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Caractérisation de la contamination autour de la plus grande fonderie de plomb d'Egypte dans le cadre d'un programme collaboratif entre les Etats-Unis et l'Egypte

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Characterization of Contamination Around the Largest Lead Smelter in Egypt Carried Out Through a Cooperation Program between USA and Egypt

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Abstract. The Government of Egypt together USAID aimed to reduce the impact of lead smelters on the environment. The major site was in Shoubra El-Kheima, where the Awadulla Secondary Lead Smelter is situated. The Awadulla Family Company owns about 70% of the lead smelters in Egypt. This work presents the results and conclusions of a detailed on-site and off-site contaminant characterization of the Awadulla Secondary Lead Smelter.

As part of the characterization of the smelter site, soil and dust samples were collected within and near the smelter using two methods. The first consisted of collecting bulk dust and soil samples from the floor and ground in the direct vicinity of the smelter. The second involved using wet wipes to collect dust samples from walls, smooth floors, duct work, window and ledges. The results indicate that the most contaminated soils can be found in industrial areas and on public streets in Shoubra El-Kheima. The highest lead concentrations of more than 780,000 mg.kg^{-1} were found inside the smelter site. Concentrations at the El-Mahy Smelter nearby reached 302,275 mg.kg^{-1}. Residential areas had considerably lower lead levels in soil and dust. Samples of surface water and groundwater were collected and tested for lead contamination. Only three samples had lead concentrations above detection limits, indicating water contamination is not a problem. The maximum area affected by deposition of lead from the Awadulla smelter appears to be no more than 500 m all around the smelter. The plan calls for moving the smelters to a new industrial area called Abu Zaabal. This move will leave behind existing structures that are highly contaminated with lead dust.

Keywords. Smelter lead contamination, Environmental impact, Lead abatement, Policy making, International partnership

1. Introduction

Occupational and environmental exposure to lead is a serious problem in countries passing through an economic and industrial transition period. The Government of Egypt (GOE) developed a Lead Smelter Action Plan (LSAP) to reduce the impact of these smelters on the environment. As part of the plan, the Cairo Air Improvement Project (CAIP) along with the Egyptian Environmental Policy Project (EEPP), funded by USAID, worked with the Awadulla Family Company and the Egyptian Environmental Affairs Agency (EEAA) to develop a comprehensive plan for lead abatement in Cairo. The EEAA Lead Exposure Abatement Plan (LEAP) addresses all sources, exposure pathways, and remedial actions associated with lead pollution in the Greater Cairo Area. As a part of this plan, secondary lead smelters located in densely populated, low-income, urban neighborhoods have come under increased scrutiny.

Thus the Egyptian Government through LSAP, CAIP and EEPP worked with the Awadulla family company, a major lead producer and lead dust emitter in Cairo, to consolidate its operations and move them to a new, more modern plant site in the Abu Zaabal Industrial Zone. This move will leave in its wake the existing structures, which are highly contaminated with lead dust.

Towards developing a long-term solution to site remediation in general and to fulfill the commitment to remediate at least one smelter site and reduce environmental and human health risks, CAIP and EEPP evaluated the hazards and developing a remediation program for Awadulla's Secondary Lead Smelter at Shoubra El- Kheima. In addition, this program aims at providing an on-site/off-site hazard assessment, evaluating applicable control technologies for the remediation and introducing a risk assessment study of the adverse effects of lead toxicity on public health.

Much work had been completed on the site. A completed preliminary analysis PA, evaluated the site in terms of its potential to pose risks to people and the environment. During this assessment, soil and water "grab" samples were taken and analyzed for various contaminants and preliminary conclusions were drawn as to the levels of metal contamination on the site. When this was complete, a more detailed soil and dust sampling program began within the smelter and in its immediate vicinity.

Based on the results of the PA and the contaminant assessment, it was felt that it was important to determine the extent of contamination near the smelter. This paper presents the study, methodology and results of this investigation. A brief overview of the existing site conditions of the smelter, the findings, and conclusions from the PA, together with the contamination assessment are included.

