La Vigie, Caudan/Riche-Terre and the Riche-Terre/Grand-Baie motorway segments for the different sampling periods are shown in table 9.

Table 9: Mean lead level (ppm) in roadside soils alongside the Réduit/Caudan, Réduit/La Vigie, Caudan/Riche-Terre and the Riche-Terre/Grand-Baie motorway segments

Segment of motorway	Traffic density	Jan-98	Jul-Sep 99	Nov 99-Jan 00
Réduit/Caudan	Very high	699±85	952±105	1108±123
Réduit/La Vigie	High	540±142	604±81	763±84
Caudan/Riche-Terre	High-Very High	-	671±67	901±71
Riche-Terre/Grand-Baie	Average	240±40	445±34	589±41

3.3.1 Traffic density

There is a significant difference in lead level in roadside soils alongside the different sections of the M1 motorway. Comparing the Réduit/Caudan segment (Very HTD, Very High Traffic Density road) with that of the Riche-Terre/Grand-Baie segment (ATD, Average Traffic Density road) using the Anova test, a p-value of 0.034 is obtained indicating a very significant difference between the two sets of results.

Mean roadside soil lead level alongside the Réduit/Caudan segment with a daily traffic density of over 27,000 vehicles (as recorded in 1992 by the NTA of Mauritius) is higher than that of the Caudan/Riche-Terre and Réduit/La Vigie segments (traffic density of about 20,000 daily). The mean soil lead content is found to be the least alongside Riche-Terre/Grand-Baie segment (traffic density not known but is supposed to be significantly less than the three other segments). A significant difference in traffic density clearly corresponds to a significant difference in the average lead levels in roadside soil as indicated by the p-value discussed earlier. This result shows that roadside soil lead level correlates well with traffic density: the higher the traffic density the more polluted is the soil near the road.

It is worthy to note that by November 1999-Jan 2000, the mean lead levels alongside the Réduit/Caudan, Caudan/Riche-Terre, Réduit/La Vigie and Riche-Terre/Grand-Baie motorway segments have reached the values of 1108, 901, 763 and 589 ppm respectively. These values can be compared with that obtained in Syria where a mean lead concentration of 826 ppm was reported in a study[33] done in Damascus City in 1997. The latter is a densely populated area with a population of about 150 000 cars. According to the authors[33], the main reason for the high lead level obtained was that only leaded fuel was available. Moreover, many of the cars were old and their engine efficiencies were poor. This case is quite similar to that of Mauritius where only leaded fuel is available on the market and many old cars are still being used.

3.3.2 Time

Figures 3-5 illustrate how the mean soil lead level increases with time alongside three segments of the M1 motorway.

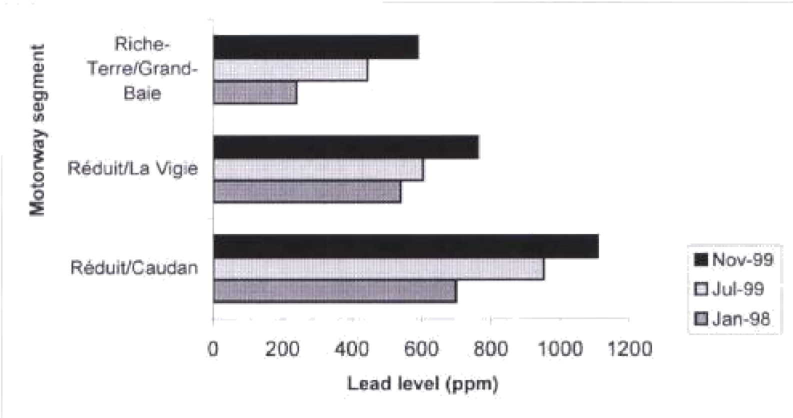

Figure 3: Mean lead level in roadside soil (ppm) alongside the Réduit/Caudan, Réduit/La Vigie and the Riche-Terre/Grand-Baie motorway segments

It can be seen that with time the mean soil level of Pb increases for the three segments of the M1 motorway. Analysis of the data obtained from these three segments indicates an exponential relation rather than a linear one as shown by the correlation values: Réduit/Caudan motorway: $R^2_{exponential}$ (0.98) > R^2_{linear} (0.95); Réduit/La Vigie motorway: $R^2_{exponential}$ (0.73) > R^2_{linear} (0.69); Riche-Terre/Grand-Baie motorway: $R^2_{exponential}$ (0.98) > R^2_{linear} (0.94). However, these correlation values have been obtained for only 3 sampling dates covering a period of only two years, so care should be taken not to draw rapid conclusion. Also, the increase might have been greater due to the severe drought that has prevailed during this period. Nonetheless, one can conclude that the levels of Pb in soil are increasing with time, as only leaded fuel is available on the local market.

