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LEAD EXPOSURE ABATEMENT PLAN
FOR EGYPT:
Results of Environmental Sampling for Lead

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by
Richard Chappell
Patricia Billig
Eugene Brantly
Steven Ault
Hossam S. Ezzeldin

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ABOUT THE AUTHORS

Richard W. Chappell, Ph.D., is a senior geochemist with Camp Dresser & McKee Inc. in Denver, Colorado. Dr. Chappell has over 15 years of experience working with metals contamination (including lead) in industrial, urban, and residential areas. He has conducted similar or related studies on over 20 sites in the U.S. and Romania. Dr. Chappell has conducted numerous investigations to characterize the nature and extent of lead levels in soil and water media, including the identification of the sources of lead contamination.

Patricia Billig is Senior Technical Director for the Environmental Health Project. She has had 18 years of field, research, and program management experience in environmental and public health toxicology, epidemiology, risk assessment, risk-based remediation, water quality, and chlorinated hydrocarbon and heavy metal chemistry. Since 1985, Ms. Billig has conducted over 100 public health and ecological risk assessments, has managed numerous multidisciplinary and multicultural project teams, and has directed and participated in environmental health activities in Egypt, Guatemala, Mexico, and Romania.

Eugene P. Brantly is EHP's Technical Director for Risk Assessment and Risk Management and leads EHP's work in comparative health risk assessment and environmental planning. He serves as EHP's Program Manager for the LEAP program. Mr. Brantly is an environmental scientist and attorney who specializes in designing environmental investigations to support policy and project development. His work has included risk assessment projects in Ecuador and India; research on risk assessment methodology; a study of health impacts from water resource development in the Senegal River Basin; policy analyses for water quality management in Central Asia; and a study of environmental impacts from tourism and urban growth in Indonesia.

Steven Ault, MSc, REHS, served from 1994 to March 1997 as Technical Director for Public Health on the Environmental Health Project, during which time he managed a portfolio of USAID projects in Latin America, Central Europe, and Egypt. He is an environmental health scientist and entomologist (BSc with PhD studies, University of California at Davis; MSc University of Liverpool's School of Tropical Medicine) and a Registered Environmental Health Specialist (Sanitarian). He is currently serving as Environmental Health Advisor for the Pan American Health Organization in Guatemala.

Hassam Ezzeldin, P.E., is an EHP consultant who was involved with Dr. Chappell of CDM in the design, implementation, and supervision of the environmental sampling and analysis plan. Mr. Ezzeldin is a Senior Engineer with Langan Engineering, a consulting and design firm in New York City. He holds a B.S. degree in Civil Engineering, a Master's Degree in Environmental Engineering, and is currently pursuing his Ph.D. in Environmental Management and Policy. He is an active member of the ASCE and has published three technical papers in the civil/ environmental engineering arena. Mr. Ezzeldin's efforts in this assignment included training of local environmental technicians and logistic coordination with all other local parties involved in the field sampling and behavioral programs.

ACRONYMS

BLL	blood lead level
CDC	U.S. Centers for Disease Control and Prevention
CDM	Camp Dresser & McKee
CWA	Cairo Water Authority
DFA	discriminant function analysis
DI	deionized water
dL	deciliter
EEAA	Egyptian Environmental Affairs Agency
EHP	Environmental Health Project
EPA	U.S. Environmental Protection Agency
EQI	Environmental Quality International (Cairo-based firm)
FAAS	flame atomic absorption spectrometry
FETP	Field Epidemiology Training Program
FSG	Field Sampling Guide (contained in Appendix A)
GFAAS	graphite furnace atomic absorption spectrometry
GIS	geographical information system
HCL	hydrochloric acid
HNO_3	nitric acid
ICP	inductively coupled plasma
ICP-MS	inductively coupled plasma-mass spectrometry

IES	industrial emission sites
IEUBK	integrated exposure uptake biokinetic model
LEAP	Lead Exposure Abatement Plan
LED	local exterior dust
MOHP	Ministry of Health and Population
NIST	(U.S.) National Institute of Standards and Technology
PTTDI	professional tolerable total daily intake
QA	quality assurance
QC	quality control
REP	regional exposure point
RF	radio-frequency (plasma)
SRMs	standard reference materials
TCOE	Technical Cooperation Office for the Environment
TEL	tetraethyl lead
μg	microgram
USAID	U.S. Agency for International Development
VES	vehicular emission sites

EXECUTIVE SUMMARY

Introduction

This report presents results from an investigation of environmental lead concentrations in Cairo, Egypt. The investigation was conducted for the Egyptian Environmental Affairs Agency, Technical Cooperation Office for the Environment (EEAA/TCOE) and was funded by the U.S. Agency for International Development, Cairo Mission (USAID/Cairo). The work was performed by the Environmental Health Project, sponsored by USAID's Global Bureau, Office of Health and Nutrition.

The goal of this investigation was to estimate the magnitude and extent of children's exposure to lead through various environmental media in the Greater Cairo metropolitan area. The investigation had three objectives:

- Characterize the distribution of lead in soil and dust throughout Greater Cairo.
- Characterize the distribution of lead in other media to which children are exposed.
- Estimate the relative contribution of each exposure pathway to the average total lead exposure of children in Greater Cairo, using an exposure model.

Investigators collected samples of soil, dust, drinking water, paint, various foods, cosmetics, traditional medicines, newpaper, and ceramics from locations throughout Cairo and analyzed the samples to determine their lead content. The initial round of sampling was conducted in November/December 1996. Additional sampling to confirm and extend results from the initial round was conducted in June 1997. The investigators then used data from this study and previously reported research in a lead exposure model to estimate the distribution of blood lead levels in young children in Cairo and the relative contribution of various exposure pathways to the expected mean blood lead level.

The Context and Intended Use of This Report

This study was performed as part of a program of technical assistance to the EEAA/TCOE for developing a Lead Exposure Abatement Plan (LEAP). The end result of these efforts will be a comprehensive plan for reducing lead exposure in the general population of Cairo with possible application to other areas in Egypt. The plan will include actions to be implemented by government agencies, private companies, and nongovernmental organizations. Although it will focus primarily on newly proposed actions, the plan will summarize actions that are already underway, such as the Ministry of Petroleum's progress in removing lead from gasoline, EEAA/TCOE's work on reducing lead emissions from lead smelters, and the Ministry of Health's work to measure blood lead levels in the Cairo population.

LEAP is being developed by EEAA/TCOE, with funding and technical assistance from USAID. USAID and EEAA/TCOE have agreed to collaborate in developing the plan under

USAID's Sector Policy Reform Program II, and under the terms of that program, the plan will be completed by 30 September 1997.

The Environmental Health Project has organized its technical assistance for developing the Lead Exposure Abatement Plan into four components: (1) an institutional assessment; (2) an environmental assessment; (3) policy dialogue, consisting of workshops and other meetings with program stakeholders; and (4) the interventions design, during which the interventions to be included in the plan were developed. EHP has completed the institutional assessment, two workshops, and the interventions design. This report describes results of the environmental assessment. The final workshop is scheduled for September 1997.

Key Findings of the Environmental Assessment

1. Blood lead levels for children in Cairo were estimated using a lead exposure model with data from this study and previously published reports. The analysis indicates that the mean blood lead levels of children in Cairo range from 14.4 μg/dL for children under 1 year to 10.8 μg/dL for children between 5 and 6 years old. Modeling results indicate that approximately 64% of children in Cairo have blood lead levels above 10 μg/dL and approximately 14% have levels over 20 μg/dL. Research has shown that blood lead levels as low as 10 μg/dL are associated with learning disabilities and lowered IQ. The current consensus among many authorities is that blood lead levels of 10 μg/dL and higher are cause for concern, and that levels of 20 μg/dL and higher justify actions to reduce the sources of exposure.

2. A wide variety of foods were tested, including bread, canned foods, dairy products, beverages, grains, meat, produce, spices, and processed foods. Most foods contained low levels of lead. Relatively high levels of lead contamination were found in certain foods, including bread and several produce and dairy items. Based on analyses using the lead exposure model, food ingestion appears to be the most important pathway for lead exposure in children. The model requires assumptions about the amount of each type of food that is included in a typical child's diet, and does not account explicitly for the variability in diets among individuals in a population. The investigators used a recent study of diet composition in Cairo and recommendations from a U.S. Federal Program for Women, Infants and Children (WIC) as an input to these analyses.

3. Many samples of ceramic cookware and kohl, a cosmetic, have high levels of lead. A leaching test using an acidic solution demonstrated that the lead in ceramics can contaminate food that is either cooked or stored in such containers. Although this investigation did not attempt to estimate what proportion of the Cairo population uses these products, anecdotal evidence indicates that many people use ceramic cookware and the use of kohl may be common, at least in some groups. The investigators were not able to estimate the relative contribution of kohl and ceramics to total lead exposure among Cairo's women or children. However, based on experience in other places, there is good reason to believe that the use of kohl and ceramics is an important exposure route for lead.

4. An extensive survey of soil and dust was conducted throughout the Greater Cairo metropolitan area. The mean concentration of lead in the soil and dust samples was relatively low. There was a small number of samples with concentrations over 500 ppm; these probably represent areas near a major source of lead ("hot spots"), such as a lead smelter or major traffic corridor. Analyses using data from this study indicate that ingestion of soil and dust is not a significant pathway for lead exposure in children in Cairo. Previously reported research has focused on "hot spots" and found higher levels of lead contamination than were found in this study of general environmental conditions. Soil and dust ingestion may be a more important exposure pathway for children living in these areas than it is for the average child in Cairo.

5. Drinking water samples had very low levels of lead contamination. Although the sampling team was not able to obtain "first-flush" water samples, which might have contained higher lead levels, the results of this study indicate that drinking water is not an important route for lead exposure in Cairo.

6. Paint samples collected during this study contained relatively low levels of lead, indicating that the use of lead-based paints is not currently an important route of exposure. There is anecdotal evidence that some private paint manufacturers may be starting or increasing the production of lead-based paints, but that information could not be substantiated during this investigation.

1 INTRODUCTION

Lead is a naturally occurring, toxic heavy metal present at background levels in many environments and at elevated concentrations in many cities of the developing and developed world. Children who are exposed to lead through contaminated soil, dust, air, water, food, and other media will generally develop elevated levels of lead in their blood. Blood lead levels as low as 10 micrograms per deciliter (μg/dL) are now known to have serious, sometimes irreversible, adverse effects on the neurological, social, and mental development of young children (Smith et al. 1989, NAS 1995, Kim et al. 1995, Needleman 1996). Cumulative lead burdens in adults are also linked to neurological and physiological problems, such as increased hypertension in middle-aged men.

This report describes the findings from a study of lead concentrations in various environmental media in the Greater Cairo metropolitan area and presents an analysis of the potential pathways by which children in Cairo may be exposed to lead.

1.1 Background

In the early 1990s, the Government of Egypt and the U.S. Agency for International Development (USAID) recognized lead as an emerging public health issue in need of attention. Several studies in the Greater Cairo area and elsewhere in Egypt found lead in older children, mothers, and industrial workers at concentrations exceeding U.S. Environmental Protection Agency (EPA) or World Health Organization guidelines. Other studies have characterized, albeit in a limited fashion, the presence of environmental lead in air, soil, and food in Egypt. To date, however, there have not been any studies of lead exposure or blood lead levels in children six years of age and under.

The Government of Egypt has undertaken efforts to reduce two of the major sources of environmental lead in Cairo. The Ministry of Petroleum has instituted measures to greatly reduce the use of leaded gasoline in Cairo. And, with technical support from USAID, the Egypt Environmental Affairs Agency (EEAA) has developed a Lead Smelter Action Plan which, when implemented, will reduce lead emissions from smelters operating in Cairo. Even with substantial reductions in lead emissions from automobiles and smelters, however, Cairo’s population will continue to be exposed to lead. Lead is persistent in the environment and will remain in soils, dust, and other media for a long time, presenting a risk of continued exposure even after the original sources (leaded gasoline and smelter operations) are removed or reduced. Furthermore, there are other sources of lead in Cairo—for example, lead additives in paint and ceramic glazes, and lead-containing materials used in cosmetics and medicines—that may be of equal or even greater importance in people’s exposure to lead, and particularly so for children.

Given these factors, USAID/Cairo and EEAA agreed to collaborate in developing a Lead Exposure Abatement Plan (LEAP) for Cairo under USAID's Sector Policy Reform Program II. EEAA is responsible for preparing the plan, and USAID/Cairo is providing technical assistance for the effort. The Environmental Health Project, a USAID-sponsored project, has been commissioned by USAID/Cairo to provide the technical assistance required by EEAA for preparing the plan.

1.2 Goals and Design of the LEAP Program

EHP has two goals in providing technical assistance to EEAA under the LEAP program. The first is to estimate the magnitude and extent of children's exposure to lead through various environmental media in the Greater Cairo metropolitan area. The second goal is to help EEAA develop a set of interventions that will reduce children's exposure to lead in Cairo, incorporate the interventions into a Lead Exposure Abatement Plan, and identify appropriate stakeholders, responsibilities, and timetables for implementing the plan.

EHP has organized its assistance for the LEAP program into four components: (1) an institutional assessment; (2) an environmental assessment and an associated investigation of exposure-related behavior in children; (3) policy dialogue, consisting of workshops and other meetings with program stakeholders; and (4) the intervention design, during which the technical elements of the Lead Exposure Abatement Plan will be prepared. EHP has completed the institutional assessment and two workshops, as described in previous reports (O'Toole et al. 1996, Moussa and Wahl 1996). This report describes results from the environmental assessment. EHP has also completed the interventions design and will soon finish a draft version of the Lead Exposure Abatement Plan. Work under the LEAP program will continue through September 1997, when a final workshop will be held to review the proposed exposure abatement plan.

1.3 Coordination with Related Efforts

The Egyptian Ministry of Health and Population (MOHP) is concerned about lead exposure in Cairo and elsewhere in Egypt and is conducting a study to determine blood lead levels for children in Cairo. The U.S. Centers for Disease Control and Prevention (CDC) is providing technical assistance to the MOHP through CDC's Field Epidemiology Training Program (FETP). Based on discussions with these parties, it was agreed that the investigations being conducted by EEAA and MOHP would be designed to complement each other. The division of responsibilities was as follows:

- The environmental assessment, to be conducted by EHP (for EEAA), would characterize (a) the distribution of lead in various environmental media in Cairo and (b) children's behavior in outdoor environments which may contribute to lead exposure.
- The blood lead study to be conducted by MOHP/FETP would characterize (a) blood lead levels in children, (b) concentrations of lead in various environmental media to which children may be exposed indoors, and (c) other risk factors which may contribute to lead exposure.

EHP would conduct an "exposure pathway analysis" using data from the environmental assessment and data from the MOHP/FETP blood lead study. This analysis would predict the range and distribution of blood lead levels likely to be found in children in Cairo and determine which exposure pathways appear to contribute the largest portion of the exposure.
EHP and FETP would coordinate their sampling and analytical protocols and conduct joint quality control and quality assurance activities to ensure that data from the two studies were comparable.

The environmental assessment has been completed by EHP and is reported in this document. Results from the exposure pathway analysis have also been developed and are presented in this report. The MOHP/FETP investigation of blood lead levels for children in Cairo began in March 1997; the results were not available at the time this report was prepared.

1.4 Objectives of the Environmental Assessment

The EHP environmental assessment was designed to produce information on environmental lead concentrations and children's exposure from activities conducted outdoors. Consistent with this focus and the allocation of responsibility between the EEAA and MOHP, the environmental assessment conducted by EHP had three objectives:

Characterize the distribution of lead in soil and dust throughout the Greater Cairo metropolitan area. To meet this objective, EHP conducted an extensive survey of soil and dust from household yards, parks, play areas, curbs, and roadside areas.
Characterize the distribution of lead in other media. To meet this objective, EHP collected and analyzed samples of water; a variety of foods including milk, bread, produce, and canned foods; ceramics used in cooking; paint; selected cosmetics; and traditional (folk) and modern medicines.
Estimate the relative contribution of each exposure pathway to the total lead exposure of children in Greater Cairo. To meet this objective, EHP used information from its environmental investigation to perform analyses with a lead exposure model. These analyses yielded results predicting the distribution of blood lead levels for children in Cairo. These results will need to be compared with results from the MOHP investigation when it is completed.

1.5 Components of the Assessment and Organization of the Report

The environmental assessment consisted of the following components.

Compile and evaluate historical data, including lead concentrations in environmental media, blood and other biological tissues, and known lead sources; use this information to develop the sampling design. Information from this survey of previous work is summarized in Chapter 5.

Design the environmental sampling program. This step included selecting the study areas, developing sampling and analytical protocols, and establishing data quality objectives. The sampling program is described in Chapter 2.
Collect and analyze environmental samples. The EHP team trained sampling personnel, environmental technicians, and interviewers; conducted in situ analyses of soil and dust samples; collected environmental samples for laboratory analysis; managed the analysis and reporting process; evaluated results from the quality assurance program; and analyzed the data and developed data summaries. EHP conducted two rounds of sampling, the first in November 1996, and the second in June 1997. Results from the sampling and analysis program are described in Chapter 3.
Conduct the preliminary exposure pathway analysis using data from the EHP investigation and a lead exposure model. Results from this preliminary analysis are presented in Chapter 4.
Develop conclusions and recommendations. These are contained in Chapter 6.

2 METHODS

This chapter describes the methods used to collect and analyze environmental media samples during the Cairo Lead Exposure Abatement Plan (LEAP) environmental sampling investigation. Section 2.1 describes the design and objectives of the sampling investigation and summarizes the types of samples collected. Section 2.2 provides details of the field collection and field analytical procedures used during the investigation. Section 2.3 summarizes the analytical methods used to quantitate chemical compositions of the various environmental media, including lead (Pb) analysis. Details regarding the analytical quality assurance/quality control (QA/QC) program implemented as part of the investigation are also provided in this section.

2.1 Sampling Design and Objectives

The primary objectives of the Cairo LEAP environmental sampling investigation were (1) to characterize the overall environmental distribution of lead in Greater Cairo; and (2) to characterize the relative effect of environmental lead-exposure pathways on young children in Greater Cairo.

The environmental sampling investigation was designed primarily to meet the first objective (characterizing Greater Cairo's overall environmental lead distribution). However, an important component of the sampling design was integration with additional information gathered to meet the second objective (characterizing lead exposure pathways). Such additional information included behavioral data and lead-source information (such as the locations of secondary lead smelters). As described in Chapter 1, achieving these two objectives is required in order to design interventions that will reduce lead exposure among young children in Cairo.

For purposes of the Cairo LEAP environmental sampling investigation, the study team defined the Greater Cairo study area as comprising portions of the Cairo, Giza, and Kalyubia governorates, including various districts or areas within them. The team included all districts within the Cairo governorate because this governorate makes up the majority of the study area. Conversely, only the western-most districts within the Giza governorate and the southern-most districts within the Kalyubia district were included. Because the team members sampled a large area, they could not cover each district sufficiently to make possible a district-based statistical analysis. However, the study was not designed with this objective in mind. Nevertheless, the team compiled extensive location information (including data on districts), which it has included in the project database (available on request from EHP).

The types of environmental samples collected as part of the LEAP investigation fall into three general categories: local exterior dust (LED) location samples, regional exposure point (REP) location samples, and food or food-related samples. Further descriptions of these sample types, along with the sampling design and protocol used to collect samples in these categories, are provided in the following three sections.

2.1.1 Local Exterior Dust (LED) Samples

The team used a 1:12,000 scale map of the Greater Cairo study area as a base map for locating LED sample sites (see Map 1, LED shown as red dots). The team overlaid the map with a grid system composed of equal-sized square blocks representing approximately 1.5 square kilometers each. The team then subdivided each block into 64 equal-size smaller blocks representing approximately 150 by 150 meters each. Within each large grid block, the team randomly selected one small block as an LED sample collection location. While in the field, team members placed a small dot in the center of the selected LED block and sampled the household (or apartment building) nearest the dot (see Map 1). The random selection of sampling sites within each grid block served to minimize any bias in selecting individual sampling locations. The team felt that this design would yield a representative random sample of the Greater Cairo housing population, while allowing the program to achieve adequate coverage of the entire Greater Cairo area.