The ambient air level concentrations of lead in Shoubra El-Kheima area was high (Howes et al[a]., 2000, Howes et al[b]., 2000 and Labib, 2001) so there is a necessity to address environmental contamination from lead smelters, which are the major source of lead in this area.

2. Materials and methods

The Awadulla Secondary Lead Smelter (CAIP[a], 2002, CAIP[b], 2002 and CAIP, 2003) began operations in 1979 and ceased smelting in August 2001. The main raw material for the plant was used batteries. Approximately 20,000 tons of batteries were recycled per year, producing 11,000 tons of lead ingots. The smelter covers an area of approximately 1,550 m^2 with a total volume of building material of about 553 m^3. After the smelting process stopped, the plant was used only to refine and manufacture lead products. Few environmental controls were in place to prohibit the dust and molten lead from coating the floors and walls of the smelter.

2.1 Location of smelter

The smelter site is within the flood plain of the Nile and overlooking the Ismaalia Canal, few kilometers from Benha, the capital of Shoubra El-Kheima Figure 1. The topography of the area is almost flat, with an average altitude of 17 meters above mean sea level. The climate is arid with annual rainfall of about 25 mm/year. Wind direction is primarily from the north. The smelter lies within a mixed industrial and residential area, approximately 40 m north of a soccer field and 30 m east of a housing block. Underlying the smelter, there are two hydrogeologic units, an upper silt and clay layer and a major alluvial aquifer. The water table is 5–6 m below the ground surface. About 125 m to the south of the site is the Ismailia Canal, which is a source of recharge to the aquifer.

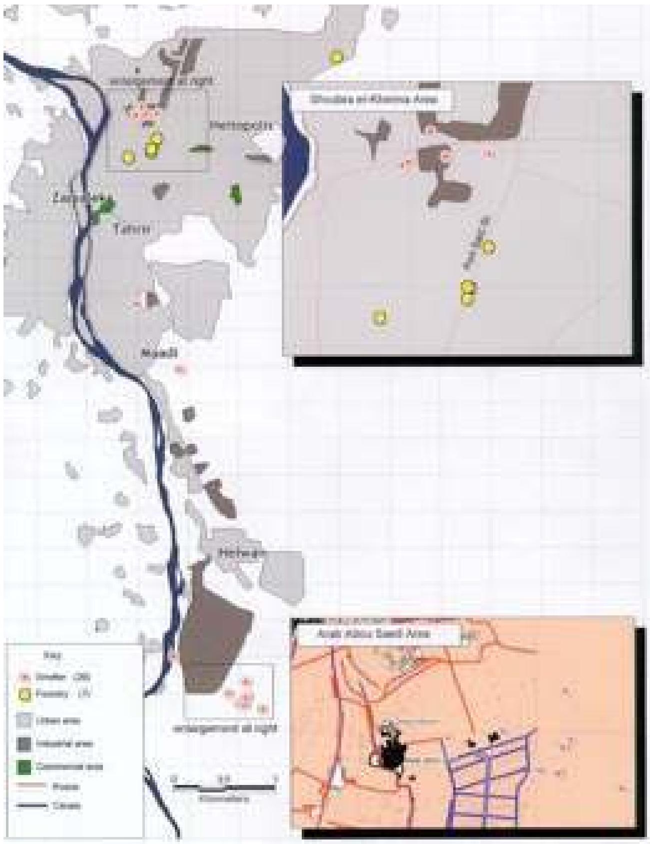


Figure 1. Location of smelter

2.2 Preliminary Assessment

As part of the PA of the Awadulla smelter site (CAIP[a], 2002 and CAIP[b], 2002), a field investigation was undergone to determine and estimate the nature of the potential hazards to human health and the environment at the site.

These studies were performed using quality assurance/quality control (QA/QC) protocols.

The results indicated that the smelter poses a multitude of health and safety hazards to remediation workers, nearby residents, and the environment. Exposure to toxic elements associated with batteries such as lead, cadmium, arsenic, antimony, and selenium can have a profound effect on long-term human health. Children and young adults playing near or within the smelter grounds could be exposed to lead through inhaling or ingesting high levels of contaminated fugitive dust. Fugitive dust from the smelter could be blown and deposited on uncovered food and agricultural products; onto the waters in the Ismailia Canal; and on the Amiriya water treatment plant, which is located about 300 m downwind of the smelter. Safety hazards also exist to workers and to children playing within site boundaries.