Mean soil lead levels also seem to increase with time along the Caudan/Riche-Terre segment (671 ppm in Sep 99 to 901 ppm in Jan 2000).

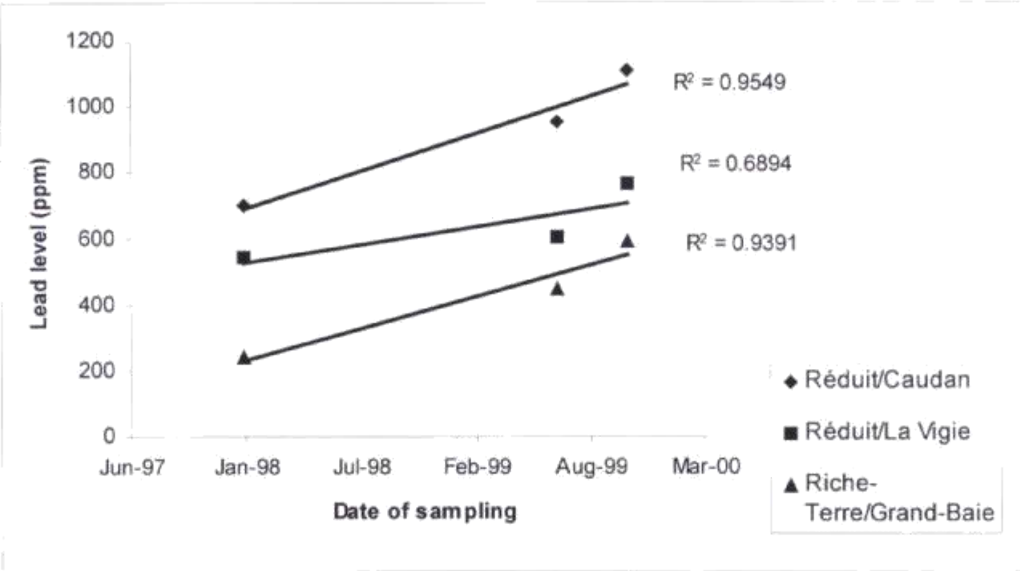

Figure 4: Linear variation of roadside soil lead level (ppm) with time

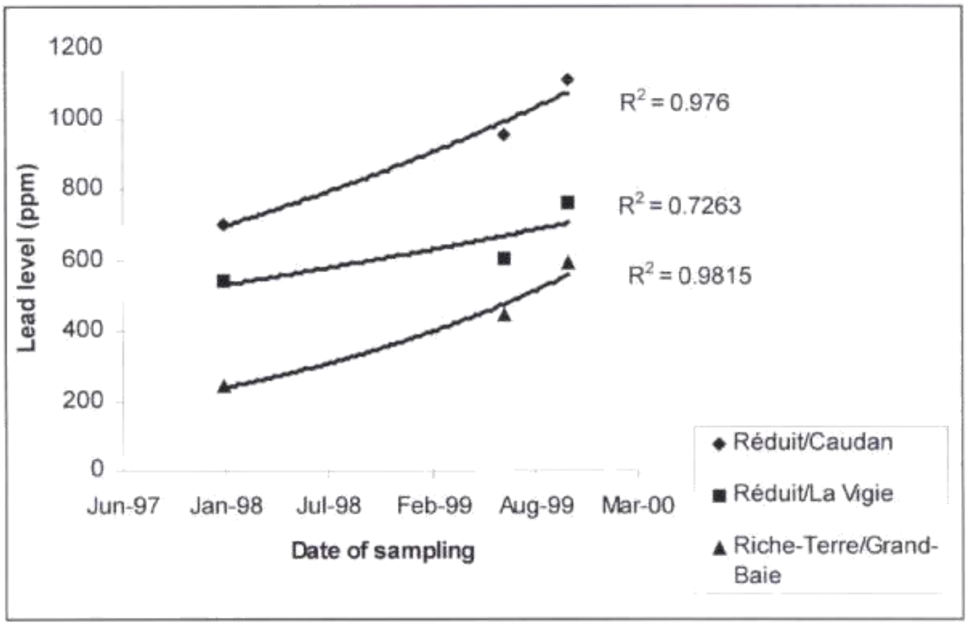

Figure 5: Exponential variation of roadside soil lead level (ppm) with time

3.3.3 Sampling site

The mean lead level and range in roadside soils collected on the left (west), right (east) and middle sides of the motorway segments, Réduit/Caudan and Riche-Terre/Grand Baie, are given in table 10.

Table 10: Lead levels (ppm) in roadside soil samples collected along the left (west), right (east) and middle sides of the M1 motorway segments Réduit/Caudan and Riche-Terre/Grand-Baie

Segment of M1	Date	West Mean ± s.e. (Range)	East Mean ± s.e. (Range)	P value (Anova)	Middle Mean ± s.e. (Range)
Réduit/Caudan	Jan-98	765±98 (226-1404)	553±164 (203-976)	0.26	- -
	July-99	789±105 (383-1541)	730±216 (378-2634)	0.81	1335±154 (652-2235)
	Nov-99	979±122 (620-1860)	780±262 (178-3012)	0.50	1566±158 (728-2270)
Riche-Terre/ Grand-Baie	Jan-98	269±49 (19-808)	107±33 (0-395)	0.03	386±132 (92-1402)
	Jul-99	462±48 (205-1008)	298±27 (166-674)	0.004	716±83 (369-1278)
	Nov-99	627±46 (363-1139)	378±32 (171-736)	0.0001	948±111 (337-1697)

Soil samples collected from the middle side of the motorway have a higher lead concentration than those collected from the right (east) or left (west) due to the two-way traffic flow.