No attempt has been made to explore further the extent to which the LED sample set represents a true random sample, as this was beyond the scope of the investigation. Obviously, an investigation designed to characterize an area as large and as densely populated as Greater Cairo faced many logistical problems, not the least of which was how to collect a sufficient number of samples within a three-week period using three two-person sampling teams. Thus, at every stage of the investigation, sampling protocols were focused on any methods that could be implemented to maximize the number of samples collected, and therefore optimize the amount of data obtained.

At each LED location, the sampling teams collected environmental samples of various types, including exterior dust, drinking water, and exterior paint (see Table 2-1). Teams collected between one and four exterior dust samples from each LED location in filter cartridges using a vacuum pump as described in Appendix A. Typically, the teams collected individual dust samples from (1) the edge of the main street in front of the chosen apartment building, (2) the vicinity of the main entrance of the apartment building, and (3) play areas near the building or other common areas where children could be exposed to dust while playing. The teams did not collect drinking water samples from every LED location; rather, they collected them only at those locations where an indoor water tap was logistically accessible. Similarly, exterior paint samples were collected only from those LED buildings that exhibited peeling paint near potential dust exposure areas (near entrances or play areas).

2.1.2 Regional Exposure Point (REP) Samples

In addition to the exterior dust, drinking water, and exterior paint samples collected at LED locations, the teams collected soil samples at various REP locations throughout the Greater Cairo study area (shown as yellow dots on Map 1). The teams selected various types of REP locations, including gardens, recreation areas, open-space areas, markets, and schools. The REP sampling areas represent locations other than around their homes where children may be exposed to lead.

Map 1

Map 1

Table 2-1
Sample Summary

Media		Number of Locations	Number of Samples
Exterior Dust	(LED)	176	411*
Soil	(REP)	76	180*
Drinking Water	(LED) (REP)	55 35	55 35
Exterior Paint		16	16
Interior Paint		2	15
Food - Initial		15	189
Food - Additional		21	195
Cosmetics/Medicines - Initial		2	9
Cosmetics/Medicines - Additional		7	28
Glazed Ceramic Pottery - Leachate		3	11
Glazed Ceramic Pottery - Chips		3	15
Glazing Materials and Clay		1	5
Newspapers		1	3
TOTAL		413	1,167

LED = Local Exterior Dust Location
REP = Regional Exposure Point Location

* Represents cases for which either lab or field portable EDXRF results were obtained.

The REP locations were selected to ensure (1) coverage across the Greater Cairo study area, and (2) approximately equal coverage across low, medium, and high standard-of-living (socioeconomic bracket) areas. The teams determined the REP locations during a concurrent behavioral study.

The teams collected between one and four soil samples at each REP location (see Table 2-1). The number of samples collected was based primarily on the relative size of the sampling areas and secondarily on the amount of exposed soil (bare ground) in the areas. The teams also collected drinking water samples from certain REP locations if an outside tap or other water source (for example, a street vendor) was available.

2.1.3 Food and Other Samples

During selection of the REP locations, locations were also selected for collecting food samples. Sites were spread across an approximately equal amount of low, medium, and high socioeconomic areas in Greater Cairo. The primary objective in collecting the food samples was to obtain a set of samples that represented the average diet of young children in Cairo, such that their average lead ingestion from food could be evaluated. Food samples were collected from both indoor and outdoor markets.

In addition to food, the teams collected samples of cosmetics, medicines, and glazed ceramic pottery to evaluate the potential of these items as lead sources. The teams limited cosmetics and medicines to those used most frequently by children, and limited glazed ceramic pottery to locally manufactured items used primarily for cooking and/or storing food. As for LED and REP samples, sampling locations for food, cosmetics and medicines, and pottery are shown (blue dots) in Map 1 and summarized in Table 2-1.

2.1.4 Other Media

Other media samples besides those collected as part of this study may indicate additional potential sources of lead exposure among young children. Air particulates, for example, are potential sources of lead. However, young children usually experience only minor exposure to lead via airborne contaminants. Many studies conducted in the United States and other countries have found that the primary route of lead exposure for young children is through ingestion rather than inhalation. Therefore, the teams did not collect air samples during this investigation. Furthermore, much air particulate sampling has already been conducted for Greater Cairo, including a 1996 EHP study (Rodes et al.), which the teams used in performing the exposure pathway analyses presented in this report.

2.2 Field Collection Methods

The sampling teams used a variety of methods to collect their environmental samples. Details of these methods are provided in the Field Sampling Guide (FSG) included as Appendix A. The following sections summarize the methods used to collect samples during the field investigation.

2.2.1 LED and REP Samples

Collection of samples at LED and REP locations followed the procedures detailed in the FSG with one minor exception: The initial program design specified that in situ measurements of lead concentration would be taken at REP locations using a field portable EDXRF spectrometer. Because of logistical constraints in transporting and operating the instrument within Cairo, however, the teams found it necessary to modify this approach early on in the sampling investigation. Instead of in situ measurements, the teams collected actual physical soil samples for nearly all of the REP locations. The protocol used to collect these samples consisted of loosening the top 1 centimeter of the soil surface and collecting the loosened soil into plastic containers. The sample collection area was restricted to approximately 0.5 square meters. The samples were then transported to the field headquarters, located at the office of Environmental Quality International (EQI) office in Zamalek, where they were analyzed using the field portable EDXRF in bench-top mode. Thus, the field measurement method used for soil samples was basically identical to that used for dust samples. This modification allowed the collection of considerably more data than would have been possible using in situ EDXRF measurements.

Field portable EDXRF was used only to screen for lead in the field to guide collection of exterior dust and soil samples. The teams used the results to adjust the initial numbers of samples necessary to characterize the distribution of lead, and to add LED/REP locations in areas containing elevated levels of lead for more precise characterization. The field portable EDXRF results, while adequate for screening purposes and probably adequate for lead characterization, were determined to be inadequate for purposes of detailed lead source characterization. Therefore, all soil and dust samples collected during the investigation were shipped to the United States for further analysis using a laboratory EDXRF instrument. Further details of the analytical procedures used are provided in Section 2.3.

Field logbooks, photo logs, and field forms used to document all sample collection activities have been compiled and are located at the EEAA’s Technical Cooperation Office for the Environment (TCOE) office in Cairo. The most relevant information from the field logs is included in the database (available on request from EHP).

2.2.2 Food, Cosmetics, and Medicines

The sampling teams used sociological information obtained during the concurrent behavioral study (see Guenena et al. 1996) to identify and select food, cosmetic, and medicinal items for sampling. As described earlier, the intent was to select items most likely to be ingested by young children in low, medium, and high socioeconomic brackets. The general methods used to collect these samples are detailed in the FSG.

2.2.3 Glazed Ceramics

In addition to foods, the teams also collected glazed ceramics for representative low, medium, and high socioeconomic brackets. This potential lead source was identified during the behavioral study conducted concurrently with the field investigation. Results of the behavioral study indicated that are usually obtained from local shops that probably fire the pottery at relatively low temperatures. Glazed pottery fired at low temperatures tends to be more susceptible to dissolution or leaching

juices. Thus, the teams decided to test various pieces of pottery to determine the amount of lead they leached when exposed to acidic foods.

three different market locations that corresponded to the teams' food sample sites. The teams obtained three items each from low, medium, and high socioeconomic areas, as determined based

manufacturers and represented the types used for household food and/or beverage storage and cooking in the Greater Cairo area.

water obtained from Cairo University's Horticulture Laboratory. The teams also combined the DI water with acid to create a leaching solution. They then conducted two separate sequential tests,

acid (HNO_3

DI water to lower the pH of the leaching solution to approximately 3. The teams filled one pottery item with pure DI water (no acid added) to serve as a positive blank control, and retained

covered the pottery items with plastic food wrap to prevent possible dust contamination.

The first portion of the tests consisted of adding a measured quantity of the DI water plus

the inside surface of the pottery for five days. Following this leaching period, samples from each item were collected into plastic bottles. The leaching solution was then replaced with the DI water

$_3$ leaching solution and the test repeated for a three-day leaching period. The teams

2.3 Analytical Methods

Table 2-2 summarizes the methods used to analyze samples collected during this investigation.

2.3.1 Field Portable EDXRF Analysis

During the field investigation, the survey teams used two field portable EDXRF instruments to

manufactured by TN Technologies, Round Rock, Texas. Lead results obtained with the field instruments were used to guide the sample collection teams and to add sample locations in areas

Thus, data generated with field portable EDXRF tools were used for screening purposes only. As alluded to earlier, field portable EDXRF results were not used directly in the evaluations provided readings were obtained. For these samples, only the lead data from the field portable EDXRF analyses were used in subsequent data evaluation.

The procedures used in conducting the field measurements generally followed the draft standard U.S. EPA Method 6800.

2.3.2 Laboratory EDXRF Analysis

Following the field investigation, all soil and dust samples were transported to the United States for analysis using a laboratory-scale EDXRF instrument. The analyses were conducted at the Denver Soil Laboratory of Camp Dresser & McKee (CDM) using a Spectrace 5000 spectrometer. Calibration of the spectrometer was accomplished using two National Institute of Standards and Technology (NIST) soil standards, NIST 2710 and NIST 2711, which are soil standards collected from Butte, Montana. Analysts obtained results for the 17 elements listed in Table 2-2, including lead. The study team used these data for all subsequent statistical analyses and mapping results provided in this report.

2.3.3 Flame Atomic Absorption Analysis

To confirm the laboratory EDXRF data, 20 soil samples collected prior to the field investigation (during an exploratory, or range-finding, investigation) were analyzed by a reference laboratory, Core Labs in Aurora, Colorado. Lab technicians conducted the analyses using flame atomic absorption spectrometry (FAAS) according to U.S. EPA Method 7420. These same 20 samples were also analyzed by Egypt's Ministry of Agriculture Research Garden Institute, operated by Cairo University and LabTec Egypt, using FAAS and a procedure similar to U.S. EPA Method 7420. The purpose of these analyses was to confirm LabTec's analytical procedures and compare the results with those obtained by EDXRF and standard U.S. EPA methods. LabTec also used FAAS to analyze an additional 27 soil and dust samples collected during the field investigation for comparison with the EDXRF results.

Finally, FAAS was used to analyze the 16 exterior paint chip samples collected during the field investigation. Again, LabTec conducted the analyses according to standard U.S. EPA procedures. In addition, LabTec used FAAS to analyze the leachate samples generated from the pottery leaching tests described in Section 2.2.3.

2.3.4 Graphite Furnace Atomic Absorption Analysis

In addition to the samples noted above, LabTec analyzed the food, cosmetics, and medicinal samples collected during this investigation. To do so, the lab used graphite furnace atomic absorption spectrometry (GFAAS) and a procedure similar to U.S. EPA Method 7421. Sample preparation included homogenation, ashing of the samples in a muffle furnace, and digestion with nitric acid.

Table 2-2
Analytical Methods

Sample Matrix	Analyte	No. Analyses	Method [1]	Laboratory
Exterior Dust	Pb Screening Pb + 16 elements[2] Pb	393 393 27	Portable EDXRF EDXRF (EPA 6800) FAAS (EPA 7420)	Field CDM Denver Lab LabTec Egypt
Soil	Pb Screening Pb + 16 elements[2] Pb Pb	175 168 20 20	Portable EDXRF EDXRF (EPA 6800) FAAS (EPA 7420) FAAS (EPA 7420)	Field CDM Denver Lab Core Labs USA LabTec Egypt
Drinking Water	Pb	90	GFAAS (EPA 7421)	LabTec Egypt
Exterior Paint	Pb	16	FAAS (EPA 7420)	LabTec Egypt
Food, Cosmetics and Medicines	Pb Pb	198 26	GFAAS (EPA 7421) ICP-MS	LabTec Egypt Quanterra USA
Pottery Leachate	Pb	11	FAAS (EPA 7420)	LabTec Egypt

[1] EDXRF = Energy dispersive X-ray fluorescence spectroscopy.
FAAS = Flame atomic absorption spectroscopy.
GFAAS = Graphite furnace atomic absorption spectroscopy.
ICP-MS = Inductively coupled plasma - mass spectrometry.
Corresponding U.S. EPA Methods in parentheses.
[2] Ag, As, Ba, Br, Ca, Cd, Cr, Cu, Fe, Mn, Ni, Sb, Sr, Ti, V, Zn.

2.3.5 Inductively Coupled Plasma-Mass Spectrometry

Twenty of the food samples collected during the investigation were transported to the United States and analyzed by Quanterra Labs in Denver, Colorado, using inductively coupled plasma - mass spectrometry (ICP-MS). The purpose of these analyses was to confirm LabTec's analytical results. Quanterra also analyzed an additional six food samples collected prior to the field investigation using ICP-MS.

To conduct the ICP-MS tests, Quanterra technicians "digested" a 1- to 2-gram sample of food in 10 ml of nitric acid (1:1), heated it to 95°C, and refluxed it for 10 to 15 minutes. They then added an additional 5 ml of 1:1 nitric acid to the sample and allowed it to reflux for 30 more minutes. After the solution had evaporated to approximately 5 ml, the technicians added 2 ml of DI water and 3 ml of 30% hydrogen peroxide and returned the sample to the hot plate to warm it and facilitate the peroxide reaction. After the peroxide reaction subsided, technicians added 5 ml of hydrochloric acid and 10 ml of DI water to the solution and allowed it to reflux for an additional 15 minutes. After cooling, the solution was diluted to 100 ml in volume with deionized water.

With an ICP-MS instrument, the food digestate being analyzed is nebulized into a spray chamber where a stream of argon carries the sample aerosol through a quartz torch and injects it into an radio-frequency (RF) plasma. There the sample is decomposed and desolvated. The ions produced are entrained in the plasma and, by means of a water-cooled, differentially pumped interface, introduced into a high-vacuum chamber that houses the mass spectrometer. The ions are sorted according to their mass-to-mass charge ratio and measured with a channel electron multiplier. In this investigation, analysts used internal standards to compensate and correct for suppressions and enhancements caused by the sample matrices.

2.3.6 Quality Assurance/Quality Control

In addition to the confirmatory analyses described above, a variety of quality control (QC) samples were analyzed during this investigation. These samples included the following:

- Standard reference materials (SRMs)—NIST 2710 and 2711, which were used to calibrate the Spectrace 5000 EDXRF instrument, were submitted to LabTec Egypt for analysis by FAAS.
- Soil/dust blanks—Acid-washed pure silica sand was analyzed by EDXRF at a frequency of 1 per 50 regular analyses. These blanks were also analyzed by LabTec to allow evaluation of possible cross-contamination during sample preparation.
- Water blanks—Mineral water samples were submitted to LabTec to allow evaluation of possible cross-contamination during sample preparation. LabTec also analyzed internal deionized water blanks per standard U.S. EPA procedures.
- Calibration control—EDXRF analyses included replicate measurements of NIST 2710 and 2711 at a frequency of 1 per 20 samples to ensure continuing calibration control. Laboratory analysis by FAAS and GFAAS followed standard U.S. EPA continuing calibration control procedures.
- Duplicates and spikes—FAAS and GFAAS analyses included analysis of duplicates and matrix spikes according to standard U.S. EPA procedures. These QC results were used to verify instrument and method reproducibility.

In addition to laboratory QC methods, the study team implemented several quality assurance (QA) procedures during the field investigation to ensure collection of high-quality data. The sample collection procedures used (see Appendix A) were developed by U.S. experts with extensive experience in conducting similar investigations. A three-day training period was established to ensure that Egyptian field technicians were prepared to implement these procedures. All training, as well as the field investigation itself, was conducted under the supervision of U.S. experts. QA procedures implemented during the field investigation included triplicate documentation via field logbooks, field sampling forms, and extensive photographic logs. These documents were checked daily by the project QA officer under the supervision of the U.S. experts. All of these documents are contained in the project files at the EEAA/TCOE office in Cairo.

3 SAMPLING RESULTS

This chapter presents the results and findings of the Cairo LEAP environmental sampling investigation. Results are presented by sample medium in Sections 3.1 through 3.8. Section 3.9 provides results for all quality control samples analyzed during the investigation. Section 3.10 provides an evaluation of the sources of lead in exterior dust. Such information may prove valuable in designing effective lead abatement programs.

Sampling was conducted in two phases. In the initial phase, completed in November 1996, the field team collected all of the soil and dust samples and a modest number of samples for other media of concern. In the second round, conducted in June 1997, the team collected additional samples to verify results from the first round and, when feasible, to locate the source of lead contamination.

All analytical results obtained during this investigation are included in a supplement to this report (available on disk or hardcopy), which includes data for all 17 analytes measured in the soil and exterior dust samples using EDXRF, plus all lead analyses by FAAS, GFAAS, and ICP-MS techniques. The disk files also include observational data reported in field logbooks and on field forms most relevant to the interpretations provided in this report. The files are provided in an ASCII format that can be imported into most spreadsheet and database programs, including EXCEL and ACCESS. The hardcopy printout contains the analytical results for the lead data only.

Most statistical results presented in this report were generated with the computer program SYSTAT. The field base map was scanned to generate a raster image file; the raster image file is not included on the diskette because of its large size. The raster image, along with the database, was imported into a geographical information system (GIS) program, MAPINFO, to allow spatial display of the data. All maps provided in this report are products of the MAPINFO program. The complete MAPINFO system (database and raster image) has been transferred to EEAA/TCOE personnel in Cairo. Training of these personnel in the use of the MAPINFO system has been conducted by U.S. experts as part of this project.

Analysis of the data collected during this investigation was limited to the purpose of characterizing the distribution of lead in environmental media in Cairo. These results were then used to characterize the effect of lead-exposure pathways on young children in Greater Cairo, as described in Chapter 4.

3.1 Exterior Dust Samples

Table 3-1 presents basic univariate statistical results for lead found in the exterior dust samples analyzed using EDXRF spectroscopy. As shown, lead concentrations in exterior dust samples ranged from 11 to 2,199 mg/kg, with a mean of 268 mg/kg and a median of 191 mg/kg for the

411 total samples collected. As indicated by the skewness coefficient of 3.5, the exterior dust lead data are highly positively skewed. After log transformation, these data closely approximate a normal (log-normal) distribution, as shown in Figure 3-1. The histogram indicates that a geometric mean near the median value of 191 mg/kg is more representative of the central lead concentration than the mean of 268 mg/kg.

United States cleanup standards for lead in soils typically range between 500 and 1,000 mg/kg, depending primarily on the environmental setting and the degree to which the lead in the soil is bioavailable, or presents a risk to human health. As shown in Table 3-1, 52 of the 411 Cairo dust samples exceeded 500 mg/kg (12.7%) and 10 exceeded 1,000 mg/kg (2.5%).

Table 3-2 provides statistical results for exterior dust lead concentration as a function of sample type, relative vehicular traffic volume, and relative socioeconomic bracket. Traffic volume and socioeconomic bracket (standard of living) observations were made in the field during sample collection and should be considered as qualitative data only (that is, they were not based on any quantitative data gathering). Nevertheless, the sampling results indicate that lead concentrations in Greater Cairo are highest in street dust, high-traffic areas, and high socioeconomic areas. Figure 3-2 further illustrates this difference by separately grouping high and low vehicular traffic volume and socioeconomic bracket samples for all exterior dust samples taken. The resulting plots indicate a significant difference in lead concentrations between high traffic volume/high socioeconomic area samples and low traffic volume/low socioeconomic area samples. A possible explanation for this difference is that a significant source of lead in Greater Cairo dust results from automobile emissions, greater quantities of which occur in the city's higher socioeconomic areas.

Map 2 shows the spatial distribution of lead concentration in exterior dust samples collected during the investigation. The symbols on this map represent the average lead concentration (average of street dust, entry dust, and other exposure area samples) found at each of the 176 LED locations. Although lead concentrations vary widely across the study area, there does appear to be a higher number of elevated lead levels in certain areas. For example, a relatively high number of elevated lead levels in dust are located in central Cairo districts (downtown Cairo, Zamalek, Mohandessin), in the more congested areas of Greater Cairo. In contrast, relatively low lead levels are found in outlying areas such as Helwan, Maadi, and Kalyubia.