Of the contaminants found on the site (CAIP 2003), lead is the most dangerous. The absorption of lead depends not only on its chemical state but also on the physical state. Particle size plays a vital role on the fate of the ingested lead; if the particles of the insoluble lead minerals are large, they will be conveyed from stomach to intestines in their original forms but if the particles are small and soluble, they will be readily absorbed (Shannon, 1998). People living close to lead smelters suffer from the hazardous effects of both sizes due to the smelter's emission of the fine particles of reactive lead oxide phases. Once absorbed by the body, the lead is taken by the blood stream and directed to soft tissues. After some time it will accumulate progressively in the bones due to its resemblance to calcium size-wise {the ionic radius of Pb2+ and Ca2+ are almost equal} (Spiro et al, 2003). Lead's adverse health effects are numerous (USEPA) and are exhibited primarily in the blood forming and nerve tissues. In blood, by inhibiting the enzymes responsible for the biosynthesis of heme. Whereas lead's invasion of the central and peripheral nerve cells is governed by the amount of blood lead level; if BLL is in the 5μg/dL lead decreases nerve conduction velocity while higher values are associated with the degeneration of the nerve cell itself (ATSDR). The contribution of lead to other health problems is manifested in growth impairments, auditory pathway and kidney function deterioration (CDC) to name a few.

2.3 Sample collection; soil, dust and water

As part of the characterization of the smelter site, soil and dust samples were collected using two methods; The first consisted of collecting bulk dust and soil samples from both the smelter floor and in the direct vicinity of the site, the second involved collecting dust samples from walls, carpeted floors, ductwork, window ledges, and other relatively smooth surfaces using damp wipe cloths (ASTM, 2002, E1728-02 and ASTM, 2002, E 1792-02).

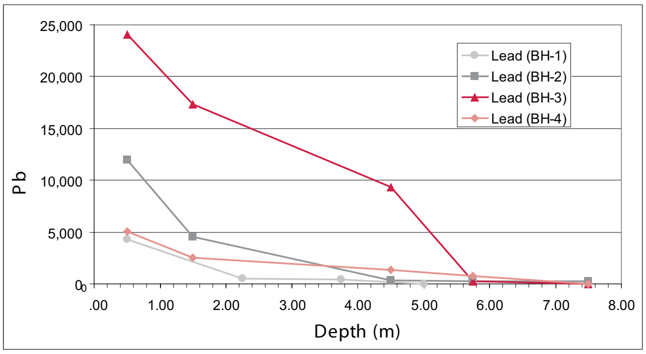


Figure 2. Concentration of Lead (in mg.kg-1) as a function of depth (in meter)

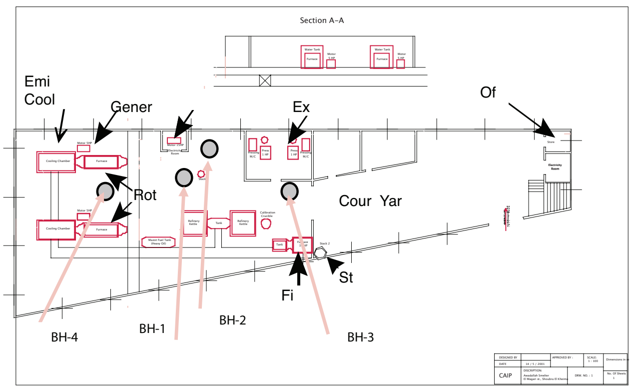


Figure 3. Borehole well location map (BH-1 through BH-4)

All samples were taken following a sampling and analysis plan (SAP) that was developed in accordance with United States Environmental Protection Agency (US EPA) and other international standards such as the American Society for Testing Materials (ASTM). The locations of the sampling points are shown in the Annex.