The lead metal concentrations on the left side (west) of the motorway are found to be higher than those on the right side (east) for the two sections of the motorway at the three sampling dates. This is due to the South East Trade Winds (SETW) which prevail 10 months yearly in Mauritius. Due to the direction of the SETW that blow from the south-east towards the western direction, the west side of the motorway accumulates more lead particles than the east side. This implies that the SETW favour the carriage of airborne lead particles in open site. It has been reported in the literature[11] that the concentration of soil lead decreases with distance from the roads. Mungur[17] has verified the above statement in the region of La Vigie motorway as shown in figure 6.

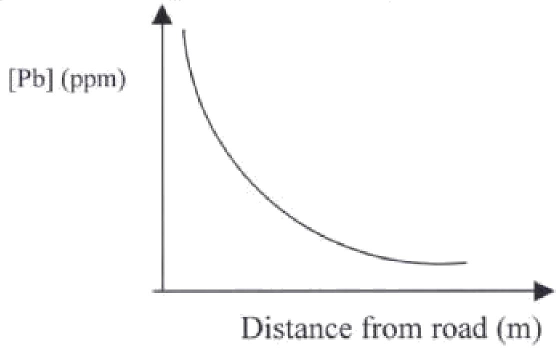

Figure 6: Decrease in soil lead level with distance from the road

From table 10, it is observed that on average soil samples collected alongside the west is 25 and 90% more polluted than samples collected on the east along the Réduit/Caudan and Riche-Terre/Grand-Baie motorway segments respectively. However, this difference is found to be significant only for the Riche-Terre/Grand-Baie segment according to Anova test ($p<0.05$).

Similar results have been reported in the literature[11,32,38]. For example, in California[32], soil downwind from the freeway (east side) contained the highest lead concentrations, and average levels exceeded those found on the west side by 93% due to prevailing winds blowing from west to east. In another study[11], Pb accumulation rates on the east side were found to be about twice those on the west due to the prevailing westerly winds.

3.4 ROADSIDE SOIL LEAD LEVELS IN SOME MAURITIAN TOWNS

The towns selected for the study are Quatre-Bornes, Beau-Bassin/Rose-Hill and Curepipe.

153 samples from fourteen roads/streets (c.f. table 7) have been analysed and the overall results are depicted in table 11 and figure 7.