3.2 Soil Samples

Table 3-3 presents basic univariate statistical results for lead found in the soil samples collected during this investigation and analyzed using EDXRF spectroscopy. As shown, lead concentrations in soil samples ranged from 5 to 1,537 mg/kg, with a mean of 128 mg/kg and a median of 74 mg/kg for the 180 total samples collected. As indicated by the skewness coefficient of 4.4, the soil lead data are highly positively skewed. After log transformation, these data more closely approximate a normal distribution, as shown in Figure 3-3. The figure indicates that a geometric mean near the median value of 74 mg/kg is more representative of the central lead concentration than the mean of 128 mg/kg.

Figure 3-1
Lead Sampling from Exterior Dust

Table 3-1
Summary Statistics for Lead - All Exterior Dust Samples

Statistic	Value [1]
Number of Cases	411
Minimum	11.4
Maximum	2199.4
Range	2187.9
Mean	268.0
Variance	74,096.2
Standard Deviation	272.2
Standard Error	13.4
Skewness (G1)	3.5
Kurtosis (G2)	17.4
Sum	110,153.1
Coefficient of Variation (CV)	1.0
Median	191.0
Cases exceeding 500 mg/kg	52
Cases exceeding 1000 mg/kg	10

[1] All results for data in units of mg/kg (ppm).

Table 3-2
Summary Statistics for Lead - All Exterior Dust Samples Grouped by Sample Type, Traffic Volume, and Socioeconomic Bracket

	Value [1]		
Statistic	**Street Dust**	**Entry Dust**	**Common Area**
Number of Cases	169	179	63
Minimum	17.5	11.5	23.1
Maximum	1941.1	2199.4	1687.3
Mean	268	280.9	231.2
Median	194.9	190.7	189.7
Statistic	**Traffic Vol = High**	**Traffic Vol = Medium**	**Traffic Vol = Low**
Number of Cases	144	116	121
Minimum	12.4	24.6	17.4
Maximum	1941.1	2199.4	2164.7
Mean	307.2	252.8	254.7
Median	228.8	184.2	180.9
Statistic	**SOL = High [2]**	**SOL = Medium**	**SOL = Low**
Number of Cases	94	150	148
Minimum	30	12.4	11.5
Maximum	1687.3	2199.4	1941.1
Mean	301.1	276.9	235.6
Median	209.2	208.7	176.6

[1] All results for data in units of mg/kg (ppm).
[2] SOL = Standard of Living (Socioeconomic Bracket).

Note: Not all samples collected during the investigation were classified according to traffic volume or standard of living.

Figure 3-2
Lead Sampling by High and
Low Vehicular Traffic Volume
and Socioeconomic Bracket

map 2

map2

Table 3-3
Summary Statistics for Lead - All Soil Samples

Statistic	Value [1]
Number of Cases	180
Minimum	4.7
Maximum	1537.0
Range	1532.3
Mean	127.7
Variance	28,270.8
Standard Deviation	168.1
Standard Error	12.5
Skewness (G1)	4.4
Kurtosis (G2)	28.9
Sum	22,979.6
Coefficient of Variation (CV)	1.3
Median	74.4
Cases exceeding 500 mg/kg	6
Cases exceeding 1000 mg/kg	1

[1] All results for data in units of mg/kg (ppm).

Figure 3-3
Lead Sampling from Soil

Soil lead concentrations are significantly lower than exterior dust lead concentrations in Greater Cairo, as illustrated in Figure 3-4. Only 6 of the 180 total soil samples exceeded 500 mg/kg, and only 1 sample exceeded 1,000 mg/kg. Map 3 shows the spatial distribution of average lead concentration in soil samples collected during this investigation.

3.3 Drinking Water Samples

Table 3-4 presents basic univariate statistical results for lead found in the drinking water samples collected. As shown, lead concentrations ranged from 0.25 to 10.9 μg/L, with a mean of 1.69 μg/L and a median of 1.27 μg/L for the 90 total samples collected. As indicated by the skewness coefficient of 3.02, the data are highly positively skewed, and therefore the median is probably more representative of the central value.

The U.S. drinking water standard for lead is currently 15 μg/L. None of the drinking water samples collected in Greater Cairo exceeded this standard.

In the United States, an often important source of lead in drinking water is leaching of lead-containing solder used at the joints of copper distribution pipes. Dissolved lead concentrations resulting from such leaching are typically higher under low pH conditions. A plot of lead concentration versus pH for the Cairo drinking water samples is provided in Figure 3-5.

As shown, pH levels generally ranged between 7 and 8, and lead concentrations are apparently unrelated to pH. This may indicate that copper piping and/or lead-containing solder is not commonly used in Greater Cairo. It should be noted, however, that lead concentrations in drinking water may fluctuate widely depending on the length of time the water comes in contact with lead-containing pipes, and that very little control over this potentially important parameter was possible during this investigation, as early morning or “first-flush” water samples were not collected.

3.4 Paint Samples

Exterior paint samples were collected from buildings at only 16 of the 176 LED locations. The small number of paint samples was due to (1) lack of the use of paint on exterior surfaces and (2) lack of peeling or otherwise deteriorating paint near potential exposure areas surrounding buildings. This situation indicates that exposure of children to paint outside of buildings is not an important concern in the Greater Cairo area. In addition, the lead concentrations in the samples that were collected were very low, ranging from less than analytical detection to a high of only 1,326 mg/kg (Table 3-5). Concentrations in paint that contains lead as an additive are typically 100 to 500 times this level. The low lead concentrations and the overall lack of exterior paint make it a highly unlikely source of lead exposure to young children.

Samples of paints being sold for interior use were collected “off the shelf” from various locations throughout Greater Cairo. A total of 15 paint and paint additives samples were collected. Lead concentrations in the samples varied over a wide range, from 0.02 to 19,200 ppm. The median value was 370 ppm. In the U.S., “lead-based paint” is defined as paint containing lead at a concentration of 5,000 ppm (0.5%) or higher. One of the 15 samples, at 19,200 ppm, would qualify as “lead-based” under this definition. The lead levels found in this study indicate

Figure 3-4
Exterior Dust (LED) and Soil (REP) Sampling

map 3

map 3

Table 3-4
Summary Statistics for Lead - Drinking Water Samples

Statistic	Value [1]
Number of Cases	90
Minimum	0.25
Maximum	10.90
Mean	1.69
Cases exceeding 15 μg/L	0

[1] All results for data in units of μg/L (ppb).

Table 3-5
Summary Statistics for Lead - Paint Samples

Statistic	Value [1]
Exterior Samples	
Number of Cases	16
Minimum	1.1
Maximum	1326.0
Mean	347.3
Median	97.3
Interior Samples	
Number of Cases	15
Minimum	0.02
Maximum	19,200
Mean	2,151
Median	370

[1] All results for data in units of mg/kg (ppm).

Figure 3-5
Drinking Water Samples: Lead versus pH Content

that interior household paint is not a significant source of lead exposure at this time, but that some paints with high lead content are available for sale in Cairo.

3.5 Food Samples

LabTec Egypt analyzed a total of 189 food samples collected during the initial round of sampling. Lead concentrations for these samples ranged from below analytical detection to 1,755 μg/kg (ppb), with a mean of 141.8 μg/kg and median of 76.4 μg/kg (see Table 3-6). Statistical results are provided in Table 3-7a (grouped by food type) and Table 3-8 (grouped by socioeconomic bracket). Figure 3-6a illustrates the distribution of lead concentrations in the various food types.

In several cases, the EHP team calculated statistics for the food groups based on replacing and/or ignoring certain LabTec results. This was done because, on confirmational analysis, the team found that LabTec tended to report erroneously high values in about 5 to 10 percent of the samples. Therefore, to present what the team believes to be more representative statistical data for food, a separate column ("adjusted data") is provided in Table 3-7a in addition to the results obtained by LabTec (shown as "all data"). See Section 3.9 for more detailed information on analytical quality assurance.

An additional 188 samples of various types of food were collected in the second round of sampling. These were analyzed by Quanterra Laboratories, Inc. in Denver, Colorado. All of the results were of acceptable analytical quality. Summary statistics for these additional samples are presented in Table 3-7b, organized by type of food. The distribution of lead concentrations in this second round of food samples is shown in Figure 3-6b.

Table 3-6
Summary Statistics for Lead - All Initial Food Samples
December 1996

Statistic	Value [1]
Number of Cases	189
Minimum	0.1
Maximum	1755.4
Mean	141.8
Standard Deviation	217.6
Median	76.4

[1] All results for data in units of μg/kg (ppb).

Table 3-7a
Summary Statistics for Lead - All Initial Food Samples
(Grouped by Sample Type) December 1996

	μg/kg (ppb)					
Statistic	**Breads**		**Canned Foods**		**Dairy Products**	
	All data	Adjusted data[1]	All data	Adjusted data	All data	Adjusted data
Number of Cases	12	NA[2]	17	16	18	17
Minimum	0.4	NA	1.35	1.35	0.10	0.10
Maximum	541.3	NA	561.6	119.1	574.7	278.3
Mean	140.3	NA	95.0	65.8	111.2	83.9
Median	92.6	NA	71.8	68.4	59.4	52.8
Statistic	**Drinks/Juice**		**Grains**		**Meats**	
	All data	Adjusted data	All data	Adjusted data	All data	Adjusted data
Number of Cases	2	NA[2]	22	21	13	12
Minimum	0.188	NA	0.48	0.48	27.39	27.39
Maximum	2.052	NA	409.2	252.0	770.2	266.6
Mean	1.120	NA	97.7	82.9	181.0	131.8
Median	1.120	NA	84.8	83.8	139.2	134.4
Statistic	**Milk**		**Processed Foods**		**Produce**	
	All data	Adjusted data	All data	Adjusted data	All data	Adjusted data
Number of Cases	5	5	23	21	37	33
Minimum	2.45	2.45	0.365	0.365	0.109	0.109
Maximum	979.2	77.3	753.1	243.1	1,755.4	247.8
Mean	227.8	36.9	149.2	99.3	170.2	90.9
Median	67.2	25.0	105.8	104.1	102.8	75.5
Statistic	**Spices**		**Tomato Products**		**Mineral Water**	
	All data	Adjusted data	All data	Adjusted data	All data	Adjusted data
Number of Cases	29	22	5	5	3	NA
Minimum	0.180	0.180	18.87	18.87	0.200	NA
Maximum	1,183.9	280.3	394.1	170.0	0.200	NA
Mean	175.0	62.9	178.8	67.57	0.200	NA
Median	25.4	16.3	77.3	46.0	0.200	NA
Statistic	**Flour**					
	All data	Adjusted data				
Number of Cases	3	NA				
Minimum	6.4	NA				
Maximum	97.4	NA				
Mean	50.9	NA				
Median	48.9	NA				

[1] See Section 3.5 for description of "adjusted" data.
[2] NA = not applicable (adjustment not needed).

Table 3-7b
Summary Statistics for Lead - Additional Food Samples
(Grouped by Sample Type)
June 1997

	μg/kg (ppb)	
Statistic	**Breads**	**Dairy Products**
Number of Cases	47	25
Minimum	37	5.9
Maximum	1,500	1,200
Mean	349	136
Median	240	36
Statistic	Flour	**Produce**
Number of Cases	12	81
Minimum	150	5
Maximum	1,000	10,100
Mean	357	454
Median	315	26

Statistic	**Milk**		
	Packaged	**Fresh**	**Total**
Number of Cases	21	9	30
Minimum	5	34	5
Maximum	190	280	280
Mean	34	118	59
Median	8.6	110	16

Table 3-8
Summary Statistics for Lead - All Initial Food Samples
(Grouped by Socioeconomic Bracket)
December 1996

	Value [1]		
Statistic	**SOL = High [2]**	**SOL = Medium**	**SOL = Low**
Number of Cases	100	53	30
Minimum	0.103	0.109	0.396
Maximum	979.2	1755.4	574.6
Mean	111.5	166.6	149.0
Median	62.8	113.1	92.8

[1] All results for data in units of μg/kg (ppb).
Spices used by all three categories excluded.
[2] SOL = Standard of Living (Socioeconomic Bracket).

Figure 3-6a
Distribution of Lead in Initial Food Samples
(Grouped by Food Type)
December 1996

(Circle and star symbols represent statistical outliers.)

Figure 3-6b
Distribution of Lead in Additional Food Samples
(Grouped by Food Type)
June 1997

(Circle and star symbols represent statistical outliers.)

3.5.1 Breads

The initial round of sampling included 12 samples of baked bread sold either loose at street markets or packaged at grocery stores. As shown in Figure 3-6a, 10 of the 12 bread samples had lead concentrations less than 200 μg/kg. The two bread samples with higher lead concentrations (315 μg/kg and 541 μg/kg) were both loose Baladi breads collected from medium socioeconomic locations. The median lead concentration in all bread samples was 92.6.

Following the first round of sampling, the team received informal reports indicating that high levels of lead had also been discovered in some samples of bread and flour collected in another area in Egypt. The source of the lead contamination was reported to be in the milling process. Based on this report and on the high lead levels in 2 of the 12 samples collected in the initial round, the team conducted a somewhat more extensive investigation of bread and flour during the second round of sampling.

A total of 37 samples of Baladi bread were collected at bakeries and street markets in three different locations in Cairo. Lead concentrations in the bread samples ranged from 54 to 1,500 ppb, with a median concentration of 230 ppb. The team also collected 10 samples of pretzels and bagels from street vendors; results from these breads were comparable to those for Baladi bread, with a range from 37 to 1,400 ppb and a median value of 265 ppb. Combining results from these three types of bread yields 47 samples with a combined median value of 240 ppb.

The team sampled bread and related media at various points in the production and distribution chain in order to identify sources of the lead contamination in bread. This was a limited investigation with a very modest number of samples.

- At one of the largest flour mills serving Cairo, the team collected two samples of grain as it was received at the mill, one sample of grain after it had been washed, and one sample each of three types of flour produced by the mill. The results for lead in the grain samples were 32, 24, and 20 ppb, all of which are below the laboratory's analytical reporting limit. The flour samples, however, contained 160, 160, and 300 ppb, indicating that there is a contamination source in the milling process. This information corroborates the informal reports mentioned earlier.
- At the three bakeries where the team collected samples of Baladi bread, they also collected samples of the flours and water being used in the bread. In all cases, the three flour samples contained significant levels of lead and the water samples were clean. The concentrations of lead in flour were sufficient to explain the elevated lead levels seen in the corresponding bread samples.
- Considering all the 12 flour samples together, the lead concentrations ranged from 150 ppb to 1,000 ppb, with a median of 315 ppb.
- Of the 37 samples of Baladi bread collected, 21 were collected from street markets at designated times in the morning and then again in the afternoon, from the same vendors, to determine whether some portion of the lead in (or on) Baladi bread could be attributed to lead-containing dust that deposits on uncovered bread while at the

market. There was, however, no statistically significant difference between the lead concentrations in bread collected in the morning and that collected in the afternoon, or between bread samples collected at the bakeries versus those collected at street markets. Baladi bread samples collected at bakeries ranged between 80 and 1,500 ppb, while samples collected from street vendors ranged from 54 to 1,200 ppb. Given the high variability of lead concentrations observed in bread in this study, it would have required approximately 300 samples of "fresh" bread at the bakery and another 300 samples collected from street markets to detect an increase of 100 ppb in the mean concentration of lead attributable to dust deposition. Resource constraints prevented the team from collecting this many samples and, consequently, the authors cannot say whether dust deposition is a significant additional source of lead contamination in bread.

The team also collected a sample of the fuel oil used to fire the ovens at one of the bakeries visited. This sample contained 600 ppb lead and, thus, could conceivably be an additional source of lead contamination in bread, although the possible magnitude of the contribution is unknown.

3.5.2 Canned Foods

The canned foods category included any foods packaged in metal cans. As shown in Figure 3-6a, all but 1 of the 17 canned foods sampled contained lead concentrations less than about 120 μg/kg. The exception was 562 μg/kg for F002-04 (spiced sardines in oil). The reason for this high lead concentration is unknown, but may be due to leaching of lead-containing solder used to seal the can. However, leaching of such solder generally does not appear to be a significant source of lead exposure in Cairo. Ignoring the one high value yields a median lead concentration in canned foods of 68.4 μg/kg.

3.5.3 Dairy Products

Dairy products analyzed in the first round of sampling included cheeses, eggs, butter, and yogurt. The concentration of lead in the 18 dairy product samples varied over a fairly wide range but generally was less than about 300 μg/kg. Sample F013-10, a butter sample, had an unusally high lead concentration of 575 μg/kg. Excluding this high value yields a median lead concentration in the dairy samples of 52.8 μg/kg.

An additional 25 samples of cheeses, butter, and yogurt were collected in the second round of sampling. Samples were collected at the outgoing shipment points for two commercial/private plants and from the retail distribution outlet for one of the largest government-operated plants. Fourteen of the samples contained elevated levels of lead, nine of which were 100 ppb or greater. Those having elevated levels of lead were three cream cheese samples (36, 38, and 100 ppb), one "falamank" cheese sample (29 ppb), two "potato" cheese samples (100 and 180 ppb), five "processed" cheese samples (64, 67, 390, 660, and 1,200 ppb), and three yogurt samples (100, 110, and 160 ppb). The median value for all dairy product samples is 36 ppb. For the 14 samples of various types of cheese, 6 contained 100 ppb lead or move, and the median level was 65.5 ppb.

3.5.4 Drinks

Two drink samples (other than water and milk) were collected, tangerine drink and banana milk drink, both of which contained very low concentrations of lead. The banana milk drink contained less than detectable limits of lead, and the tangerine drink had a lead concentration of only 2.05 μg/kg.

3.5.5 Grains

The grains category included pasta, beans, and rice. All of the grain samples were collected in the initial round. Of the 22 samples collected, 9 had lead concentrations above 100 ppb, and 7 had concentrations below 20 ppb. Sample F015-04, a dome sample, had an anomalously high lead concentration of 409 μg/kg. Excluding this high value yields a median lead concentration in grains of 83.8 μg/kg.

3.5.6 Meats

Thirteen beef and poultry samples were included in the meats category. Except for one sample, F004-14 (loose Baladi pastrami), which contained an anomalously high lead concentration of 770 μg/kg, the meat samples contained generally less than about 300 μg/kg. Ignoring the high value yields a median lead concentration in meats of 134.4 μg/kg.

3.5.7 Milk

Five milk samples were collected in the initial round. Lead concentrations of 2.45, 12.69, 77.26, 67.22, and 979 μg/kg were measured for half cream, milk (2 samples), buttermilk, and powdered milk, respectively. The high level measured in the powdered milk sample was likely in error, based on confirmatory data (see Section 3.8); further analysis indicated the lead concentration in this sample was 25 μg/kg. The lower value was used in further analysis of the data.

Twenty-one additional milk samples were collected in the second round from commercial processing plants. These included samples of raw milk immediately after milking, before pasteurization, after pasteurization, and finished packaged products available for sale at the plant's retail outlet. The samples ranged in concentration from 5 ppb to 190 ppb, with a median of 8.6 ppb. Five samples had concentrations above 50 ppb, 4 of which were collected after pasteurization and 1 of which was collected immediately after milking.

Nine samples of fresh and boiled milk collected from local motorcycle vendors ranged from 34 to 280 ppb, with a median of 110 ppb. Seven of the ten samples had concentrations over 50 ppb lead. This is a higher level of contamination then that seen in samples from the commercial processing plant. This contamination could originate from motorcycle exhaust, since the fresh milk canisters are usually mounted very close to the vehicles' exhaust point, or from lead solder used in the canisters, or possibly from particles deposited on the dipper used to dispense milk from the canisters.