High levels of lead contamination along with the other hazardous heavy metals were found in most dust, soil, and water samples at the site. The maximum percentage of lead found in the dust samples taken from the floor of the site showed up to 67.91% lead, with soil samples reaching a maximum of 78.26% lead. In the PA, the variation in lead concentration with depth was surveyed from the upper 0.5 m to depths ranging from 5 m to 7.5 m at four locations as illustrated in Figure 2. Figure 3 shows the borehole (BH) locations (4 locations).

Groundwater sampling from wells drilled on and near the site showed: Antimony and arsenic were not detected in the samples. Traces of cadmium, chromium, and selenium were found in a few samples. Lead was found, and exceeded the drinking water limits (> 0.5 mg.L^{-1}) in the majority of the samples, posing a hazard to human health if consumed directly.

For the PA, each of these was evaluated on a preliminary basis. It was determined (CAIP 2003) that the dispersion of contaminated fugitive dust by wind and direct contact were the principal pathways of concern. The residents living nearby—especially those living directly to the south, in the direction of prevailing winds—together with the smelter workers are most at risk.

3. Results

3.1 Soil and dust heavy metal concentration

Table 1 shows the results from 26 extra samples taken from the site as the Contaminant Assessment was compiled. These soil and dust heavy metal concentration values helped pinpoint the sampling locations of greatest contamination. Once the "hot spots" were defined, the source, nature, and extent of hazardous contamination within and in the direct vicinity of the smelter could be properly assessed for risk assessment and remediation purposes.

As a guide to various action levels for lead clean up, values have been coded to the guidelines based on those used by the State of Rhode Island (Rhode Island Department of Health**,** 1992) in the US.

There are few guidelines for total concentrations of cadmium, zinc, chromium, selenium, arsenic, and antimony in soils. Standards for the most part in the US are based on analyses performed using US EPA method 1311 Toxicity Characteristic Leaching Procedure (TCLP) tests.

Wipe sampling is used to determine contamination levels on the surfaces of equipment and on building structures. The results of the lead wipe samples are shown in Table 2. As a guideline, those values exceeding US EPA clearance standards—residential standards—for floors, interior windowsills, and sliding window troughs to 40, 250 and 400 μg/900 cm^2 respectively, are shaded.

Table 1. Chemical analysis of dust and soil samples

Sample No.	Pb (mg/kg)	Se (mg/kg)	As (mg/kg)	Sb (mg/kg)	Cr (mg/kg)	Zn (mg/kg)	Cd (mg/kg)
S-1	80137.5	N.D	164.5	822.5	N.D	899.75	2.75
S-2	140000	N.D	166	1519.75	N.D	841.74	9.5
S-3	329912.5	N.D	205.75	4278	N.D	1087	2.5
S-4	340825	N.D	227.75	10282	N.D	962.75	5.5
S-5	671025	N.D	184	3920.5	N.D	392.5	N.D
S-6	669925	N.D	152.5	2919	N.D	352.5	1.5
S-7	28787.5	N.D	N.D	893	N.D	99	N.D
S-8	782625	N.D	2130	28801.5	N.D	308.5	2.5
S-9	43100	N.D	N.D	552.25	N.D	1220.5	N.D
S-10*	4126.25	N.D	N.D	54.25	N.D	226.75	N.D
S-11**	398.25	N.D	N.D	3.5	N.D	181	N.D
S-12‡	600	N.D	N.D	.25	N.D	266.5	N.D
S-13**	462	N.D	N.D	1.25	N.D	622.25	0.25
D-1	175000	N.D	198	2346	11.25	1469.3	6
D-2	146075	N.D	277.5	4992	221.25	6691.5	2.5
D-3	275925	N.D	272.5	3598	338	2463.5	6.5
D-4	215712.5	N.D	392.5	3359.75	32.25	1096.5	0.5
D-5	653650	N.D	248.5	8008.5	N.D	1985.5	N.D
D-6	679100	N.D	825	20925	N.D	1439	N.D
D-7	603575	N.D	152	11365	N.D	588.5	N.D
D-8	19637.5	N.D	N.D	291	N.D	1454.5	1.25
D-9*	5350	N.D	N.D	16.5	N.D	849	0.25
D-10‡	672	N.D	N.D	3.75	N.D	206	0.5
D-11*	1758.75	N.D	N.D	18.75	N.D	408	1.75
D-12‡	802.5	N.D	N.D	101.5	N.D	700	3.25
S-14**	228.75	N.D	N.D	22	N.D	177.75	N.D
D-13**	279	N.D	N.D	18.25	N.D	228	N.D