Table 11: Soil lead levels (ppm) in some Mauritian towns

Location	N	Range	Arithmetic mean	Geometric mean	% RSD
Quatre-Bornes	69	57-716	283±14	259	42
Beau-Bassin/ Rose-Hill	68	24-1299	290±30	215	85
Curepipe (excluding Trou aux Cerfs)	25	18-375	159±19	127	60

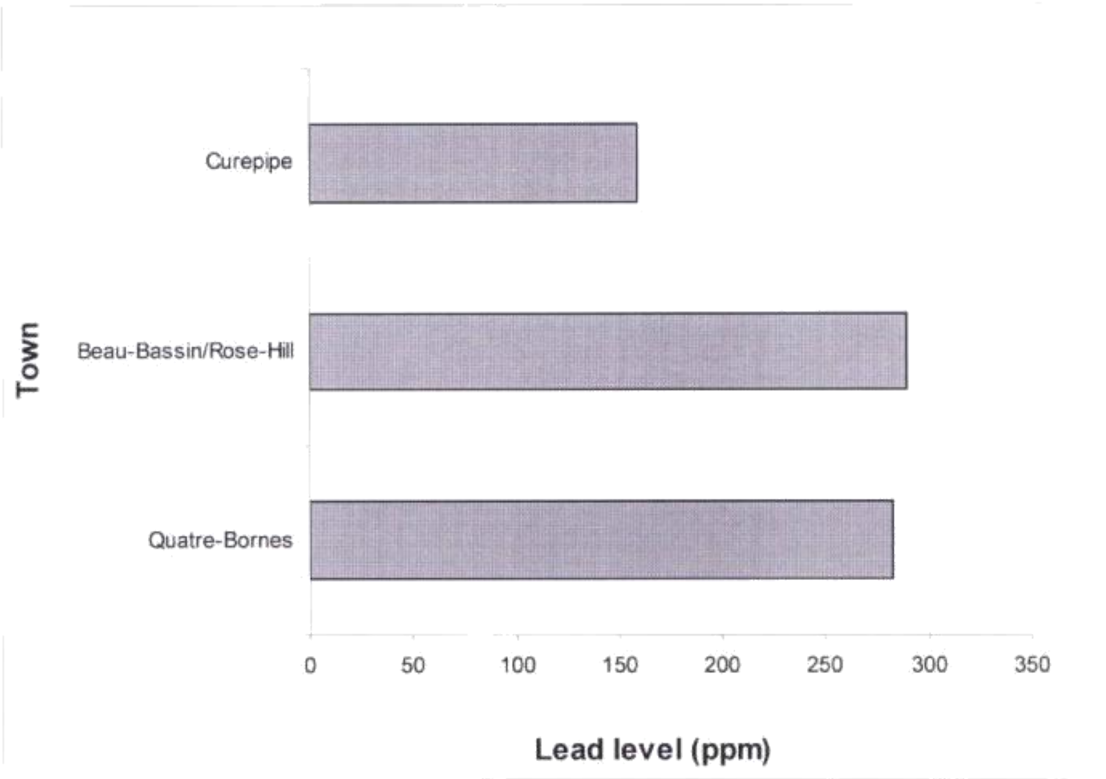

Figure 7: Mean soil lead level (ppm) in some Mauritian towns

The mean soil lead values alongside these roads vary between 159 ppm for Curepipe to 290 ppm for Beau-Bassin/Rose-Hill. Although these values are relatively low, it is noteworthy that levels of up to 1299 ppm have been obtained in soil samples collected at Vandermeersh Street in Beau-Bassin/Rose-Hill.

Among the towns studied, Curepipe is found to be the least polluted whereas Quatre-Bornes and Beau-Bassin/Rose-Hill have similar soil lead content. However, this trend has to be taken with care as only a few roads/streets from these towns have been selected for the study. Moreover, it would have been interesting to correlate the lead levels with the traffic densities of the roads. Unfortunately data about the traffic densities are not available.

Many factors like topology of the sampling site, exposure to wind, presence of brick fences or bamboo hedges and washing by rain may influence the retention of lead in the soil. One plausible reason that can be put forward to explain the lower lead levels in road soils in Curepipe is the higher amount of annual rainfall, hence favouring washing, runoff and leaching of lead particles.