3.5.8 Processed Foods

Processed foods tested included such items as potato chips, tea and coffee, and sweets (jellies, chocolates, and the like). All but two of the foods in this category had lead concentrations less than 250 μg/kg. The two exceptions were F002-22 (crunchy potato chips) and F011-04 (Blue Tea Pot tea), which contained lead concentrations of 594 and 753 μg/kg, respectively. Ignoring these two anomalously high values yields a median lead concentration in processed foods of 104.1 μg/kg.

3.5.9 Produce

A total of 37 samples of fruits and vegetables were collected in the first round of sampling. The majority of the samples were collected loose, primarily from street vendors. All but four of the samples had lead concentrations less than 250 μg/kg. The four samples with high lead levels were F002-17 (potato, 731 μg/kg), F003-01 (cucumber, 437 μg/kg), F008-01 (cucumber, 1,755 μg/kg), and F015-07 (kale, 373 μg/kg). Excluding these four high values yields a median lead concentration in produce of 75.5 μg/kg.

Nine types of produce that showed elevated lead concentrations during the initial sampling were selected for additional analysis in the second round. These items were also selected based on the most important produce relative to consumption by children. For each item, two subsamples were prepared: unwashed and washed.

Six of the produce types had low lead concentrations: tomato (11-21 ppb), peaches (16-31 ppb), onion (5-17 ppb), lemon (13-38 ppb), green pepper (18-44 ppb), and eggplant (12-25 ppb).

As in the first round, results from the second round also indicate higher lead levels for leafy vegetables, potatoes, and cucumbers. Lettuce samples had the highest lead concentrations, ranging from 230 ppb to 10,100 ppb in the unwashed samples. All nine of the unwashed samples and 2 of the 5 washed samples had concentrations over 100 ppb. Washing lettuce had a clear effect in reducing lead levels: the median value for unwashed samples was 960 ppb, compared to 54 ppb for washed samples.

Cucumbers also showed relatively high levels of lead contamination, with values ranging from 18 to 2,800 ppb in the unwashed samples. Ten of the 13 unwashed samples had values exceeding 100 ppb. Washing also had clear benefits for cucumbers, reducing the median concentrations from 310 for unwashed samples to 20 ppb for washed samples.

Similar results were obtained for potatoes, with somewhat lower levels. The lead concentrations ranged from 17 to 570 ppb for unwashed samples; 9 of the 12 unwashed samples had lead values exceeding 100 ppb; and washing reduced the median lead concentration from 255 ppb to 14 ppb.

The sampling team traced lettuce samples back to a village in which, according to anecdotal information, as much as 90% of the lettuce sold in Cairo is apparently grown. A soil sample from a lettuce field contained 54 ppm lead, comparable to levels seen in the soil survey conducted in the Greater Cairo area. Lead levels on lettuce sampled from the fields were as high or higher than levels found on unwashed samples collected from markets in Cairo, indicating that most, if not all, of the contamination seen on lettuce samples at the points of retail sale may occur before harvesting.

3.5.10 Spices

The spice category included a wide variety of foods, primarily seasonings, flavorings, oils, and herbs. Lead concentrations in these items varied over a very wide range. Twenty-two of the 29 total samples had lead concentrations less than about 250 μg/kg. Those samples with lead concentrations above that level were as follows:

Sample ID	Description	Lead Content μg/kg
F002-49	Parsley	747.2
F011-12	Molasses	280.3
F014-02	Dokka	484.3
F014-03	Arugula	302.5
F014-04	Dill	475.4
H001-04	Caraway seeds	492.9
H001-10	Tilia leaves	1,183.9

Ignoring the above samples yields a median lead concentration in the spice samples of 8.96 μg/kg. Most of the samples with lead concentrations less than 250 μg/kg were below 50 μg/kg. Note that the two spices with the highest concentrations are leafy plants which may collect dust in the same manner as lettuce and kale.

3.5.11 Tomato Products

This category included four samples of tomato paste and one ketchup sample. Three of the five samples had lead concentrations ranging between 19 and 77 μg/kg. The remaining two samples, both tomato pastes contained in glass jars, had concentrations of 378 and 394 μg/kg, respectively. The two high values may be in error based on confirmatory data (see Section 3.8); further analyses of these two samples resulted in lead concentrations of 46 and 170 μg/kg, respectively. Using the lower values, the median concentration of the five samples is 46 μg/kg.

3.5.12 Mineral Water

The three mineral water samples collected all had lead concentrations below the analytical detection limit of 0.2 μg/L.

3.6 Cosmetics and Medicine Samples

Nine samples of various cosmetics and medicines were collected as part of the initial investigation. Eight of the samples were medicines used primarily by children as home remedies for common ailments. The one cosmetic sample taken was kohl, which is used as an eye cosmetic by women and young children. Lead concentrations in all but two of the samples were less than 45 µg/kg (many were below 1 μg/kg). The two samples with high concentrations were M001-04 (oral rehydration solution, 413 μg/kg) and M001-05 (aspirin tablets, 316 μg/kg). Based on quality control results, these high concentrations appear to have been anomalous.

Information obtained during the initial investigation indicated that lead concentrations in kohl may vary considerably depending on the ingredients used to produce a particular item. During an initial range-finding study (prior to the field investigation), four samples of kohl of various types (primarily of different colors) were collected and qualitatively analyzed using EDXRF spectroscopy. The results indicated that various inorganic elements are generally used to create the different kohl colors. One of the four samples (one of two black varieties) was composed of essentially pure lead sulfide, a mineral known as galena. The other varieties of kohl examined contained very low levels of lead, generally less than about 50 μg/kg.

Twenty-eight additional samples of kohl were collected in the second round from various locations throughout Cairo. Eighteen of the samples were manufactured locally, while ten were imported from nearby countries.

Kohl, commonly used in Egypt among female adults and young children, is applied directly to the conjuctival surface of the eye as an eyeliner. It is an ancient tradition in Egypt, dating back to the pharaohs' era, and is usually used on special occasions such as weddings and religious events. Some families in Egypt apply kohl on newborn babies for a period of one week as they believe that it helps enlarge the baby's eyes.

Summary Statistics for Lead - Cosmetics ("Kohl") Samples

Statistic	**Value [1]**		
	Local	**Imported**	**Total**
Number of Cases	18	10	28
Minimum	9.5	14.2	9.5
Maximum	562,000	629,000	629,000
Number Over 100,000 ppm	7	7	14
Median of High Level Samples	378,000	161,000	250,000
Number Under 1,000 ppm	11	3	14
Median of Low Level Samples	21.9	57.1	38.3

[1] All results for data in units of mg/kg (ppm).

The sample results varied over a wide range; the samples contain either high concentrations of lead or almost none. The local kohl samples range from 9.5 to 562,000 ppm (56%), while the imported samples range from 14.2 to 629,000 ppm (63%). Seven of the eighteen local samples (39%), and seven of the ten imported samples (70%), had concentrations above 100,000 ppm. The median of 14 samples 100,000 was 250,000 ppm.

This variation could be explained based on some information gathered by the team during sampling. There are two methods of kohl preparation. One type of kohl consists of lead sulfide (Pb_2S_3) known as "galena" with antimony sulfide (AnS) crystals. Another local method of preparation consists of burning the following ingredients together: sumach (Rhus coriaria L.), nutmeg tree (Myristica fragrans - Houtt), extracts resulting from burning frankincense (Boswellia carterii L.), sugar crystals (Saccharum officinarum L.), and perfumed cherry (Prunus mahaleb L.). Then, the resulting ash is used as kohl product.

Obviously, samples of the first kohl type showed very high lead levels while the samples of the second type were low in lead.

3.7 Pottery

3.7.1 Pottery Leachate Test

The methods used to test glazed ceramic pottery samples collected during this investigation are detailed in Section 2.2.3. The purpose of this testing was to evaluate whether the leaching of lead from the glazed interior surface of pottery items during cooking or storing of foods could represent a potential lead-exposure pathway. A statistical summary of the pottery leachate data is provided in Table 3-9, which indicates that lead concentrations that potentially could be leached from pottery vary considerably, from a low of 13.24 μg/L to a high of 47,160 μg/L in the leachate. These results are for weak acid leachate solutions meant to approximate acidic foods that could be stored in pottery containers. For the two pottery items leached with deionized water only, analysts obtained solution lead concentrations of 2.90 μg/L and 23.78 μg/L, respectively. Results of the pottery leaching test indicate that high concentrations of lead potentially could be leached into acidic foods cooked or stored in glazed ceramic containers like those tested.

Table 3-9
Summary Statistics for Lead - Pottery Leaching Test

Statistic	Value [1]
Number of Cases	11
Minimum	13.24
Maximum	47,160.0
Mean	9,507.1
Median	1,951.0

[1] All results for data in units of μg/L (ppb).

3.7.2 Pottery Chips

Fifteen samples of glazed ceramics pottery, different shapes and colors, were collected at various locations that were representative of three socioeconomic levels. The lead concentrations in these pottery chip samples detected by an XRF instrument were either very high or very low. The results range between 5 and 63,000 ppm. Eight of the 15 samples had concentrations above 10,000 ppm; the other 7 were 140 ppm or less.

A relationship appears to exist between lead content and the pottery source (i.e., manufacturer and/or socioeconomic level). The seven chip samples with low lead content were collected from a vendor in the low socioeconomic area where manufacturers produce an inexpensive ceramic that contains a small amount of glaze on its surface. Samples that showed high lead levels were fully glazed on both sides of the pottery and were purchased in the middle and higher income areas.

Summary Statistics for Lead-Glazed Pottery Samples

Statistic	**Value [1]**
Number of Cases	15
Minimum	5
Maximum	63,000
Mean	13,734
Median	10,360

[1] All results for data in units of mg/kg (ppm).

3.7.3 Glazing Materials and Clay

Two samples of glazing materials were collected. Clay is painted with this material and then heated at approximately 600 C for one week. Also, three samples of the clay used to make that type of pottery were collected.

The lead concentrations in the two glaze samples were 41,300 and 59,800 ppm, or approximately 4-6% lead. This was expected and is consistent with the information obtained by the team during sampling. The glazing materials are made from the same “galena”used in making kohl, as described in Section 3.6 above. The clay sample results were quite low at 14.2, 15.6, and 16.1 ppm.

3.8 Newspaper

During the field sampling, the team heard several people express a belief that lead is transferred to food when it is wrapped in newspaper. Three samples of newspaper were collected to determine if the inks being used contain lead. All three samples had low levels of lead: 22, 28, and 32 ppb.

Summary Statistics for Lead - Newspaper Samples

Statistic	Value [1]
Number of Cases	3
Minimum	22
Maximum	32
Mean	27.3
Median	28

[1] All results for data in units of mg/kg (ppm).

3.9 Quality Control Samples

The quality assurance/quality control (QA/QC) methods employed during this investigation are described in Section 2.3.6 of this report. With regard to analytical QC samples, the study team followed U.S. EPA procedures as closely as possible. An important part of the QC program was confirmation of the quality of all analytical data. The types of confirmation samples used included performance evaluation samples, or standard reference materials (SRMs), blanks, and duplicate or referee laboratory analyses. The SRM samples were obtained from the National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland. The more pertinent of the QC results are discussed below.

The team submitted 26 exterior dust samples for lead analysis via both EDXRF and FAAS and obtained a correlation coefficient of 0.952 between the two methods. As illustrated in Figure 3-7, EDXRF results were generally higher than FAAS results. The difference is likely due to incomplete digestion prior to FAAS analysis, compared with the total analysis obtained with EDXRF. Incomplete digestion was also indicated by the FAAS results obtained for SRM 2711, an NIST soil standard. LabTec Egypt analyzed the standard twice and obtained results of 969 mg/kg and 719 mg/kg, compared with the accepted concentration of 1,162 ± 31 mg/kg. SRM 2711 was one of two standards used to calibrate the EDXRF spectrometer.

In addition to the 26 exterior dust samples analyzed by EDXRF and FAAS, the team submitted 14 soil and dust samples collected prior to the field investigation for analysis by three different methods: EDXRF, FAAS, and inductively coupled plasma (ICP) spectrometry. The ICP analyses were conducted by Core Labs. Results of the analyses (see Table 3-10) indicated good agreement between EDXRF and ICP (correlation coefficient of 0.959); however, the FAAS results LabTec obtained were consistently lower than both the EDXRF and the ICP results. This difference, again, is likely due to incomplete digestion during the FAAS procedure.

Twenty-one food samples were analyzed for lead by both GFAAS (LabTec) and ICP-MS (Quanterra Labs). As Table 3-11 shows, the results agree reasonably well for all but three of the samples: F001-03, powdered milk (979 μg/kg versus 25 μg/kg); F001-20, tangerine drink (2 μg/kg versus 120 μg/kg); and F001-21, tomato paste (378 μg/kg versus 46 μg/kg). The reason for the discrepancy has not been identified. The study team

Figure 3-7
Scatter Plot of Exterior Dust Lead Concentration by EDXRF versus Lead Concentration by FAAS, LabTec Egypt

selected these 21 samples for confirmatory analysis because it believed they represented the most important food items in the diet of young children in Cairo.

In addition, both LabTec and Quanterra Labs analyzed two food SRMs: SRM 8433 (NIST corn bran), with an acceptable lead concentration of 140 ± 34 μg/kg, and SRM 8418 (NIST wheat gluten), with an acceptable lead concentration of 100 ± 50 μg/kg. Quanterra's results for these two SRMs were 160 μg/kg (SRM 8433) and 120 μg/kg (SRM 8418), which were within the acceptable limits. LabTec's results for SRM 8433 were 139, 149, 209, 220, and 545 μg/kg. For SRM 8418, LabTec's results were 203, 266, 272, 426, and 530 μg/kg. Only two of these results, 139 and 149, were within acceptable limits. This indicates a tendency for LabTec's data to be biased on the side of higher than actual lead concentrations in the food samples submitted. The team has not identified the reason for this discrepancy, although a likely explanation is laboratory contamination during sample preparation. Quanterra analyzed SRM 8433 and SRM 8418 during the second round of sampling and obtained results within acceptable ranges, 150L μg/kg for SRM 8433 and 93 μg/kg for SRM 8418.

In summary, analytical results on QC samples indicate a high level of confidence in the accuracy of dust and soil samples analyzed by EDXRF. Similarly, water and paint results are also expected to be accurate. Conversely, however, food analytical data likely contain about a 5 to 10 percent bias on the high concentration end for lead for samples collected during the first phase. The team believes that quality control problems by LabTec Egypt during preparation and/or analysis of the foods may be responsible for this bias, and the team has therefore made adjustments to account for this bias by removing certain high results from the blood lead modeling simulation provided in Chapter 4. The food samples analyzed at Quanterra during the second phase of sampling have a high level of confidence.

3.10 Evaluation of Lead Source in Exterior Dust

The results provided in Section 3.1 and Chapter 4 indicate that exterior dust may be one of the primary means of lead exposure among children in Greater Cairo. Therefore, in order to evaluate and design effective lead abatement programs, one must understand the source of lead in exterior dust. This section provides an evaluation of the source based on data the study team collected during its investigation.

The results presented here are based on two multivariate statistical methods, element correlations and factor analysis. Both of these techniques incorporate the complete elemental analyses (17 elements, including lead) the team obtained for the exterior dust samples using EDXRF. The basic principle behind this type of multivariate analysis is that certain relationships between or among the variables involved may indicate the source of lead. Examination of such relationships, which may be complex depending on the number of significant variables involved, may identify chemical signatures (or fingerprints) that identify the source of lead.

Table 3-10
Comparison of Analytical Results for Lead in Soil and Dust Samples Between Three Methods

Sample ID	EDXRF	ICP (Core Labs)	FAAS (LabTech)
C-001	16.5	21.2	15.8
C-002	21.4	30.3	36.3
C-003	36.8	41	22.4
C-004	114	172	44.5
C-008	160	139	68.6
C-009	254	216	97.4
C-010	235	226	116.7
C-011	91	103	119.8
C-012	59	88	8.6
C-013	171	122	46.9
C-014	164	110	53.6
C-015	237	219	103.6
C-016	440	431	336.7
C-017	201	143	88.7

[1] All results for data in units of mg/kg (ppm).

Table 3-11
Comparison of Analytical Results for Lead in Initial Food Samples

Sample ID	Description	LabTec Egypt [1]	Quanterra Labs [1]
F001-03	Powdered Milk	979	25
F001-20	Tangerine Drink	2	120
F001-21	Tomato Paste	378	46
F001-22	Vegetable Ghee	77	33
F001-31	Milk	77	14
F001-34	Ketchup	26	25
F001-40	Baladi Bread	109	90
F002-08	Flour	49	30
F002-37	Tomato Paste	77	65
F002-48	Banana Milk Drink	0.2	13
F003-18	Tomato Paste	394	170
F004-02	Baladi Bread	50	96
F004-03	Biscuits	182	160
F007-02	Foul Medanics	8.4	62
F008-06	Baladi Bread	541	430
F011-01	Flour	6.4	10
F013-04	Potato	88	28
F013-07	Rice	99	19
F013-09	Foul	12	67
F014-08	Fava Beans	52	87
F015-10	Lib Seeds (pumpkin)	168	130

[1] All results in units of μg/kg (ppb).

3.10.1 Correlation of Lead with Other Elements

The study team evaluated simple correlation coefficients between lead and each of the 16 other elements measured with EDXRF (see Table 3-12). The highest correlation (0.536) was obtained with bromine (Br). Figure 3-8 plots the lead versus bromine concentrations in the Greater Cairo dust samples, to illustrate how closely these two elements are correlated. The association between them suggests an automobile emission source for lead in Cairo's dust, as bromine is commonly added to leaded gasoline in the form of ethylene dibromide, which serves as a scavenger to remove lead during gasoline combustion. The team obtained other relatively high correlations for lead and zinc (Zn) (0.496) and lead and antimony (Sb) (0.414). The lead/zinc and lead/antimony associations may indicate an industrial source of lead. Zinc is used in a wide variety of industrial applications in Cairo, and antimony is commonly used to harden lead alloys, and is typically associated with lead in automobile batteries. Spatial distributions of the lead/bromine, lead/zinc, and lead/antimony ratios for the street dust samples are shown in Maps 4, 5, and 6, respectively. These maps are located in Appendix B.

As shown in Table 3-13, the correlations between lead and bromine, lead and zinc, and lead and antimony were not the highest correlations among the elements the team measured, indicating that in terms of the total quantity of dust, the portion containing lead is probably not the primary portion. For example, high correlations between calcium and strontium (0.826), calcium and barium (0.551) and barium and strontium (0.526) suggest that much of the dust in Greater Cairo may be derived from cement sources. Both strontium and barium are typically associated with calcium sulfate (gypsum), which is used in cement manufacturing. Other high correlations, such as those between copper and zinc (0.775), iron and manganese (0.709) and copper and nickel (0.702) indicate that various other industrial sources are possibly significant contributors to the total dust volume in Greater Cairo.

Table 3-12
Correlations Between Lead and Other Elements in Exterior Dust

Element		Correlation with Pb
Bromine	Br	0.536
Zinc	Zn	0.496
Antimony	Sb	0.414
Iron	Fe	0.368
Cadmium	Cd	0.334
Barium	Ba	0.328
Nickel	Ni	0.324
Manganese	Mn	0.300
Copper	Cu	0.264
Strontium	Sr	0.252
Titanium	Ti	0.204
Calcium	Ca	0.190
Silver	Ag	0.142
Arsenic	As	-0.076
Chromium	Cr	0.037
Vanadium	V	-0.031

fig 3-8

Table 3-13
Highest Correlations Among 17 Elements in Exterior Dust

Elements	Correlation Coefficient
Ca - Sr	0.826
Cu- Zn	0.775
Fe- Mn	0.709
Cu- Ni	0.702
Mn- Ti	0.663
Ni - Zn	0.641
Fe- Ti	0.599
Ba- Ca	0.551
Br- Pb	0.536
Ba- Sr	0.526
Pb- Zn	0.496
Sr - Ti	0.489
Ca- Ti	0.487
Ca- Mn	0.467
Mn-Sr	0.467
Fe- Sr	0.465
Cr- Ni	0.458
Pb-Sb	0.414

3.10.2 Factor Analysis

Factor analysis is a method of examining the interrelationships between many variables (factors) measured for a set of objects. In terms of this investigation, the variables represent the 17 elemental concentrations determined using EDXRF, and the objects are the exterior dust samples for which these elements were measured. Factor analysis was limited to exterior dust because this medium is likely the most important source of lead exposure among Egyptian children outside of their home. The goal of the factor analysis was to identify relationships between the variables that may be attributable to particular sources of dust.