Table 2. Lead content in wipe samples

µg Pb/wipe	Sample No.		µg Pb/wipe	Sample No.
6476.5	W1		758625	W16
11307.5	W2		537250	W17
1625.5	W3		141862.5	W18
17867.5	W4		174412.5	W19
1633.5	W5		305687.5	W20
9997.5	W6		12807.5	W21
12775	W7		1831.75	W22
18915	W8		458.25	W23
39965	W9		518.25	W24
12280	W10		106.5	W25
43027.5	W11		1918.5	W26
100825	W12		8.99	blank
696750	W13		97.98%	L.C.S recovery
1129750	W14		98.129%	L.C.S.D recovery
14190	W15			

Table 3. Metal analysis summary in bulk dust samples

Sample Statistics	Pb (mg/kg)	Se (mg/kg)	As (mg/kg)	Sb (mg/kg)	Cr (mg/kg)	Zn (mg/kg)	Cd (mg/kg)
Mean	325507.71	N.D.*	399.75	6051.56	150.69	1309.96	3.73
Maximum	782625.00	N.D.	2130.00	28801.50	338.00	6691.50	9.50
Minimum	4126.25	N.D.	152.00	54.25	11.25	99.00	0.50
Std. Dev.	275025.49	N.D.	527.38	7701.19	156.56	1482.13	2.76
N*	18	0	14	18	4	18	11

Tables 4. Metal analysis summary in soil samples

Sample Statistics	Pb (mg/kg)	Se (mg/kg)	As (mg/kg)	Sb (mg/kg)	Cr (mg/kg)	Zn (mg/kg)	Cd (mg/kg)
Mean	1172.36	N.D	N.D	20.63889	N.D	404.2778	1.2
Maximum	5350	N.D	N.D	101.5	N.D	849	3.25
Minimum	228.75	N.D	N.D	0.25	N.D	177.75	0.25
Std. Dev.	1631.86	N.D	N.D	31.49879	N.D	255.7571	1.30384
N*	9			9		9	5

N* = number of samples above detection limits; N.D. = not detected

Tables 3 and 4, present the metal analysis summary in bulk dust and soil sampling (CAIP, 2003 and Labib et al, 2003). Results indicate that all of the samples analyzed for lead within the boundaries of the smelter building pose an extreme environmental lead hazard according to the Rhode Island standards. According to these guidelines, remediation of the site would require that the majority of the material be removed and disposed of in a regulated landfill. Concentrations of lead at the site range between 4126.25–782625 mg.kg^{-1}, with an average of 275025 mg.kg^{-1}, ultimately reaching an incredibly high level of 27% lead. The highest concentrations of lead appear to be in soil samples S-5, S-6, and S-8, and dust samples D-5 through D-7, taken from the northern portion of the smelter, in close proximity to the furnaces.