The streets selected are found mostly in the residential areas. The vehicular emitted lead particles are either deposited near the brick walls or on the roadside soil. Accumulation of lead in soil will be favoured if these brick walls prevent wind to blow away the lead particulate matter. Bamboo hedges have similar effects.

Among the roads/streets studied, mean soil lead levels are found to be the highest at Vandermeersh Street, Beau-Bassin/Rose-Hill (690 ppm) and Avenue des Orchidées, Quatre-Bornes (369 ppm). The lowest mean values are obtained in soils collected alongside Marly Street, Rose-Hill (102 ppm) and Pope Hennessy Street, Curepipe (141 ppm).

The high lead levels observed in Vandermeersch Street may be explained by high traffic density especially during peak hours. It is noteworthy that soil samples collected along the side of the road that lies in the open (adjacent to the jogging ground) have a lower mean lead level than soil samples collected at the other side (485 ppm compared to 894 ppm). This may be explained by wind effect. Soil samples at the latter side are protected from the wind by brick walls or trees, hence favouring lead accumulation from car exhausts. This has also been observed in the literature[36] where the highest soil lead levels were found near buildings in inner-city neighbourhoods. Two factors were proposed: small, airborne lead-dust particles from leaded gasoline that collected on buildings and were washed into surrounding soils, and lead-paint chips, dust and debris that settled out into houseside soil.

3.5 ROADSIDE SOIL LEAD LEVELS IN SUB-URBAN AND RURAL AREAS

The roads chosen in the sub-urban and rural areas are:

- Palma to Mont Roches via Bambous
- Vacoas to Mare aux Vacoas via La Marie

It is found that the soil samples collected alongside the segment of the road from Palma to Bambous/Tamarin junction are more polluted with lead (mean 317 ppm) than those from either Bambous/Tamarin junction to Mont Roches (mean 167 ppm) or Vacoas to Mare aux Vacoas (mean 166 ppm). The higher traffic density at Palma can explain this trend.

It is noteworthy that out of the 64 soil samples analysed, only eight (12.5%) are found to have a lead content of more than 400 ppm.

CHAPTER FOUR

CONCLUSION

4. CONCLUSION

The main objectives of the study were:

(i) to determine the level of lead pollution in roadside soils along motorways, in towns and in some rural areas,

(ii) to monitor this pollution with time,

(iii) to investigate whether there is any correlation between lead content in soil and traffic density, wind direction and other factors, and finally

(iv) to compare the soil lead content values obtained with those reported in the literature in other parts of the world.

A total of 733 soil samples have been collected, dried, sieved, digested using microwave technique and analysed for lead by atomic absorption spectrometry.

The main observations are:

- There is a large variation in roadside soil lead level (range of 0-3012 ppm with a mean of 487±15 ppm). The highest soil lead values are obtained alongside the M1 motorway between Réduit and Caudan and the lowest soil lead values are obtained near Plaine Champagne and Trou aux Cerfs.

- Lead soil levels alongside roads in Beau-Bassin/Rose-Hill, Quatre-Bornes and Curepipe vary from 18 ppm to 1299 ppm. Curepipe is found to be the least polluted (mean 159 ppm) whereas Quatre Bornes and Beau-Bassin/Rose-Hill have similar soil lead content (mean of 283 and 290 ppm respectively). One reason that can be put forward to explain the lower lead levels in roadside soils in Curepipe is the higher amount of rainfall, hence favouring washing, run-off and leaching of lead particles.

- Among the roads/streets studied in the towns, mean soil lead levels are found to be the highest at Vandermeersh Street, Beau-Bassin/Rose-Hill (690 ppm) and Avenue des Orchidées, Quatre-Bornes (369 ppm). The lowest mean values are obtained in soils collected alongside Marly Street, Rose-Hill (102 ppm) and Pope Hennessy Street, Curepipe (141 ppm).

- Excluding soil samples collected alongside Plaisance/Grand Baie motorway, most of the soil samples have a lead content of less than 400 ppm.

- In the towns, only four soil samples (all collected alongside Vandermeersch St, Beau-Bassin-Rose-Hill) have a lead content exceeding 800 ppm.