Results of the factor analysis indicated that about 60 percent of the total variance in the data set (17 elements measured in exterior dust samples) could be explained by only four factors. Within each of these factors, the study team determined certain elements among the 17 to be more highly loaded or correlated (responsible for the majority of the variance explained by the factor) than other elements. Table 3-14 provides the most highly loaded elements for the four factors. (For ease of interpretation, only those elements with absolute loadings of 0.500 are shown.)

The most significantly loaded elements for factor 1 are calcium, strontium, and barium. Thus, factor 1 can be interpreted as representing primarily a cement source. Likewise, the most significantly loaded elements for factor 3 were bromine and lead, indicating that this factor may represent primarily an automobile emission source. Interpretation of the other two factors is more difficult; nevertheless, factor 2 (copper, nickel, and zinc) probably represents various industrial sources, while factor 4 (iron, manganese, and titanium) probably represents a natural soil source. A possible interpretation of factor 4 is that it represents wind-blown deposition of dust derived from native soils within or surrounding the Greater Cairo area, such as desert soil dust.

The factor analysis results support the source interpretations using correlation coefficients presented in Section 3.9.1. The factor analysis results, however, are generally more useful than the correlation coefficients for examining how the various possible dust sources are spatially distributed throughout the Greater Cairo area. The study team examined this spatial distribution by multiplying the standardized concentrations and loadings for each element and factor to obtain factor scores for each dust sample. The team normalized the scores to have zero mean and unit variance and plotted them on maps of Greater Cairo (see Maps 7 through 14 in Appendix B). Thus, a sample with a high positive score for a particular factor indicates a close association between the sample and factor. For example, given the interpretations described above, if a particular exterior dust sample had a high positive score for factor 3, that indicates primarily an automobile emission source for the sample. The team calculated factor scores for all exterior dust samples collected during the investigation and included them in the database available from EHP.

Maps 7 and 8 show plots of factor 1 (calcium, strontium, and barium) for exterior street dust and entry dust samples. As shown, factor 1 scores, which, as noted earlier, may represent cement dust sources, varied considerably over the Greater Cairo area.

Table 3-14
Factor Analysis Loadings - Exterior Dust

Element	Correlation (Loading)			
	Factor 1	Factor 2	Factor 3	Factor 4
Ca	0.865	--[1]	--[1]	--[1]
Sr	0.849	--[1]	--[1]	--[1]
Ba	0.786	--[1]	--[1]	--[1]
Ti	0.582	--[1]	--[1]	0.520
Mn	0.516	--[1]	--[1]	0.596
Cu	--[1]	0.900	--[1]	--[1]
Ni	--[1]	0.833	--[1]	--[1]
Zn	--[1]	0.790	--[1]	--[1]
Br	--[1]	--[1]	0.814	--[1]
Pb	--[1]	--[1]	0.784	--[1]
Sb	--[1]	--[1]	0.553	--[1]
Fe	--[1]	--[1]	--[1]	0.585
% Variance Explained	18.5	16.8	12.3	10.7

[1] Correlation less than 0.500.

Comparison of the two figures indicates that cement sources were more apparent in entry dust samples than in street dust samples. As shown in Map 8, the highest factor 1 scores generally were located in the central and southern portions of Greater Cairo. Although the factor 1 scores are highly variable, there appears to be an association between factor 1 and cement manufacturing industries located in the south, particularly in the Helwan area. This indicates that cement emissions are a primary contributor of dust in these areas.

Maps 9 and 10 display plots of factor 2 (copper, nickel and zinc) for exterior street dust and entry dust samples. The highest factor 2 scores were located primarily in the central portion of Greater Cairo. This likely reflects a greater contribution of industrial dust sources than other dust sources in the area. Some of the highest factor 2 scores were obtained for samples collected near small shops that likely generate metallic wastes.

Maps 11 and 12 show plots of factor 3 (bromine and lead) for exterior street dust and entry dust samples. The highest factor 3 scores were located primarily in the central portion of Greater Cairo. Comparison of the two figures indicates that high factor 3 scores were more prevalent in the street dust samples than in the entry dust samples, which likely reflects a closer association with automobile emissions among the former. The team obtained some of the highest factor 3 scores for samples collected from streets with very high vehicular traffic volumes. Samples with high factor 3 scores tended to have relatively high lead concentrations and relatively high bromine/lead ratios.

Maps 13 and 14 depict plots of factor 4 (iron, manganese and titanium) for exterior street dust and entry dust samples. The highest factor 4 scores generally were located in the north, south, and east portions of Greater Cairo, although their prevalence varied greatly. Almost all of the samples collected in north-central Greater Cairo (Shubra El-Khaima District) had relatively high factor 4 scores. It is likely that dust derived from native soil is a significant contributor to the total amount of dust in this area. Samples with high factor 4 scores had generally low lead concentrations.

4 ESTIMATED BLOOD LEAD LEVELS IN YOUNG CHILDREN

This chapter uses the results of the environmental lead sampling investigation and the behavioral study to estimate the potential blood lead levels of young children ($\leq$ 6 years) in Cairo. Young children are the population of most concern because they are typically more exposed to lead than older children or adults due to their natural tendency toward hand-to-mouth contact. In addition, young children are more sensitive than older children or adults to the toxic effects of lead because their neurological system is still developing.

Because the environmental sampling investigation was designed to characterize Greater Cairo's ambient environment, and the behavioral study was designed to characterize the general population of young children within Greater Cairo, blood lead levels estimated from this information will, by definition, apply only to the overall population of young children. Children living near specific lead "hot spots" or exposed as a result of a parent's occupational exposure are not specifically represented in this chapter.

4.1 Rationale for Estimating Blood Lead Levels

Blood lead levels are an important biomarker of lead exposure in children. Much of the toxicological literature detailing the health effects of lead on children relates such effects to blood lead levels. In addition, the capability to sample and measure blood lead levels is rapidly increasing on an international scale. The U.S. Centers for Disease Control and Prevention (CDC) currently maintains an International Blood Lead Proficiency Testing Program whereby laboratories in many countries participate in a monthly quality control program to ensure that blood lead levels are internationally comparable.

Although measuring blood lead levels is preferable to estimating them, estimations may be desirable for determining, based on environmental lead sampling results, whether blood lead sampling is warranted. The integrated exposure uptake biokinetic (IEUBK) model developed by the U.S. Environmental Protection Agency (see Section 4.3) is one available tool to estimate blood lead levels in populations of young children based on environmental lead data. The IEUBK model may also be used to estimate which exposure pathways are most important, even when blood lead levels are available.

4.2 Blood Lead Levels of Concern

Blood lead levels deemed to be of concern in young children have decreased since 1970, as illustrated in Figure 4-1. This reduction is based on research indicating that even low

fig 4-1

blood lead levels ($\leq$10 μg/dL) are associated with learning disabilities and loss of IQ points. The more gross symptoms of childhood lead poisoning, such as lead lines on teeth and bones, reduced growth, and hearing problems, have been recognized for some time and are relatively easy to identify.

Assessing learning disabilities and IQ effects, however, requires more sophisticated measurement tools that are not widely available or universally agreed upon. The weight of evidence demonstrating significant neurological effects at even low levels of lead exposure, however, is great enough that blood lead levels exceeding 10 μg/dL are of concern.

4.3 The IEUBK Model

The IEUBK model for lead uptake in children is a stand-alone, PC-compatible software package developed by the U.S. EPA (EPA 1994). It allows the user to estimate, for a population of young children, a plausible distribution of blood lead concentrations, based on available information about the children's potential exposure to lead. From this distribution, the model estimates the probability that blood lead concentrations in the population will exceed the user-selected level of concern if exposure occurs at the environmental concentrations assumed in the model. The selected level of concern used in this report is 10 μg/dL. The user can then evaluate an array of possible changes in environmental concentrations that would reduce the probability that blood lead concentrations would exceed the level of concern.

The uptake, retention, and excretion of lead in the body is a complicated process shown conceptually in Figure 4-2. The oval shapes show examples of media, such as soil and dust, while the large rectangle illustrates the compartment which is central to lead distribution in children, the blood plasma pool and associated extracellular fluid. The lower rectangles show various locations in a child's body where lead may be retained, including the kidneys and liver. Excretion mechanisms are shown as circles.

The primary value of the IEUBK model is that it permits the user to make rapid calculations and recalculations of a very complex set of equations that includes many exposure, uptake, and biokinetic parameters. This ability is valuable in evaluating the significance of, or potential risk posed by, various environmental media. In addition, climate and behavioral variations may also cause variations in intake exposure assumptions, such as the amount of soil or dust ingested per day.

Table 4-1 lists selected IEUBK model default values and modifications based on the Lead Exposure Abatement Plan (LEAP) environmental lead data and behavioral study. (A complete listing of all default assumptions in the model is presented in Appendix C.) It has been determined through calibration and validation that the model comes closest to predicting actual blood lead levels when mean values or values that represent the central tendency of the data are used for all parameters. Based on the LEAP environmental lead data, results from the behavioral study and previous air data, the default environmental lead values and intake assumptions have been adjusted as described in the next two sections.

fig 4-2

Table 4-1
Selected IEUBK Model Default Values with Modifications Based on Cairo Data

Parameter	Units	Default Value*	Modification Based on Cairo Data
Air			
Outdoor air lead concentration	$\mu g/m^3$	0.10	3.4
Time outdoors	hours/day	1-4	none
Inhalation rate	m^2/day	2-7	none
Diet			
Dietary lead intake	μg Pb/day	5.5-6.3	66.8 (median)**
Drinking Water			
Lead concentration in drinking water	μg/L	4	none
Drinking water ingestion rate	L/day	0.2-0.6	none
Soil and Dust			
Concentration Soil Dust	 μg/g μg/g	 200 200	 74 (median) 192 (median)
Soil/dust ingestion rate	g/day	0.09-0.14	0.12-0.18***

* Some default values are constant over the six year age range and are represented by a single value. Values assumed to change from year to year are represented by a range of values.

** See Section 4.4.2 and Tables 4-3 and 4-4.

*** The behavioral study indicated that soil/dust ingestion rates are likely to be higher than the default values for the model due to the dry climate and the lack of vegetation in children's play areas. Based on the qualitative observations in the behavioral study, a 30% increase in soil/dust ingestion rates was assumed.

4.4 Environmental Media Concentration Exposure Assumptions

Tables 4-2 to 4-5 provide statistical summaries of the LEAP environmental lead data. The following sections describe how the data are used to develop exposure assumptions for input to the IEUBK model.

4.4.1 Soil, Exterior Dust, Drinking Water, and Exterior Paint

Table 4-2 provides minimum, maximum, median, and mean values for soil, exterior dust, and drinking water samples. Lead was not detected in the exterior paint samples. Fifteen samples of interior paint were collected. Of these 14 samples were less than 5,000 ppm lead content which is the U.S. minimum level of concentration defined as "lead-based" paint by U.S. standards. The one sample with a value over 5,000 ppm had a concentration of 19,200 ppm. The data for soil and dust are lognormal, which results in mean values being higher than median values because of the presence of a few high values. The median values are, therefore, more representative of the central tendency of the data. Only median values are used as inputs to the IEUBK model. As noted in Chapter 3, most of the soil and dust results the team obtained were well below U.S. guidelines for cleanup, and no drinking water results exceeded the "at the tap" standard for lead in drinking water in the United States.

Most of the highest lead levels in dust occur in street dust samples in high traffic areas. These high traffic areas are distributed widely within the Greater Cairo area. However, the highest values are located in Downtown Cairo, in the Zamalek and Mohandessin areas.

4.4.2 Food

Because the first round of food sampling was a preliminary screening of more than 75 food items, sample sizes for individual food items were small. In addition, as noted in Section 3.5, there were some significant quality control (QC) problems with the first round food data which appear to have resulted in the food lead concentrations being biased high. Based on a knowledge of the laboratory procedures utilized, QC data results, and professional judgment, an "adjusted" set of food data from the first round of sampling was developed; see Table 3-7a. Additional food samples were collected in a second round of sampling to confirm the presence of lead in selected media, improve the concentration estimates, and, where possible, identify the source of lead. Results from the second round are presented in Table 3-7b.

Table 4-3 provides minimum, maximum, and median lead concentration values for the major groups of food items sampled using the "adjusted" values presented in Table 3-7a or values from the second round of food sampling presented in Table 3-7b, as noted. In order to interpret the significance of these values, it is necessary to add food ingestion or exposure assumptions, that is, the weight of food items ingested on a daily basis. Based on such information, one can then calculate a population's potential total lead intake per day from dietary sources.

Table 4-4 provides estimated daily ingestion rates for young children for each of the foods listed in Table 4-3. Rates are given in terms of kilograms consumed per day. These

Table 4-2
Lead Concentration Results Summary
For Soil, Dust, Drinking Water and Paint

Item	Units	Sample Size (N)	Minimum	Maximum	Median	Mean	Standard Deviation	Guidelines
Soil	mg/kg	180	5	1,537	74	128	168	500[1]
Exterior Dust	mg/kg	411	11	2,199	191	268	272	NA[2]
Drinking Water	μg/L	90	0.3	11	1	2	2	15[3]
Exterior Paint	mg/kg	16	ND[4]	1,326	97	347	467	NA[2]
Interior Paint	mg/kg	15	0.02	19,200	370	2,151	4,879	5,000[5]

1 U.S. Environmental Protection Agency 500 mg/kg guideline suggests no action required for residential areas. 1,000 mg/kg is a value where some action is typically taken in residential areas, e.g. reducing exposure by covering soil or planting vegetation.
2 Not available.
3 United States "at the tap" drinking water standard.
4 Not detected.
5 In the U.S., paints containing 5,000 mg/kg or more lead are considered "lead-based."

Table 4-3
Lead Concentration Results Summary for Food
(in mg/kg-wet weight)

Food Item	Sample Size (N)	Minimum	Maximum	Median
Fresh bread[1]	47	0.037	1.5	0.240
Fresh produce[1]	81	0.005	10.1	0.026
Milk[1]	30	0.005	0.280	0.016
Dairy Products (other thanmilk)[1]	25	0.006	1.20	0.036
Grains (without bread)	22	ND	0.252	0.085
Beef/fish/poultry	12	0.027	0.267	0.134
Tomato pastes	3	0.019	0.077	0.026
Canned food	16	0.001	0.119	0.068
Herbs/oils/butter	22	ND	0.232	0.009
Processed food	22	ND	0.243	0.090
Drinks (without milk or water)	2	ND	0.002	0.001

[1] Based on data from second round of food sampling (see Section 3.5).

ND=Not Detected

Table 4-4
Food Ingestion Assumptions and Lead Intake Estimates

Food Item	**Ingestion Rate kg/day**	**Ingestion Assumption** (equivalent to)	**Lead Intake Rate[1] Median Value μg/day**
Fresh bread	0.12	5 slices of packaged bread/day	28.8
Produce	0.16	2 (80g) servings/day	4.2
Milk	0.4	2 (200ml) servings/day	6.4
Dairy (without milk)	0.1	2 (50g) servings/day	3.6
Grains (without bread)	0.1	2 (50g) servings/day	8.5
Meat/fish/poultry	0.05	1 (50g) serving/day	6.7
Tomato paste	0.02	1 (20g) serving/day	0.5
Canned food	0.05	2 (25g) servings/day	3.4
Oil/butter	0.02	1(20g) serving/day	0.2
Processed food	0.05	2 (25g) servings/day	4.5
TOTAL	1.07	1070g food/day	66.8[2, 3]

[1] This value is calculated by multiplying the median lead concentration (mg/kg) in Table 4-3 times the ingestion rate (kg) and multiplying by 1,000.

[2] Following are the provisional tolerable total daily intake levels (PTTILs) for lead recommended by the United States Food and Drug Administration. These values are based on the current lowest observed effect levels of lead in blood for adults (30 μg/dL) and infants, children and pregnant women (10 μg/dL):

Adults: 75 μg of lead per day
Pregnant Women: 25 μg of lead per day
Infants and Children: 6 μg of lead per day

[3] The current Egyptian Standard for allowable daily intake of lead is 500 μg/day for a 70 kg adult and 35 μg/day for a 10 kg child (see Section 4.4.2).

Table 4-5
Lead Concentration Results Summary
for Ceramics Leachate, Cosmetics, and Medicine

Item	Units	Sample Size (N)	Minimum	Maximum	Median	Mean	Standard Deviation
Ceramics Leachate	μg/L	11	13	47,160	1,951	9,507	15,250
Cosmetics (kohl)[1]	mg/kg	14	104,000	629,000	250,000	295,000	170,000
Medicine	μg/kg	8	ND[2]	413	0.4	93	170

[1] Twenty-eight samples of kohl were collected, of which 14 had lead concentrations over 100,000 mg/kg, and 14 had concentrations under 1,000 mg/kg. High concentration samples are made from galena, which is essentially pure PbS. Summary statistics are reported for the group of high concentration samples only.

[2] Not detected.

ingestion rate assumptions are based on a recent nutrition study in Cairo (Kirksey et al. 1992) and a U.S. Program for Women, Infants and Children (WIC). The resulting lead intake rates per day (in micrograms of lead per day) are based on median food lead concentration values. The ingestion assumptions that are the basis for the ingestion rates are also provided in Table 4-4. Based on food samples analyzed for this investigation and the ingestion assumptions provided in Table 4-4, the average total lead intake from dietary sources among young children in Cairo is approximately 67 µg/day.

Clearly, these ingestion assumptions are overestimates for infants (0-1½ years) which, in turn, may result in somewhat overestimated lead intakes for the 0-6 year age range. However, there is evidence, based on six mothers selected randomly in Cairo, that lead intake from breast milk alone could average 58 µg/day (Saleh et al. 1996a). This evidence suggests that the estimate of total daily intake (67 µg/day) may be appropriate even for some infants.

The default value in the IEUBK model for lead intake from dietary sources ranges from 5.5 to 6.3 µg/day for the 0-6 age range. This value is based on national "market basket" surveys in the United States and approximates the U.S. Food and Drug Administration's recommended provisional tolerable total daily intake (PTTDI) level for lead for infants and children of 6 µg/day.

Currently, the Egyptian Agency for Standardization (Government of Egypt), Egyptian Standard (2360-1993) for the Maximum Allowable Limits for Heavy Metals in Food, specifies a maximum allowable weekly intake of lead per kg of body weight. For adults, the allowable weekly intake is 0.05 mg/kg and for children it is 0.025 mg/kg. For a 70 kg adult and a 10 kg child, the allowable daily intake levels would be approximately 500 µg and 35 µg, respectively.

4.4.3 Ceramics Leachate, Cosmetics, and Medicine

Table 4-5 provides a summary of the lead concentration values for the ceramics leachate, cosmetics, and medicine samples. These values would need to be combined with ingestion assumptions or, in the case of cosmetics, dermal uptake assumptions in order to estimate quantitatively lead uptake in children from these sources. Such an analysis was not done for this study; however, these items are clearly additional potential sources of lead exposure for children. Ceramics with leaded glazes and kohl, in particular, have been identified in other countries as important sources of lead exposure; even though the amount of lead exposure from these sources is difficult to quantify, use of these substances has often been correlated with elevated blood lead levels in children (Romieu et al. 1995, Parry and Eaton 1991). Any blood lead studies of children in Cairo should include surveys regarding the nature and frequency of use for these items.

4.4.4 Ambient Air

At least six studies of lead in suspended particulates collected from ambient air were conducted in the Greater Cairo area between 1982 and 1996. EHP chose to use information from these studies rather than conduct additional ambient air sampling as part of the LEAP investigation. The weight of evidence indicates that using a value of 3.396 $\mu g/m^3$ is appropriate for characterizing exposure to children throughout Greater Cairo. The six studies are summarized and discussed in Section 5.1.1.