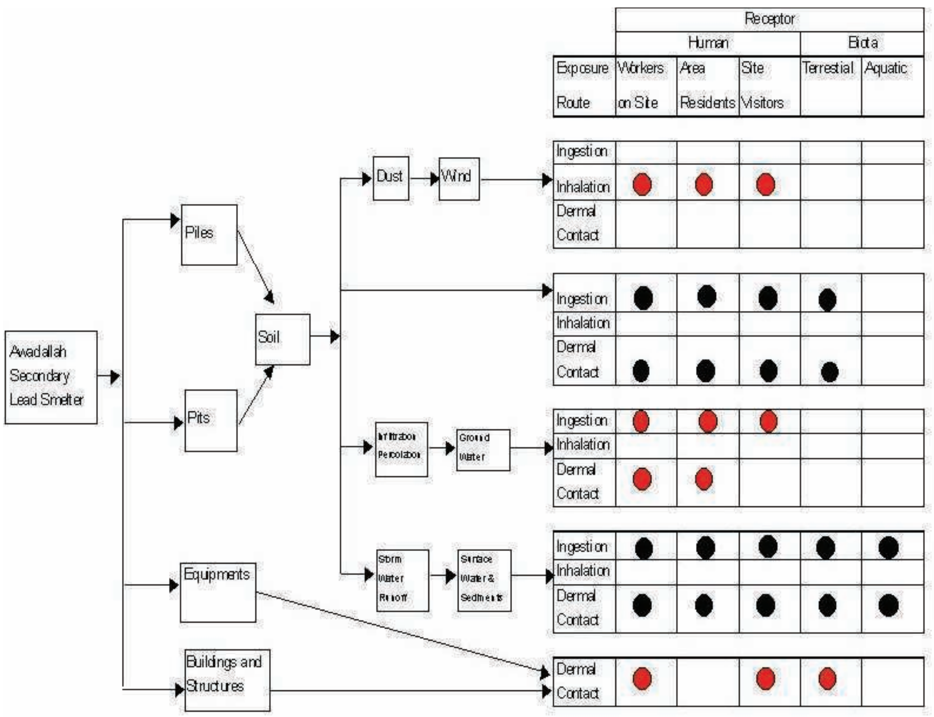
For those samples taken outside the building and downwind (S-10, D-9, and D-12), high lead content was revealed with the exception of soil samples S-11 and S-13. The data obtained for the dust and soil samples implies that they are either lead-contaminated or a lead hazard. These samples range in concentration between 228.75–5350 mg.kg^{-1}. The first was taken south of the Ismailia Canal and the second just west of the smelter building. The mean concentration of these samples is 1172.36 mg.kg^{-1}. In general, these values are especially alarming since these samples were taken in areas such as a football field where childrens' health could be adversely affected. Proper steps should be taken to remediate the site.

Lead wipe samples also indicate a high level of lead contamination inside the building for walls, floors, ductwork, machinery, and other parts of the building. Lead concentrations exceed US EPA standards for all samples taken within the smelter building. This indicates that all material in the building should be handled carefully during remediation.

Outside the building, wipe samples from nearby residential structures also revealed high levels of lead content. The only exception was sample W-25. Even though the results of these samples were compared to a relatively strict standard for households, the high concentrations exhibited by the samples both in and directly outside the smelter indicate that there is a high risk to human health from dust exposure.

For the other metals analyzed at the site, concentrations of chromium, arsenic, antimony, and to some extent cadmium, indicate that lead is not the only pollutant of concern at the site. These contaminants, as mentioned before, could pose a human health risk through exposure to dust through dermal contact and inhalation, as well as other exposure pathways.

In order to facilitate the evaluation and identification of potential risks to people either working inside the smelter or living close to it, a graphic representation of the site dynamics is shown in Figure 4. This conceptual site model helps to set a well-defined order of priorities for the remedial activities that would be conducted at the site.



The diagram shows:

Sources of contamination—waste piles, storage areas, pits, and ponds

Media affected by the contamination—soil, groundwater, surface water, buildings, walls, structures, and equipment

Release and transport mechanisms of the hazardous pollutant

Actual and potential environmental receptors.

Figure 4. Conceptual Site Model of the Awadulla Smelter

The results of the Contaminant Assessment of the site validate the findings of the preliminary assessment. Conclusions drawn include:

High concentrations of lead and other hazardous metals in the soil—reaching a maximum value 78%—render the site heavily polluted.

Lead soil and dust samples taken indicate that the smelter and the site pose an extreme environmental hazard.

Wipe samples indicate that all walls, floors, ductwork, machinery, and other surfaces in the building are contaminated with lead dust.

Dust and soil samples taken directly outside the building from nearby streets, play areas, buildings, and other structures show varying levels of lead contamination and indicate that lead hazards exist outside the smelter area.

Other metals, including chromium, cadmium, antimony, and arsenic found in contaminated dust and soil and on surfaces could pose potential health risks to workers and nearby residents. Selenium was not detected in any of the samples.