- The majority of the soil samples collected alongside the Réduit/Caudan and Caudan/Riche-Terre motorway segments have lead levels exceeding 600 ppm indicating that these segments are the most polluted ones.

- The mean lead level observed in roadside soils correlates well with traffic density. For instance the mean lead level in soils alongside the Réduit/Caudan motorway segment (very high traffic density) > Riche-Terre/Grand-Baie motorway segment (average traffic density). A p-value of 0.034 is obtained using Anova test. Similarly, alongside roads having low traffic density such as at Mare aux Vacoas, Plaine Champagne and Trou aux Cerfs , the soil lead levels in most of the samples are found to be very low (<100 ppm).

- The mean soil lead level is found to increase with time alongside the La Vigie/Grand Baie motorway segment. For example, for the Réduit/Caudan segment, the mean soil lead level has been found to increase from 699 ppm in Jan 98 to 1108 ppm in Nov 99. An exponential increase is even observed for the Réduit/Caudan and Riche-Terre/Grand-Baie segments. However, this exponential increase might have resulted due to the severe drought that has prevailed during the sampling periods.

- Mean soil lead content is found to vary with sampling site. Soil samples collected from the middle side of the motorway (Réduit/Caudan and Riche-Terre/Grand-Baie) have a higher lead concentration than those collected from the right or left due to the two-way traffic flow.

- The South East Trade Winds greatly influence the carriage of lead particles from leaded vehicular emissions across the roads. Due to the direction of the SETW which blow from the South East towards the western direction, the west side (downwind) of the motorway accumulates more lead particles than the east (upwind) side.

- Accumulation of lead particles alongside roads also depends on whether the sampling site lies in the open air (favouring carriage of deposited lead particles by wind) or is protected by walls that favour accumulation as found in the case of Vandermeersh Street in Beau-Bassin/Rose-Hill.

- Soil lead content is found to be lower in certain sites due to the following reasons:
  (a) sampling site found on sloping land favours washing away of lead particles.
  (b) disturbed sites, for instance freshly ploughed soil near sugar cane fields
  (c) sites found alongside newly constructed roads or roads under construction
  (d) in dry areas where the soil will not absorb and retain much lead particles, instead it will favour carriage of lead particles by wind.

- In November 1999-Jan 2000, the mean lead levels alongside the Réduit/Caudan, Caudan/Riche-Terre, Réduit/La Vigie and Riche-Terre/Grand-Baie motorway segments have reached the values of 1108, 901, 763 and 589 ppm respectively. These values can be compared with that obtained in Syria where a mean lead concentration of 826 ppm was reported in a study[33] done in Damascus City in 1997. The latter is a densely populated area with a population of about 150 000 cars. According to the authors[33], the main reason for the high lead level obtained was that only leaded fuel was available. Moreover, many of the cars were old and their engine efficiencies were poor. This case is quite similar to that of Mauritius where only leaded fuel is available on the market and many old cars are still being used.

- Comparing with results of other countries, it is observed that the mean soil lead levels alongside residential roads in Mauritius are less than those observed in Calcutta[35] but much greater than those in Singapore[34]. One reason that may be postulated is that in Singapore, the majority of vehicles is currently using unleaded petrol.

- Since a good correlation is obtained between soil lead and traffic density, it can be deduced that leaded-gasoline is the main source of lead pollution in roadside soil in Mauritius.

Proposed Measures

Due to the relatively high lead levels measured in soil where more than 50% of the 733 samples have a lead level higher than the recommended 500 ppm set by many countries including Canada, U.S.A. and England, the Mauritian population, especially children, may be faced with a serious lead health hazard.

Hence, it is advisable that appropriate measures be taken by the Government of Mauritius to consider the possibility of importing **unleaded petrol**. This would definitely contribute to lower the lead burden brought by vehicular exhaust to the environment, either in air, soil or water. In many countries, mostly the developed ones, where leaded fuel has gradually been replaced by fuel free from lead, a dramatic decrease in lead levels in soil and blood of children has been observed. As stated before, in Singapore[34], the low concentration of lead found in soil is due to the fact that only unleaded gasoline is consumed in that country.

Moreover, other sources of lead that also contribute to increase lead pollution, for example leaded paint, should be more strictly regulated.

CHAPTER FIVE

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5. BIBLIOGRAPHY

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