4.5 Behavioral Exposure Assumptions

The LEAP behavioral study (Guenena 1996) indicated that soil/dust ingestion rates among young children likely are higher than the default values for the IEUBK model because of Cairo's dry climate and the lack of vegetation in most children's play areas. Some of the behavioral observations suggest frequent and relatively high exposures to soil and dust (compared to more temperate and vegetated play areas for children where the default assumptions were set for the IEUBK model).

- In Cairo, children spend a good part of their time walking to and from school, and this is also the time when they play, buy various food items from street vendors, and are exposed most to soil and dust.
- Two games were by far the favorites of school children: football in the case of boys; and hopscotch in the case of girls, a game in which they pick up a stone and throw it inside a diagram drawn on the ground. Younger children were found to play with marbles. These are all games that include direct contact with the ground and stir up a lot of dust. Other games and activities include running after each other, hide and seek, or riding swings. Children often use swings while holding a sandwich, a packet of potato chips, or a candy bar in their hands.
- It was often noted that even when food fell on the ground, it was picked up and eaten. This frequently happened in the presence of parents, who didn't try to stop their children from such behavior.
- Playgrounds in public schools are crammed with children during breaks, which only last for an average of 20 minutes per day. Unless there is a physical education lesson, children have little room to play and move around freely. However, breaks are a time when children bring out their packed lunches, and when soil and dust disturbances occur.
- Generally speaking, children play much more often on dusty ground than in green areas. In many public parks and in the Cairo Zoo, it is prohibited to play or sit on the grass. For upper- class children, on the other hand, outdoor recreational activities mainly take place in private clubs where there are large green areas for their use.
- Hand-mouth contact is frequent among children of all classes, especially among the younger ones. Children often pick up food items they have dropped on the floor and resume eating.

Based on the qualitative observations made in the behavioral study, the study team assumed a 30 percent increase in soil/dust ingestion rates, as shown in Table 4-1, over the default values in the IEUBK model.

4.6 Estimated Blood Lead Levels

As noted earlier, Table 4-1 summarizes selected inputs to the IEUBK model, including those modified based on the LEAP environmental lead data and behavioral study. Table 4-6 provides estimated values for blood lead and lead uptake for children six years of age and under, based on the IEUBK model. Figure 4-3 illustrates the results as a probability density function.

Using the median values for environmental lead concentrations presented in Table 4-6, estimated mean blood lead levels for young children range from 14.4 μg/dL for children under 1 year to 10.8 μg/dL for children between 5 and 6 years old. The results indicate that approximately 64% of children 6 years and under have blood lead levels over 10 μg/dL, and approximately 14% have blood lead levels over 20 μg/dL.

4.7 Health Implications

Figure 4-4 illustrates observed levels at which inorganic lead affects children's health and identifies some of the potential health and neurological effects. Even low blood lead levels have several potential adverse health effects on children. A series of 14 peer-reviewed studies by several authors from different institutions support the hypothesis that decrements in children's cognition occur at blood lead levels well below 25 μg/dL, even though some inconsistencies can be found among these studies. A 1991 report by the CDC describes the studies' findings at great length. According to CDC's report, *Preventing Lead Poisoning in Young Children*, among the data measured in the studies were the mean IQ scores (in most cases adjusted for potential confounding factors) achieved by children with different blood lead levels. The studies (illustrated in Figure 4-5) give no threshold for the lead-IQ relationship, meaning that any amount of lead is expected to have some adverse effect on cognitive ability. Most of these investigators reported lower IQ scores among the more highly exposed children. Specifically, a 1990 meta-analysis of 24 studies by Needleman and Gatsonis, cited in the CDC report, strongly supports the hypothesis that children's IQ scores are inversely related to their lead burden.

It is important to note the overall population effect of lead levels in children: lead exposure resulting in a downward shift of only 4 to 6 points in mean IQ scores substantially increases the prevalence of children with severe deficits (those with IQ scores less than 80). This effect is of concern not only to individual parents and families, but to school districts, education ministries, and society as a whole.

4.8 Uncertainties

As discussed previously, actual blood lead measurements are the most direct and convenient measure of lead exposure in young children. Environmental lead data combined in a biokinetic model with exposure assumptions can provide only an indirect estimate of blood lead levels for the population of children assumed to be exposed within the area where the sampling occurred.

Table 4-6
Estimated Blood Lead Levels and Lead Uptake Rates
Based on Median Environmental Lead Values

Year	Blood Level (μg/dL)	Total Uptake (μg/day)	Soil+Dust Uptake (μg/day)	Diet Uptake (μg/day)	Water Uptake (μg/day)	Paint Uptake (μg/day)	Air Uptake (μg/day)
0.5-1	14.4	27.95	3.62	23.32	0.29	0.00	0.72
1-2	13.5	31.94	5.67	24.34	0.76	0.00	1.17
2-3	12.3	33.98	5.87	25.19	0.81	0.00	2.11
3-4	12.0	35.13	6.05	25.96	0.85	0.00	2.27
4-5	11.3	34.55	4.52	26.85	0.92	0.00	2.27
5-6	10.8	35.69	4.15	27.39	0.99	0.00	3.17

fig 4-3

fig 4-4

fig 4-5

In addition to being an indirect estimate of blood lead levels, there are several sources of uncertainty in using environmental data and exposure assumptions. Some may clearly contribute to overestimating lead exposure, such as a pattern of high bias in environmental data, while the impact of others may be unknown, such as environmental data with a high degree of variation.

Several sources of uncertainty are associated with the Cairo environmental data and the exposure assumptions. While some significant factors have likely resulted in overestimates of exposure, others, such as assumed soil/dust ingestion rates, may have resulted in underestimates of exposure. The most significant sources of uncertainty and their potential impact on estimated blood lead values are summarized in the following sections.

- **Food Data**

  Data quality sample results for soil, dust, and drinking water were well within acceptable limits indicating that these results are reliable; however, those for the first round of food samples were often outside of acceptable limits and suggest that the sample results were biased high approximately 10 percent of the time.

  Because the first round of food sampling was a preliminary screen of more than 75 different types of food, sample sizes were small for some individual items, such as milk (5 samples) and bread (10 samples). Thus, it was difficult to distinguish between anomalous values, resulting from identified laboratory quality problems, and outliers, which represent true variation in the media being sampled.

  As described in Section 3.5, a second round of food sampling was undertaken to confirm estimated concentrations of lead in selected food items. Confidence in the data from the second round of sampling is high, and these data were used in estimating child blood lead levels.

- **Unidentified/Unmeasured Sources of Lead Exposure**

  Some potential sources of lead exposure, such as ceramics and kohl, could not be quantitatively included in the model at this time. Clearly, these other sources could significantly add to the lead burden for children, and their exclusion represents a potential underestimation of total lead exposure to children.

  In addition, there is evidence, based on samples from six mothers selected randomly in Cairo, that infants' lead intake from breast milk alone could average 58 μg/day (Saleh et al. 1996a). This evidence would indicate that the ingestion assumptions for infants, although not accurate for food type, may be close to reality for overall lead intake.

- **Assumed Soil/Dust Ingestion Rates**

  Based on qualitative information from the LEAP behavioral study, the assumed soil and dust ingestion rates for children were increased 30 percent over the default value in the IEUBK model. While it is doubtful that soil ingestion rates are lower than assumed, they may be higher. Therefore, the assumed soil and dust ingestion rates may underestimate lead exposure.

- **Food Ingestion Rates**
  The assumed food ingestion rates are not Cairo- or Egypt-specific and represent a source of uncertainty. Whether they represent a potential overestimate or underestimate of exposure is unknown.

5 COMPARISON WITH OTHER ENVIRONMENTAL AND BIOLOGICAL LEAD STUDIES IN EGYPT

A number of studies of environmental and biological lead have been conducted in Egypt over the past 20 years. Many, but not all, of these studies are discussed below. A full list of references with abstracts of lead studies in various media and populations in Egypt (found in a search of Pollution Abstracts and MEDLINE completed on 10 December 1996) is available from the EHP library. All of the studies cited below were conducted prior to late 1996, when sales of leaded gasoline in Cairo were halted. These studies were conducted by different investigators, among different populations and sites, in different years and seasons of the year, with different methods of sampling and analysis. Thus, direct comparison of data and results from one study to another is often problematic. However, as a whole, the set of studies summarized in this chapter give a general sense of the range of environmental and biological lead information available on Greater Cairo and other parts of Egypt.

In addition to the Egypt studies, Section 5.5 discusses the results of an environmental urban lead exposure and blood lead level study in Mexico City. This study is one of the only studies similar in scale to the LEAP investigations.

5.1 Environmental Media Studied

5.1.1 Ambient Air[2]

This section summarizes data on lead concentrations in ambient air collected as part of various studies in the Greater Cairo area between 1982 and 1996. In total, the six studies reported 25 separate annual mean concentrations representing different locations in Greater Cairo. For 23 of the locations, the annual mean lead concentration ranged from 0.15 to 3.396 $\mu g/m^3$. The other two locations had reported annual means of 17.250 (Shobra El Kheima) and 86.9 (El Waily) $\mu g/m^3$. These results warrant further explanation in considering their applicability to this assessment.

The results from Shobra El Kheima (IGSR 1996) appear to be significantly influenced by local smelter activity and, therefore, are characteristic of a "hot spot" rather than of Greater Cairo. The results from El Waily (Shakour and El-Taieb 1994) are more problematic. First, the values in this study are more than an order of magnitude higher than values reported from any of the five other studies. The El Waily district is reported to contain three secondary lead

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[2] It should be noted that the prevailing winds in Cairo emanate from the north-northwest. (From Rodes and Nasralla et al. 1996, Volume II, Table 5).

smelters which, if active at the time of the air sampling and if the air sampling station was located downwind, could be responsible for the high reported values. Assuming that this was the case, this location would also represent a "hot spot" rather than ambient conditions in Greater Cairo. An alternative explanation is that the laboratory experienced quality control problems and the results are biased high. It is worth noting that the Institute of Graduate Studies and Research study (IGSR 1996) reported an annual mean of 1.610 $\mu g/m^3$ from the El Waily district, based on measurements taken between December 1995 and March 1996. The authors do not know whether there was any change in smelter activity prior to December 1995 which would explain the difference in results.

It is appropriate for the air value used in the IEUBK model (EPA 1994) to be conservative, i.e., more likely to overestimate rather than underestimate ambient air lead concentrations for Greater Cairo. Because this assessment is intended to characterize lead exposure in the general populace, however, it would not be appropriate to use values that reflect "hot spots." The weight of evidence regarding annual mean air lead concentrations in Greater Cairo suggests that using a value of 3.396 $\mu g/m^3$, the highest mean value recorded in 23 of the 25 stations, is appropriate for the model-based analysis described in Chapter 4.

Results from each of the six studies are summarized below.

Ali et al. (1986) reported ambient lead concentrations in air particulates at five stations in Greater Cairo measured over a one year period (September 1983 to August 1984):

Station	**Minimum ($\mu g/m^3$)**	**Maximum ($\mu g/m^3$)**	**Mean ($\mu g/m^3$)**
1-city center	2.2	4.9	3.0
2-residential	1.2	1.8	1.4
3-residential	0.5	0.7	0.6
4-commercial/residential	1.9	2.6	2.2
5-residential/industrial	1.2	1.4	1.3

As was the case with a later study (Nasralla et al. 1994; see below), the minimum and maximum concentrations represent seasonal means and the mean represents the annual mean. The report states that the air samples were taken at 6±2 m above street level.

Ali and Nasralla (1990) conducted a study of lead concentrations in human hair as a bioindicator of exposure. As part of this study, they also collected air particulate samples in each of three Greater Cairo districts:

Station	Minimum ($\mu g/m^3$)	Maximum ($\mu g/m^3$)	Mean ($\mu g/m^3$)
1-residential/commercial (Abdeen, Azbakia and Monira districts)	NA*	NA*	1.5
2-residential/industrial (Imbaba and Shoubra El Keima districts)	NA*	NA*	1.3
3-residential (Dokki district)	NA*	NA*	0.8

* NA = not available

The ambient air particulate samples were reportedly collected over a 24-hour period once per week during the one year (1988) study. This report provided some additional information regarding Station 2, in that the Imbaba and Shoubra El Keima districts contain relatively more industrial activity (in addition to similar high traffic volume), i.e., relatively more foundries and smelters. However, since Stations 1 and 2 both had similar mean air lead levels, it appears that local industrial activity at Station 2 did not significantly affect ambient lead particulate concentrations measured at this station.

Nasralla et al. (1994) reported ambient lead concentrations in Cairo air particulates measured at three different stations during 1990-1991:

Station	Minimum ($\mu g/m^3$)	Maximum ($\mu g/m^3$)	Mean ($\mu g/m^3$)
1- residential/commercial	1.65	2.10	1.83
2- city center	2.07	3.80	2.97
3- residential	0.31	0.77	0.48

The minimum and maximum concentrations represent seasonal means (averaged over a 3-month period), while the mean represents the annual mean (averaged over the entire year). The mean annual lead concentration for all three stations over the one-year study period was 1.76 $\mu g/m^3$. The exact locations for these three stations were not provided; however, they likely all were located within Greater Cairo.

Shakour and El-Taieb (1994) measured lead in blood samples (adolescents and adults) and in ambient particulate samples from an industrial/residential area (El Waily district) of Greater Cairo. The El Waily district where the air particulates were collected reportedly contains three secondary Pb smelters. Twenty-four hour air particulate samples were collected from a position 10 m above the ground level twice per week for three months. The report also presents data from two other studies (Shakour, 1982; Shakour and Hindy, 1992) where air particulate lead measurements were conducted at other Greater Cairo districts. Results presented in this report are as follows:

Station	Minimum (μg/m^3)	Maximum (μg/m^3)	Mean (μg/m^3)
1-residential/industrial (El Waily district)	14.6	220	86.9
2-city center	--	--	2.8
3-residential (El Maadi district)	--	--	0.15

Ambient lead concentrations obtained at Stations 2 and 3 are similar to lead concentrations obtained at other areas in Greater Cairo. However, lead concentrations reported for air particulates collected at Station 1 are between 10 and 100 times higher than levels measured in other studies. The report concludes that this is due to the influence of secondary lead smelting activities in this area.

The University of Alexandria, Institute of Graduate Studies and Research (IGSR) monitored particulate air lead concentrations at several stations in Greater Cairo (in addition to stations in three other major Egyptian cities) between December 1995 and March 1996. Stations were grouped into two general categories: vehicular emission sites (VES) and industrial emission sites (IES). Sampling at each station was conducted over a 7-day period using high-volume samplers to collect 24-hour particulate samples. Results of this study were as follows:

Station	Minimum (μg/m^3)	Maximum (μg/m^3)	Mean (μg/m^3)
1-Ramsis Square (VES)	2.303	4.751	3.396
2-El Ataba Square (VES)	1.530	4.882	2.560
3-El Giza Square (VES)	0.652	1.448	1.057
4-Shobra El Kheima (IES)	8.190	31.024	17.250
5-El Waily (IES)	0.665	2.130	1.610
6-El Matarya (IES)	0.385	2.700	2.560

The average 24-hour lead concentration for all six stations was 4.74 μg/m^3. Excluding Station 4, which appears to be significantly influenced by local smelter activity, the average ambient lead concentration was 2.24 μg/m^3. Except for Station 4, these results compare well with results reported from previous studies. Note that the ambient Pb concentrations measured at Station 5 (El Waily district) do not agree with the results reported by Shakour and El-Taieb (1994).

Rodes et al. (1996) also measured ambient air lead concentrations at various Cairo locations as part of a source apportionment study:

Station	**Minimum (μg/m^3)**	**Maximum (μg/m^3)**	**Mean (μg/m^3)**
B-Background (Thebes School, near Airport)	0.170	0.695	0.359
C-City Center	0.733	1.440	1.002
M-Maadi District	0.088	0.458	0.235
S-Shobra El Kheima	0.467	0.512	0.490
T-Tabeen Institute (Helwan)	0.367	0.811	0.491

The above data are for PM_{10} particulate samples, rather than total suspended participates as most likely is repeated in all of the other studies. Table 4-2 of the report also presents data for a 7-day composite collected from Station C, in which a PM_{10} lead concentration of 2.5 μg/m^3 was measured.

Sessions et al. (1994), in the context of a comparative analysis of environmental health risks in Cairo, concluded from the evidence available at that time that a reduction of particulate lead in Cairo air to natural background levels would reduce the number of deaths from cardiovascular disease attributable to lead by 6,300 to 11,100 deaths per year, and improve children’s mean IQ scores by 4.25 points.

5.1.2 Settled Dusts

As noted above, IGSR studied lead in street dust and in suspended particulate matter from ambient air in Cairo, Alexandria, Tanta, Assuit, and Fuka. With respect to lead in roadside dust (measured in parts per million, or ppm), IGSR findings are shown in Table 5-2.

The highest lead level in street dust associated with a traffic source was 900 ppm, in Ramsis Square in Cairo, while the highest lead level in street dust associated with an industria source (smelters) was 9,125 ppm,[3] in Shoubra El-Kheima. Alexandria’s lead levels in street dust, for both industrial and traffic sites, were all below the levels found in Cairo.

[3] In comparing data reported here, note that 1 ppm = 1 mg/kg = 1 μg/g.

According to a separate study in the El-Waily and El-Maadi residential areas of Cairo from May to July 1992 by Shakour and El-Taieb (1994), the mean concentration of lead in street dust was 1,965.7 ppm in El-Waily and 239.5 ppm in El-Maadi.

Table 5-2
Lead Concentrations in Road Dust at Traffic and Industrial Sites in Some Egyptian Cities
(in ppm)

Location	Activity	Site	Concentration (ppm = mg/kg)
Greater Cairo	Traffic	Ramsis El-Ataba Giza	900 820 557
	Industrial	Shoubra El-Kheima El-Waily El-Mattarya	9,125 850 520
Alexandria	Traffic	El-Shohada Square Victoria Square Sidi Gaber	390 231 200
	Industrial	Hagar El-Nawatya El-Sabahya El-Mex	430 350 295
Tanta	Traffic	El-Bahr St. El-Nahhas St.	720 720
Assiut	Traffic	El-Mahatta Om-El-Batal	150 145

Source: IGSR 1996, p. 23

Ali (1991) found that lead concentrations in dust that had settled on orange leaves (agricultural dust) reached more than 1,000 ppm in some samples collected from an orange orchard close to Cairo on the Cairo-Alexandria highway; the concentrations decreased the farther the sampled trees were located from the highway edge.

In a later study of lead deposition (dust fall) on 12 sites in El-Waily in the vicinity of a secondary lead smelter in northeast Cairo, before and after the smelter's closure in 1994, Shakour and El-Taieb, Paper A (n.d.), found that lead was deposited at the rate of 5.7 mg/m^2/day prior to the smelter's closure. After the smelter closed, the rate dropped to 1.8 mg/m^2/day, a 68% decrease.

In a 1993–94 dust fall study in seven sites in the industrial area of Shoubra El-Kheima, Shakour and El-Taieb, Paper B (n.d.), found that lead deposition ranged from 78.5 to 785.3 $\mu g/m^2$/day (Table 1). The same paper (in the Abstract) also refers to the deposition rate as 78.4 to 795.3 *grams*/m^2/day. Because of this contradiction in units of measurement, this study is not useful.

Table 5-3 summarizes the settled dust lead concentrations found in Greater Cairo and its immediate environs in the LEAP study and others. As noted in Section 3.1, in 411 samples of exterior dust in Greater Cairo, EHP found a mean lead concentration of 268 mg/kg (ppm), a median of 191 mg/kg, and a range of 11 to 2,199 mg/kg. The IGSR (1996) study in Cairo found a mean of 759 mg/kg, and a range of 557 to 900 mg/kg at heavy-traffic sites; and a mean of 3,498 mg/kg and a range of 520 to 9,125 mg/kg at heavy-industry sites. Shakour and El-Taieb (1994) found a mean of 1,965 mg/kg at the industrial site of El-Waily, and a mean of 239 mg/kg in the predominantly residential area of El-Maadi.