The results of this study strongly indicated that there was a potential for off-site contamination that should be further investigated and properly established in order to adopt the remediation alternative that is most suitable for the site and its ultimate implementation.

3.2 Surface water and groundwater

A surface water and groundwater sampling plan was developed and carried out by IWACO, Egypt. For surface water samples from the Ismailia Canal, 10 samples were taken up- and down-stream from the smelter site. For groundwater, it was determined that there were 92 wells in 72 locations within a 1-kilometer radius of the smelter site. A total of 64 water samples (both raw and filtered), taken from available locations, were analyzed.

3.3 Sampling methodology

3.3.1 Soil and Dust

The sampling method used consisted of collecting bulk dust and soil samples using US EPA and ASTM approved methods (ASTM, 2002, E1728-02 and ASTM, 2002, E 1792-02). Prior to sampling, an SAP was developed for the site. In general, samples were taken using a small shovel and fine brush. It was felt that the larger the sample the better, but at least 200 grams would be collected at each sampling location. The sample portion of concern was that which would pass through a 250-micron screen. During sampling circular templates of 0.3-m diameter were used on the sampling spot at the point location and three soil samples were collected and mixed within the template. With the spoon down to a depth indicated by a 1.5 cm test hole, the scoops were collected until a circular hole of approximately 5 cm diameter was created.

For areas where the soil was hard, a garden hoe was used to dig out a hole of 5-cm diameter and a depth of 1.5 cm. For dust samples, similar procedures were used within the 0.3 m circles, except a brush was used to gather the dust, which was then placed into plastic bags.

All laboratory analyses were made according to US EPA method 3050 B: Acid Digestion of Sediments, Sludge, and Soil (US EPA, 1987).

3.3.2 Surface Water and Groundwater

All surface and groundwater samples were taken, preserved, and placed on ice and sent to a qualified laboratory for analysis in accordance to the SAP. Samples in the field were analyzed for measure of acidity or alkalinity (pH), specific conductance, temperature, total dissolved solids, dissolved oxygen, and salinity using calibrated field instruments according to the SAP. In the laboratory, the samples were analyzed for selected trace metals using approved methodologies. For QA/QC, six duplicate samples, 1 blank sample, and 6 cross-referenced samples were taken. All samples were delivered within 24 hours to the Egyptian General Authority for Geological Survey and Mining (EGSMA) laboratories for analysis. The cross-reference samples were delivered to the Cairo University Center of Environmental Hazard Mitigation Laboratory.

4. Discussion

4.1 Soil and Dust

Table 5 summarizes results for lead concentrations in soil and dust samples taken within a 1 km radius of the Awadulla Secondary Lead Smelter by land use. Examination of this table indicates that the most contaminated soils can be found in industrial areas and on the public streets of Shoubra El-Kheima. The maximum concentration of 782,625 $mg.kg^{-1}$ was found inside the Awadulla smelter. At the El-Mahy lead smelter, about 700 meters east of the Awadulla facility, the only sample taken showed a concentration of 302,275 $mg.kg^{-1}$.

The remediation plan for the site depends on the maximum limit permissible for lead concentrations in the soil. However, for the zone surrounding the Awadulla smelter, which is determined to be a circle of 1-km radius, approximately 50% of the area should be considered exposed and appropriate mitigation measures implemented. The exposure area is confined to the east and west of the Awadulla facility and north of the Ismailia Canal.

Residential areas, for the most part, have considerably lower lead levels in soil and dust than industrial areas and public streets. However, the majority of the samples—62% of those taken—indicated that the soils and dust are *at least lead-contaminated*. For public streets, 83% of the soil and dust samples are *at least lead-contaminated*. For industrial areas, *all the samples taken were at least lead-contaminated*. Utility areas appear to be as lead-contaminated as residential areas. Overall, for all samples, 75% of the areas sampled are *at least* lead-contaminated and as illustrated in Figure 5, 41% of the samples showed a significant lead-hazard, with 9% showing an extreme lead-hazard.