Table 5-3
Lead Concentrations in Settled Dust in and around Greater Cairo*
(in ppm)

Study	Site(s)	Mean	Median	Peak	Range	No. of Sampling Sites
LEAP	Greater Cairo, street dust	268	191	2,199	11 - 2,199	411 (random samples)
IGSR 1996	Greater Cairo, high traffic	759	—	900	557 - 900	3? (selected for high traffic)
IGSR 1996	Greater Cairo, heavy industry	3,498	—	9,124	520 - 9,125	3? (selected for heavy industry)
Shakour and El-Taieb 1994	El-Waily, industry	1,965	—	—	—	? (selected for heavy industry)
Shakour and El-Taieb 1994	El-Maadi, residential	239	—	—	—	? (selected for residential)
Ali 1991	Cairo-Alexandria highway, orange orchards	—	—	> 1,000	—	? (selected for high traffic)

* Note: 1 mg/kg = 1 ppm = 1 μg/g.

5.1.3 Soils

In a study of cultivated areas in southern metropolitan Cairo (Helwan, Hawndia, Eltebin, and Elsaf) where several lead and zinc smelters, power stations, cement plants, and fire brick factories and a major highway are located, Ali, Ibrahim, and Nasralla (1992) found high concentrations of lead in agricultural soil and on cultivated plants. Lead was found at a peak concentration of 1,076.2 ppm in soil in sites within 500 meters of the lead and zinc smelters. High concentrations of lead extended up to 10 km downwind from the smelter sites. The authors noted that the fire brick factories, the smelters, and automobile traffic (leaded gasoline) contributed to the high lead concentrations in the study area. They attributed the high concentrations of lead in soil near the main highway (range of 176.6 to 230 ppm) and lower concentrations in soil away from the main highway (range of 8.5 to 30.5 ppm) to leaded gasoline pollution from vehicular traffic.

In comparison, Section 3.2 describes the results of the EHP team's soil sampling from parks, squares, and other sites that children frequent in Greater Cairo. In the 180 samples analyzed, the lead concentration ranged from 5 to 1,537 mg/kg (ppm), with a mean of 128 mg/kg and a median of 74 mg/kg of soil. The team found that the concentration of lead in urban soil in Cairo is much lower than the concentration of lead in settled dust (street dust).

5.1.4 Food and Vegetation

Nasralla and Ali (1985) tested edible plants (tomato, pepper, carrot, radish, lettuce, and cabbage) for lead contamination; the crops were grown in agricultural fields in the Nile Delta next to six highways experiencing different traffic densities. The sampling transects originated next to the highway and terminated 130 meters from the roadside. Lead concentrations in tomatoes and lettuce generally decreased the farther away from the highway the plants were located. The authors attributed the gradient to lead deposition from gasoline emissions from vehicular traffic. The study also proposed that lead uptake may occur through roots and foliage. The authors noted that leafy vegetables, with their high lead concentrations, posed the greatest health risk. These usually exhibited higher mean concentrations of lead than other plants in their roots. However, the tops of leafy vegetables (lettuce, cabbage) and root vegetables (radish, carrot) contained high lead levels. For roots, the concentrations were 34.2 to 63.4 mg/kg (ppm) for lettuce and 34.3 to 57.8 mg/kg for cabbage, compared with carrots and radishes (1.5 to 6.1 mg/kg and 1.6 to 7.2 mg/kg, respectively). For tops, the concentrations were 13.3 to 43.3 mg/kg for lettuce and 7.5 to 24.9 mg/kg for cabbage, compared with carrots and radishes (12.5 to 42.7 mg/kg and 14.2 to 46.6 mg/kg, respectively).

Ali (1991) found the concentration of lead ranged from 2.2 to 27.5 μg/g (dry weight) in peeled naval oranges collected from four orange orchards adjacent to the Alexandria-Cairo highway near Cairo. On the peel itself, lead concentration varied from 4.2 to 31.2 μg/g (dry weight). The concentration varied according to the distance of the sampled trees from the highway; lead concentrations were higher the closer the sampled trees were to the highway. The authors attributed the gradient to lead deposition from gasoline emissions. Lead in the orange leaves themselves reached a high of 296 μg/g.

Ali, Ibrahim, and Nasralla (1992) found concentrations of lead on two species of vegetation in the highly industrial area of Helwan and environs. Lead concentration on washed leaves of *Raphanus sativus* was about 15 ppm (of leaf) at one site. In contrast, lead concentrations on the leaves of the grass *Demostachya bipinnata* ranged from about 950 ppm at a distance of 500 meters from a lead and zinc smelter complex to a low of 200 ppm at 2,500 meters from the complex. Both plant species also absorbed some lead into their roots and shoots: about 10 ppm in the root of *R. sativus*, and about 1,500 ppm in the root and shoot of *D. bipinnata*.

A study by Rakha, El Haleim, and Fricke (1994) in Egypt examined 11 raw vegetable and 7 raw fruit types, 3 types of canned fruits, and 4 types of canned vegetables (with lead-soldered and unsoldered electric-sealed cans) for presence of lead and other contaminants. Lead was found in the fruit juices from lead-soldered cans at concentrations ranging from 19 ppb to 926 ppb (wet weight), and in the electric-sealed cans from 4 ppb to 906 ppb (wet weight). They also found lead concentrations in fresh vegetables ranging from 4 ppb to 666 ppb (wet weight) for leafy parts, and from 4.2 to 134 ppb (wet weight) for the "fruit" portions of fresh vegetables.

The results of food sampling conducted in the EHP study are presented in Section 3.5 and Table 4-3, above. Median lead concentrations[4] ranged from a low of 0.001 mg/kg (wet weight) in bottled beverages to highs of 0.134 mg/kg in beef/fish/poultry, 0.090 mg/kg in processed foods, 0.076 mg/kg in fresh produce, and 0.072 mg/kg in fresh bread. Our study found high lead levels in some fresh produce (vegetables and fruits), though generally at lower concentrations than the levels reported by Nasralla and Ali (1985) and Ali (1991). The implications of high lead concentrations in foods often consumed by young children are discussed in Sections 4.4.2 and 4.7 above.

5.1.5 Milk

The EHP team was not able to identify any prior studies of lead concentrations in milk. There have been at least two studies of lead concentrations in vegetable materials used as feed for cattle, buffalo, and goats. Belal and Saleh (1978) reported lead concentrations ranging from 1.35 ppm to 18.60 ppm in wheat stalks and sunflowers, respectively, and "high" concentrations of lead on clover and mallow in Egypt. Ali (1993) also reported high concentrations of lead in clover and mallow. These data are grounds for concern because lead can pass into the human food chain in milk from animals. EHP found low to high lead levels in milk products sold in Cairo (see Section 3.5.7); the sources may be animal feed or steps in the processing, storage, transport, or vending of milk. Also, anecdotal evidence from Cairo indicates that fresh milk is still sold by mobile milk vendors using cart, donkey, or motorbike; their unsealed milk containers and ladles are exposed to street dust and gasoline emissions during transport, and may be a source of lead contamination.

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[4] *Median* lead concentrations are discussed here rather than *mean* lead concentrations because the calculation of the mean tends to skew numbers upward or downward when there are extreme-end values.

5.1.6 Drinking Water

As noted in Section 3.3, lead concentrations in 90 samples of drinking water taken from outdoor taps did not exceed the U.S. EPA drinking water standard of 15 μg/L. The concentration of lead in water in Greater Cairo averaged 1.69 μg/L, with a median concentration of 1.27 μg/L and a range of only 0.25 to 10.9 μg/L. In Section 3.5, the small number of samples of mineral water analyzed were all at or below the detection limit of 0.2 μg/L. These data contrast with a report from Saleh et al. (1996), who suggested that leaded water pipes are a major source of lead exposure for breast-feeding mothers and children in Cairo, but provided no references or data to substantiate their claim. The authors called for a ban on leaded drinking water pipes in Egypt.

The PRIDE comparative health risk study by Sessions et al. (1994) cited a study by Zahran (1992) on lead in 116 samples of tap water from various parts of Greater Cairo, which found lead at a mean concentration of 492 μg/L. The Sessions team points out that the Zahran study "inexplicably" contradicts a 1992 Cairo Water Authority (CWA) study of lead in treated water, in which the highest concentration found was 5.9 μg/L—an 83-fold difference between the findings of the two studies. The current LEAP study results (maximum of 11 μg/L; median of 1.27 μg/L) (see Section 3.3) are in close agreement with the 1992 CWA study and indicate that lead levels in the sources sampled by EHP do not exceed U.S. EPA or WHO drinking water standards for lead.

5.1.7 Medicines and Cosmetics

The results of analyses of medicines and cosmetics are discussed in Section 3.6. There appear to be no other published studies on lead concentrations in cosmetics and medicines in Egypt. However, the EHP team found a very high concentration of lead in one of four samples of kohl, an eyeliner cosmetic that is put on the external upper and lower eyelids, and sometimes on the internal eyelids, of newborns in rural Egypt (personal communication, Dr. Halla Al-Hennawy, 1996). The team found no data on the prevalence of this practice, but anecdotal information indicates it is widespread. This practice may also be common among rural families that have recently moved to urban areas; this possibility should be carefully examined in a future behavioral study.

As an example of lead poisoning occurring from cosmetic use among urban populations, a study by Al-Saleh et al. (1996) in Arar, Saudi Arabia, reported a case of lead poisoning in a three-month old boy. The boy had had kohl applied to his eyes and to his umbilical cord stump from the time the cord fell off until the boy reached 40 days of age. The boy's blood lead level was extremely high—215μg/dL, and he received chelation therapy. The mother had also used kohl on her eyes during pregnancy, and hence maternal-fetal transmission of lead could have contributed to the boy's poisoning. Lead concentrations in food and water in the home were low. A subsequent survey of 108 children and their families in Arar described in the same study found that even after more than 40 years of urban living, many of the city's residents still used traditional cosmetics and folk medicines, including henna, bokhoor, anzroot, bint dahab, noqd, and teething powder. In the survey, 17 of 21 children who had elevated blood lead levels were found to have been exposed to kohl applied either to the eye or the umbilicus at birth.

Fernando et al., cited in Al-Saleh et al. (1996), found that Bedouins in Kuwait still burned and inhaled a mixture of lead sulphide and wood, which was claimed to help calm irritable infants and children.

In other work on kohl in the Middle East, Nir et al. (1992) found blood lead levels significantly higher among 24 infants to whom kohl was applied than among 30 infants to whom it was not applied (mean of 11.2 versus 4.3 μg/dL, respectively, $P < 0.001$); no significant differences were found in other parameters. Shaltout et al. (cited in Nir et al. 1992) reported 20 cases of lead encephalopathy in Kuwaiti infants and postulated that the source of lead was kohl.

In other countries folk medicines have been found to be sources of lead and lead poisoning (Al-Saleh et al. 1996; Nir et al. 1992; Flattery et al. 1993). Our study found two "occidental" medicines to have high lead concentrations. Further study of traditional and modern medicines sold in Egypt is warranted.

5.1.8 Pottery

The results of our leaching test analyses of paint-glazed ceramics (pottery) are reported in Section 3.7. We found no other published reports of lead concentrations in leachate from painted pottery in Egypt. Our study found a wide range of lead leachate concentrations, from 13.24 μg/liter to 47,160 μg/liter. Our results indicate that high concentrations of lead could potentially be leached into acidic foods cooked or stored in such containers.

5.1.9 Paint

We report in Section 3.4 the results of our analyses of exterior paint from 16 residential buildings in Greater Cairo. (In our study design, we did not have an opportunity to analyze interior paint samples.) The lead concentrations of the exterior paint samples analyzed were generally very low, ranging from below the detection limit of the EDXRF equipment to a high of 1,326 mg/kg (concentrations in lead-containing paints are typically 100 to 500 times higher than this). The relatively low level of lead in exterior paint may be attributable to the use of a whitewash-based paint for exterior surfaces (a limestone-and-water-based paint, readily mixed and color tinted at home by the consumer) instead of other water- or oil-based commercial paints.

We found no published studies of lead levels among paints in Egypt. However, Shakour's 1995 occupational study found workers in Egyptian paint manufacturing plants with elevated BLLs, suggesting that exposure to lead occurs in these workplaces. EHP's discussions with government and private sector officials in Cairo yielded conflicting information on the prevalence of lead in paint manufactured in Egypt in 1996; some individuals said lead is still being used in paint manufacturing, while others said that the use of lead in paint has ceased. EHP is collecting further samples of paint to help clarify this point.

5.1.10 Gasoline

We did not sample lead concentrations in gasoline because recent data are available on this subject. For example, a study by Shakour (1991) found that the commercial gasoline used in Cairo, both the 80-octane and the 90-octane varieties, had a lead content of 0.85 g/liter. The particulate matter emitted from automobiles using this gasoline contained a mean of 38.07% lead by mass, depending on the engine speed. According to Shakour, total daily emissions of lead into the atmosphere increased steadily from 1980 to 1990, from about 240 kg/day in 1980 to about 470 kg/day in 1990; the author appeared to attribute most of this increase to a rise in consumption of leaded gasoline in the city.

An unpublished 1996 USAID/Cairo Environment Office study of lead content in gasoline sold in Cairo and the Nile Delta found concentrations as shown in Table 5-4.

Table 5-4
Lead Concentrations in Gasoline in Egypt, 1996

Geographic Area Sampled	Octane	Average Lead (g/L)
Cairo	90	0.25
Alexandria	90	0.23
Nile Delta	90	0.27
Cairo	80	0.32
Alexandria	80	0.27
Nile Delta	80	0.51

According to the USAID study, the 1980 U.S. EPA regulations limited lead content to 0.5 g/gallon, or 0.129 g/L. In Europe, the standard is set at 0.15 g/L of tetraethyl lead (TEL) in gasoline. The USAID study also noted that Egypt maintains seven refineries: two each in Alexandria and Suez, and one each in Cairo, Tanta, and Assuit. The refineries in Alexandria and Suez do not produce leaded gasoline; the Cairo refinery was to have stopped producing leaded gasoline in 1996. The USAID study also noted that according to the Ministry of Petroleum, Egypt imported 1,800 tons of TEL in 1993 but only 600 tons in 1995 and the downward trend in leaded gasoline consumption in Egypt has apparently continued.

5.1.11 Newspaper

Unpublished reports in Egypt have referred to high levels of lead in newsprint, which is often used to wrap foods such as fresh breads, fish, and produce. Some are concerned that the lead could be transferred to newsprint-wrapped foods. Lead is a common component of ink, including regular newsprint ink and ink printed on high-gloss papers such as those used in magazines.

5.1.12 Kohl

Kohl is a fine powder that has the appearance of mascara and is used as an eye cosmetic by women and children in Egypt. Users apply it directly to the conjunctival surface of the eye by dipping a metal, wooden or glass applicator rod into the fine powder and streaking it across the eye ball.

Traditional preparations of eye cosmetics containing high concentrations of lead have been identified in India, Pakistan, Bangladesh, Saudi Arabia and the Sudan. There is also evidence for the use of such materials in Iran, Lebanon, and Nigeria. These materials are also known as "surma," which originates from the Urdu word for antimony. The use of kohl in Egypt can be traced to the pharoahs, when its major constituent was antimony sulphide. In recent times, however, because of the scarcity of antimony sulphide, kohl is prepared by grinding "galena," a naturally occuring mineral that is essentially pure lead sulphide. Thus, much of the kohl that is available in Egypt today contains extremely high concentrations of lead.

Various forms of kohl are available for purchase in Cairo, ranging from raw galena (PbS), to domestically prepared products, to imported products from Saudi Arabia, India, and elsewhere. The products range in color from black through various shades of grey to white, and may contain various herbs, pearls, menthol, plant juices and vegetable ash.

The principal route of exposure appears to be ingestion. When kohl is applied to a baby's eyes, the child is likely to cry or produce tears, wipe its eyes with its hands, and then suck on its fingers or hands, transfering lead from its eyes to its mouth. Healy et al. (1982) examined the possibility of transcorneal transport in rabbits and concluded that this is an unlikely mechanism for lead absorption.

The team did not find any studies conducted in Egypt regarding the health effects associated with use of kohl. There is ample evidence from other places, however, to conclude that the use of kohl presents serious health hazards for children in Egypt, and probably for adult women as well. Kohl users have substantially higher blood-lead levels than non-users. As stated earlier, elevated blood lead levels can lead to a range of developmental problems and physiological damage in children and adults. Some of the documented cases from the United Kingdom, Kuwait, and Saudi Arabia are summarized below.

- **Case One (Warley et al. 1968)**
  A three year old Indian boy, resident in England for two years, was admitted to a London hospital with lead encephalopathy. His blood lead level was 178 μg/dL (the normal upper limit for pediatric patients is 0-40 μg/dL). On screening the family, the mother and a five year-old sibling had blood levels of 65 μg/dL and 72 μg/dL respectively, but no overt evidence of lead poisoning. The only factor common to the three affected members of the family was use of surma. A sample of the powder contained 80% lead sulphide (PbS).

 # Case Two (Snodgrass et al. 1973)

Twelve children from five families were studied over a six month period. Ten of the children had blood lead levels over the upper limit for normal pediatric patients. Three patients (aged 2-3 years) had lead levels ranging from 61-69 μg/dL and required rapid treatment. Samples of surma were obtained from three of the families and were found to contain 80-85% lead sulphide. In all cases the substance had been brought into the country by a relative as a gift from India.

 # Case Three (Betts et al. 1973)

A retrospective investigation was carried out on 38 children admitted to a Birmingham children's hospital between 1966 and 1971 with blood lead levels greater than 37 μg/dL. Eight of the children had been admitted with blood lead levels above 99 μg/dL; all of these had lead encephalopathy and one of the eight had died. Fifteen of the children were Asian. Kohl/surma was indicated as the main source of lead for this group of patients.

 # Case Four (Ali et al. 1978)

Blood lead levels in 62 Asian children in a Nottingham children's hospital were measured. Kohl/surma had been applied to the eyes of 37 of the children at some time before their admission; it had not been used on the other 25 children. The mean blood lead level in those who had not used surma was 20.3 ± 8.7 μg/dL, compared to 34.2 ± 14.1 μg/dL in those who had.

Analysis of 29 different samples of surma showed 23 of them to be composed largely of lead sulphide. The 18 grey samples had high lead contents, 14 containing over 80% and 3 containing 75-80% lead as lead sulphide. The five black samples had lead sulphide contents varying between 12% and 32%.

 # Case Five (Fernando et al. 1981)

A male infant aged 28 days had been nursed in the Special Care Baby Unit, Maternity Hospital, Kuwait, for 20 days and fed on adapted infant formulae. He was re-admitted eight days after discharge due to irritability. On return to the hospital, considerable quantities of kohl were observed on the infant's eyelids and eyebrows. The boy developed convulsions after admission. The blood lead level of the infant at 29 days was 38.6 μg/dL. The mother's blood lead level at the same time was 27.0 μg/dL.

The source of lead was kohl applied daily to the infant's eyelids. It was also possible that the infant was born with an elevated cord blood lead level, since the blood lead levels in a mother and her infant are generally similar at birth (Harris and Holley 1972). The mother used a lead-based kohl as an eye cosmetic.

 # Case Six (Fernando et al. 1981)

A breast-fed female infant aged 4 1/2 months, from a Bedouin family in Kuwait, was admitted for vomiting of two months duration and irritability. She was pale and showed signs of spasticity and brain damage. Her blood lead level was 92.8 μg/dL. Convulsions were noted on the second day of her hospital stay. Chelation treatment was given preceded by decongestive measures and a significant improvement was noted. The source of lead was excessive grey kohl which was observed on the infant's eyelids and eyebrows and also on the mother's eyelids.

Case Seven (Saleh et al. 1996b)
As an example of lead poisoning occurring from cosmetic use of kohl among urban populations, a study in Arar, Saudi Arabia, reported a case of lead poisoning in a three-month-old boy using kohl.

5.2 Lead in the General Population

In a 1992 study in the El-Waily residential area of Cairo (Shakour and El-Taieb 1994), 21 children, ages 3.5 to 15 years with a mean age of 9, and 9 adults were tested for lead. A control group of 15 adults and children (of unstated age and residence) was also tested. The mean blood lead level in the El-Waily children was 55.18 μg/dL (range 22 to 80 μg/dL, standard deviation [SD] 17.20). The mean was 20.70 μg/dL in the child controls (range 12 to 28 μg/dL, SD 5.20), and 49.11 μg/dL in the adult controls (range 25 to 90 μg/dL, SD 24.66). The authors noted that the difference between the El-Waily and control children was highly significant ($P < 0.001$). According to the authors, about 85% of the El-Waily children's blood lead levels exceeded 30 μg/dL.

A 1988 study by Ali measured blood lead levels in 825 adult men and women and children from the Greater Cairo metro area and rural Egyptian areas. None of the subjects had been occupationally exposed to lead. The subjects' ages ranged from 7 to 60 years; 31.2% were from the Menoufia and Benisuef governorates (lower and upper Egypt), and the balance from Greater Cairo. In this mixed population, blood lead levels ranged from 13.25 to 65.84 μg/dL, with a mean of 27.87 μg/dL. Only 12.12% of the sample population had blood lead levels less than 15 μg/dL, while 59% had levels greater than 25 μg/dL. The mean was slightly higher in males than in females (29.46 μg/dL versus 27.50 μg/dL). Urban dwellers averaged 29.70 μg/dL, while rural dwellers averaged 26.73 μg/dL. This slight difference held when the populations were disaggregated by sex; that is, rural males and females had slightly lower blood lead levels than urban males and females.

F.S. Ali's 1988 study of 134 children showed that the mean blood lead levels in male children under 10 years of age (N=49) was 21.13 μg/dL, while those of males ages 10 to 19 averaged 26.70 μg/dL (N=73). In female children, the respective means by age group were 19.78 μg/dL in those under 10 versus 26.30 μg/dL in females 10 or older. In a mixed population of children ages 7 to 12, the author found the mean blood lead level was 22.11 μg/dL, with a range of 13.25 to 39.00 μg/dL. The mean in urban children was significantly different ($P < 0.001$), at 23.20 μg/dL vs. 19.57 μg/dL in rural children.

Ali and Nasralla (1990) found mean lead concentrations in the hair of 118 male Cairenes to be 12.1 μg/g. For comparison, the mean lead concentration in the hair of 40 rural town dwellers in Egypt was 5.5 μg/g. The difference in the means of the two groups of men was statistically significant at the $P < 0.001$ level.

In a U.S. EPA-funded study, Saleh, Afify, Ragab et al. (1996) found lead residues in the breast milk of 120 Egyptian women from 20 different governorates.[5] The mean values of lead were significantly lower in breast milk in rural areas and small cities than in industrial and highly populated cities. The authors attributed the higher levels of lead in mothers' milk among residents of Cairo, Alexandria, and Assuit (66.0 μg/L, 49.2 μg/L, and 101.4 μg/L, respectively) to heavy automobile traffic and the use of leaded gasoline, and the use of leaded water pipes in the areas. Samples from 13 other governorates slightly exceeded the World Health Organization standard (see footnote below), while 4 governorates were below the standard. The lowest concentrations (9.0 μg/L) were reported from the Matrouh and Minia governorates. The authors considered the lead levels in Egyptian mothers' milk to be moderate compared with results in other countries. The USAID-funded study by Saleh, Ragab, Kamel et al. (1996) reported the same data and drew the same conclusions.

5.3 Lead in Occupational Sites and Populations

Shakour (1995) compared the blood lead levels of 1,943 male workers exposed to lead in workplaces in selected industries: lead smelting, battery manufacturing, electronics soldering, paint manufacturing, printing, sheet metal production, and building materials manufacturing. The mean for all workers was 53.16 μg/dL. Blood lead levels ranged from 11 μg/dL among sheet metal workers and solderers to 116 μg/dL among a group that included both sheet metal and paint plant workers. About 60% of the workers exceeded the national standard of 40 μg/dL. Smokers exhibited higher blood lead levels than nonsmokers ($P < 0.05$). Smelter workers had the highest mean, at 68.77 μg/dL, followed by battery manufacturing workers at 57.19 μg/dL.

Youssef (1991) studied blood lead levels in 360 people in Greater Cairo: 110 students (ages 8 to 15) and 250 adults (ages 16 to 60), both male and female. Among the adults, 161 were male administrative workers in a bus company, and 89 were married women, most of whom worked only in the home, and some of whom worked in the same office as the study's male subjects. In this mixed population, mean blood lead levels increased steadily with age, from 16.76 μg/dL for those under age 15 to 33.81 μg/dL for those over 55. Males averaged higher levels than females (33.34 μg/dL versus 22.80 μg/dL). Smokers' blood lead levels were higher, on average, than those of ex-smokers and nonsmokers (36.23 μg/dL versus 33.82 μg/dL and 25.83 μg/dL, respectively).

Nasralla et al. (1984) found the mean blood lead levels of male traffic police officers in Cairo ranged from 39.00 μg/dL for moderately exposed officers to 62.70 μg/dL for heavily

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[5] The 1972 World Health Organization daily permissible intake (DPI) of lead is 5.0 μg/kg of body weight per day for adults; this is equivalent to about 15.5 parts per billion in mothers' milk, according to Saleh, Afify, Ragab et al. (1996).

exposed officers.[6] A comparison sample of male urban and rural residents found their mean BLLs to be less: 30.50 μg/dL for the urban dwellers and 12.14 μg/dL for the rural dwellers.

Abu Ali et al. (1986) studied the blood lead levels of 106 workers in a newspaper printing plant and found a mean of 67.10 μg/dL. The authors noted no blood lead level data for the control group of 20 people. The mean concentration of respirable lead particulates in the air in the plant ranged from a high of 9.13 $\mu g/m^3$ in the smelting, printing, and lettering sections of the plant to a low of 0.20 $\mu g/m^3$ in the wood engraving section. The mean concentration of lead fumes in the air in the plant ranged from a mean high of 17.70 $\mu g/m^3$ in the smelting, printing, and lettering sections of the plant, to a low of 0.25 $\mu g/m^3$ in the photogravure section. In comparison, according to the American Council of Governmental Industrial Hygienists (ACGIH 1996), the recommended threshold limit value-time weighted average (TLV-TWA) is 50 $\mu g/m^3$ of elemental or inorganic lead, which workers should not exceed in any 8-hour workday.

Other studies of workers have been conducted in Egypt. All of the following studies identified elevated blood lead levels in workers in various industries. Kamal et al. (1991) found a mean of 29.2 μg/dL in a cohort of 126 traffic police in Cairo. Ahmed et al. (1987) found very high blood lead levels (mean of 68.3 μg/dL) in a cohort of traffic controllers in Alexandria. Anwar (1994) and Anwar and Kamal (1988) found a mean blood lead level of 30 μg/dL and signs of chromosomal damage in a cohort of 28 Cairo traffic police highly exposed to particulate lead, compared to a control group of police trainers. Amr et al. (1993) reported elevated lead levels and neuro-psychiatric signs in exposed industry workers in Egypt. El-Gazzar et al. (1989) found abnormal lipoprotein patterns in workers in an Egyptian battery manufacturing plant.

5.4 Comparing EHP Results with Other Egyptian Studies

The EHP team compared the results of the environmental sampling with results of other key studies in Egypt. With respect to settled (street) dust, we found dust concentrations over Greater Cairo to average 268 ppm (see Section 3.1), which is similar to the 239 ppm measure found by Shakour and El-Taeib (Paper A) in the residential district of El-Maadi. Our results are lower than the concentrations found at the high-traffic and high-industry study sites in the 1996 study by IGSR (1996) with means of 759 ppm and 3,498 ppm for high-traffic and high-industry, respectively, and the study by Shakour and El-Taeib (1994) in the industrial area of El-Waily, with a mean of 1,965 ppm.

For soils in Greater Cairo, the lead concentrations in our study ranged from 5 to 1,537 mg/kg, with a mean of 128 mg/kg and a median of 74 mg/kg (see Section 3.2). These concentrations are lower than, but comparable to, the results found in studies near a highly trafficked road in Greater Cairo, where soil concentrations ranged from 176 to 230 ppm (Ali, Ibrahim, and Nasralla 1992).

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[6] In the United States, occupational exposures that result in an individual blood lead levels of greater than 45 μg/dL are considered unsafe and are cause for removing the affected person from the exposure source and medically evaluating him or her for chelation therapy.

The 17 canned food samples we analyzed had lead concentrations less than 120 μg/kg (see Section 3.5.2), with the exception of one can with 562 μg/kg. These findings compare to a range of 4 to 926 ppb found in canned foods by Rakha, El Haleim, and Fricke (1994).

In the 37 samples of fresh produce (see Section 3.5.9), we found lead concentrations generally less than 250 μg/kg, with four exceptions, and a median lead concentration of 75.5 μg/kg. This compares to range of 4 to 666 ppb of lead found in the Rakha, El Haleim, and Fricke (1994) study of fresh fruits and vegetables. Leafy vegetables examined by Nasralla and Ali (1985) found much higher lead concentrations than our study, ranging from 2 to 78 mg/kg. Ali's 1991 study found lead concentrations in orange peels ranging from 2 to 31 μg/g, higher than our study. We did not find comparable published Egyptian data for other foods examined, such as breads, dairy products, grains, milk, processed foods, and spices.

For drinking water in Greater Cairo, our study results found lead concentrations in tap water at less than 11 μg/L, with a median of 1.27 μg/L (see Section 3.3). These figures are comparable to results of the 1992 Cairo Water Authority (CWA) study of lead in treated water which found lead at a peak concentration of only 5.9 μg/L. Our findings contrast drastically, however, with the study of Zahran (1992): in 116 samples of tap water from various parts of Greater Cairo, the mean concentration of lead was reportedly 492 μg/L. As noted above, the results of our study and that of the CWA indicate that lead levels in the sources do not exceed U.S. EPA or WHO drinking water standards for lead.

In the EHP study, lead concentrations in kohl ranged from less than 50 mg/kg (a low level) to one black kohl sample, called galena, which was nearly pure (73%) lead sulfide (see Section 3.6). These findings are comparable to analyses of kohl used in Saudi Arabia and Israel which found a similar range of lead concentrations (Al-Saleh et al. 1996; Nir et al. 1992). Similar to our findings in Egypt, grey and black kohl in Middle Eastern countries contained extremely high lead concentrations (Al-Saleh et al. 1996).

For other substances such as paint (Section 3.4), medicines (Section 3.6), and glazed ceramics (Section 3.7), we did not find published data from Egypt with which to compare our results.

5.5 Comparison with Mexico City Study

Mexico City is one of the few cities in the world comparable to Cairo in population size, economic development level, and economic diversity. A recent environmental and blood lead study in Mexico City by Romieu et al. (1995) found blood lead levels in children under 5 years to range from 1 to 31 μg/dL, with a mean of 9.9 μg/dL (SD 5.8 μg/dL). Forty-five percent of the children over 18 months had blood lead levels greater than 10 μg/dL, a recognized level of concern for children. The LEAP study used environmental lead concentrations and the IEUBK model (Section 4.3) to estimate blood lead levels in young Cairene children (0-6 years).

The following table compares some of the environmental data for each study with the measured blood lead levels in Mexico City and the estimated blood lead levels in Cairo:

Table 5-5: Mean Lead Values

Media	Mexico City	Cairo
Soil (mg/Kg)	117.2	128
Dust (mg/Kg)	205.6	268
Drinking water (μg/L)	4	2
Blood Lead (μg/dL)	9.9 (measured)	13.3 (estimated)

The major environmental predictors of blood lead levels for young children in Mexico City were lead content in glazed ceramics used to prepare children's food, and lead in dirt on children's hands. Both the mean, as well as the range, of soil/dust values in Mexico City and Cairo, however, would not be considered particularly high by U.S. guidelines. Of particular interest in the Mexico study, therefore, is the fact that the lead content of soil/dust on children's hands was significantly correlated with blood lead values. This could indicate, as was assumed in the Cairo estimates for blood lead values, a higher soil/dust intake rate than data for children in more temperate climates suggests.

6 CONCLUSIONS AND RECOMMENDATIONS

The EHP environmental assessment characterized lead concentrations in a variety of environmental media. Data from the environmental analyses were then used to estimate the probable distribution of blood lead levels in young children in Cairo and to identify the lead exposure pathways that are probably of greatest significance to children's exposure. Subject to agreement by USAID/Cairo and EEAA, these pathways will be addressed during the intervention design phase of the Lead Exposure Abatement Plan (LEAP) program.

The findings presented in this report support the conclusions and recommendations given below. Conclusions are described in the text, followed by related recommendations delineated as bulleted items.

6.1 Estimated Blood Lead Levels in Children

Analyses with a lead exposure model estimate that approximately 64% of the young children (ages 0 to 6) in Cairo have blood lead levels higher than 10 μg/dL and approximately 14% have levels higher than 20 μg/dL. Although there is no internationally recognized standard for blood lead, research has shown that levels as low as 10 μg/dL are associated with learning disabilities and the loss of IQ points. The blood lead level deemed to be a threshold for concern has been steadily lowered over the last 25 years, as studies have been able to demonstrate more and more subtle detrimental effects at lower blood lead levels. No research has yet demonstrated the existence of a "safe" lower limit below which lead does not cause harmful effects in children. The current consensus among many authorities is that blood lead levels of 10 μg/dL and higher should be a cause for concern, and that levels of 20 μg/dL and higher are sufficient to warrant action to reduce the sources of exposure.

Results from this study justify taking action to reduce lead exposure for children in Cairo. Efforts to define appropriate interventions should proceed.

Note: Preliminary results from the blood lead study being conducted by the Egyptian Ministry of Health and Population should be available soon and will provide a direct measure of blood levels in children of ages 2 to 6 years. These data should be used to confirm or modify model-based estimates of the magnitude and extent of children's exposure to lead and to identify additional risk factors that may not have been identified in this study.

6.2 Food as an Exposure Pathway

The study produced clear evidence of lead contamination in bread, some types of fresh produce, and raw milk sold by small-scale vendors. No evidence of significant levels of lead was found for many other types of food. The lead contamination in bread is clearly introduced in the process of milling grain into flour; this result is consistent with previous findings in investigations that the MOHP has conducted elsewhere in Egypt. The effect of other potential sources for lead contamination in bread, including using lead-contaminated fuel oil in bakery ovens and leaving bread uncovered at street markets, could not be demonstrated. Because the lead contamination on lettuce and other produce can be washed off, it is most likely due to deposition of lead-containing particles from agricultural soils and airborne dust. The source of lead contamination in informally vended raw milk is not clear; several potential sources can be postulated (e.g., lead solder in storage cans, exposure to motorcycle and auto exhaust during transport, use of a dipper that has surface contamination from lead-containing dust).

Bread, lettuce, potatoes, cucumbers, and milk are important elements of children's diets in Cairo. Results from analyses with the IEUBK model indicate that consumption of foods contaminated with lead is responsible for a daily lead intake as high as 60 μg/day in children from 0 to 6 years of age; approximately half of this level is attributable to bread alone. Egyptian standards set the acceptable daily lead intake at 35 μg/day for children. In the United States, the standard for daily intake is 6 μg/day for children.

- Prompt action should be taken to identify and eliminate the sources of lead contamination in bread.
- Public education messages (and, possibly, other interventions) should be used to encourage growers, vendors, and consumers to wash fresh produce in order to eliminate surface contamination with lead-containing soil and dust.
- Additional investigations should be undertaken to determine the source of lead contamination in milk sold by small-scale vendors.

6.3 Soil and Dust as an Exposure Pathway

EHP's objective in examining lead levels in soil and dust was to measure the general distribution of lead throughout Cairo, without concentrating on specific "hot spots" (e.g., high-traffic areas or areas near lead smelters) where high concentrations have been measured in previous studies. The lead concentrations found in soil and dust were relatively low, compared to previous results for "hot spots" in Cairo and to experience in other countries. EHP has a high level of confidence in the accuracy of these results, based on the large number of samples analyzed, the consistency of the results, and the satisfactory quality control conditions for this part of the study.

Analyses using the IEUBK model indicate that ingestion of soil and dust is not a significant pathway for lead exposure in children in Cairo, even when, to account for the dry, dusty climate in Cairo, assumptions for the amount of soil and dust ingested are increased by 30% above the default values used in the United States. There is some uncertainty in this analysis, however, since it is extremely difficult to obtain an accurate estimate of the amount of soil and dust ingested by children, and no studies on the subject were identified for children in Cairo.

This study indicates, therefore, that a widespread program to remediate contaminated soil and dust in playgrounds, school yards, and other places where children are exposed would not be warranted in Cairo. This study did not examine lead concentrations in soil and dust at "hot spots" and does not preclude the potential importance of taking remedial action at such sites.

- EHP recommends that a general program to remediate contaminated soils and dust is not necessary in Cairo.
- Results from the MOHP blood lead survey should be evaluated to determine whether there is an association between children with high blood lead levels and exposure to soil and dust in areas where these media would be expected to have high levels of lead contamination (i.e., "hot spots"). If such an association is demonstrated, actions to remediate contaminated soils and dust in these areas may be warranted.
- Even though ingestion of soil and dust is not the most important pathway for lead exposure in children, it does contribute to children's exposure and can be reduced through public education directed at changing the behavior of children and their caretakers. Such elements should be considered in developing the design of a public education campaign for reducing lead exposure.

6.4 Other Exposure Pathways

6.4.1 Cosmetics and Traditional Medicine

Of the nine materials tested, only the cosmetic kohl showed high concentrations of lead. The lead concentrations in many samples of kohl were extremely high, however, since it is prepared from a material called "galena" that is mostly lead sulfide. In addition to its use as a traditional cosmetic in women, kohl is also applied to the eyelids of infants and young children in several Middle Eastern countries. There is evidence from other countries that this practice can result in high blood lead levels in children. The data from this study demonstrate that lead-containing kohl is available in Cairo and is probably creating a lead exposure problem in some women and children, although the extent of the problem is not yet clear.

- Interventions should be developed to prevent the use of kohl on children or to develop safe alternative materials. These interventions should be based on further investigations to determine to what extent various population groups in Cairo use kohl, especially for children.

6.4.2 Ceramics

Results from this study demonstrate that some of the ceramic ware available in Cairo markets and used for cooking does present a potential hazard from lead that may leach from the glaze when in contact with acidic solutions, such as tomato products. More extensive studies from other countries—in this case, Mexico—demonstrate that lead from ceramic ware can be an important exposure pathway for lead.

Interventions should be developed to reduce lead exposure from the use of ceramic ware contaminated with lead. Designing the intervention depends on first collecting additional information on consumer's practices in purchasing and using it.

6.4.3 Paint

Results from this study indicate low levels of lead in samples of exterior paint that were removed from or had flaked from buildings, and in fresh paint being sold for interior use. However, there are conflicting reports regarding current practice in the industry, with some indication that private paint manufacturers may be increasing the use of lead to formulate paints. Although paint does not appear to be an important source of lead today, it could easily become more significant if lead-based paints were widely distributed and used.

6.5 Public Health Education as an Intervention

Any comprehensive program to reduce childhood lead exposure will need to include a public health education program targeting young children and their caretakers. The need for a public health education program is driven by two factors. First, lead is persistent in the environment long after primary sources have been removed, and removing or cleaning vast amounts of soil and dust is impractical. Second, changes in hygiene behavior and supervision of children in lead-contaminated environments have been shown to be effective in reducing blood lead levels even in the absence of large-scale remediation.

A public health education program should be developed as part of the Lead Exposure Abatement Plan. It should be designed on the basis of information regarding risk factors for lead exposure developed in EHP's investigations, the MOHP blood lead study, and from additional work to gather information on the knowledge, attitudes, and practices (KAP) of children and caregivers regarding lead exposure.

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Appendix A

Field Sampling Guide

Appendix B

Maps 4 through 14
(Referenced in Chapter 3)

Appendix C

IEUBK Model Worksheet

(Source: EPA 1994, pp. 2-47 to 2-50)