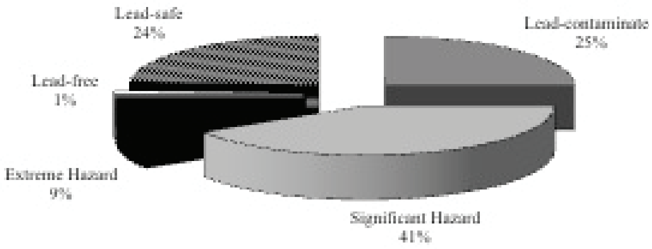


Figure 5. Soil and Dust Samples Compared with Rhode Island Guidelines

4.2 Surface Water and Groundwater

The results of the groundwater sampling effort showed that 23 of the 32 samples (72%) analyzed exceeded the GOE Law 48/82 standard of 0.05 $mg.L^{-1}$ for drinking water, with all but one sample exceeding the WHO standard of 0.01 $mg.L^{-1}$. As shown in Table 6, dissolved lead concentrations in wells in the direct vicinity of the smelter ranged between 0.003 and 1.602 $mg.L^{-1}$ with an average of 0.133 $mg.L^{-1}$.

Table 6. Trace metal analysis in groundwater

	Lead	Zinc	Cadmium	Selenium	Chromium
Count	32	5	14	11	5
Average (mg/L)	0.133	0.474	0.112	0.074	0.038
Max. (mg/L)	1.602	0.810	0.800	0.200	0.060
Min. (mg/L)	0.003	0.330	0.001	0.010	0.020

Concentration of zinc, cadmium, selenium, and chromium were also elevated. One sample taken from a well at the Mobil fuel station just north of the Ismailia Canal showed a value of 0.06 $mg.L^{-1}$ for chromium, which exceeds both the GOE Law 48/82 and WHO standard of 0.05 $mg.L^{-1}$ for drinking water. Lead was not detected in the Ismailia Canal.

These results of the surface water and groundwater-sampling program are consistent with those presented in the PA, which indicated that many wells had concentrations

Table 5. Lead Levels in soil and Dust Samples by Land Use

Variable	Soil Lead Concentration (mg/kg)						
	Cultivated Land	Industrial Areas	Open Space	Public Streets	Residential Areas	Utility Areas	All Areas
Number of Samples	2	24	2	36	49	22	135
Average	1021	62797	521	5293	1314	764	13200
Minimum	507	507	325	233	140	121	121
Maximum	1535	665600	717	68273	10488	3090	665600
Median	1021	2889	521	1264	627	623	957

considerably above the GOE and WHO standards. As for the surface water, the lead has probably been tied up with sediment and settled to the bottom of the canal.

5. Challenges encountered during the study

Knowing the "state of the site" was only part of the picture. It deemed necessary to ascertain that the smelters imposed no adverse health effects on the residents living in the proximity of both Awadulla and El-Mahy smelters. Thus a screening epidemiological study (Safar and Lotfi, 2006) determining the body lead load was conducted to provide insight on the potential impacts of lead contamination in this targeted area. A number of 299 blood samples were obtained from males, females (of reproductive age) and children. Children under seven years of age were specially focused upon, as they are the most vulnerable to the hazardous effects of lead. The work also correlated between the blood lead levels BLL with the outdoor dust and soil results and the indoor environment; household dust, tap water and interior paint.

The investigation revealed that outdoor soil and dust contamination were the major factor of lead exposure affecting the residents. No lead in drinking water was observed. It was also evident that the inhabitants, due to their limited education and low socio-economic standard, were unaware of measure of protection against lead toxicity.

The results of the study underlined the dire need to impose field action. The elevated BLL readings initiated the implementation of total remediation of the smelter sites and renovation of the adjacent schools.

6. Conclusions

Conclusions that can be drawn from this study include:

Fifty percent of soil and dust samples exhibited a high degree of lead contamination, indicating that these soils may pose a significant to extreme risk to nearby residents.

The maximum area affected by dispersion of lead from the Awadulla smelter appears to be no more than 500 m all around the smelter.

The burden of contamination seems to be at a maximum within the first 100 m around the smelter.

Based on air dispersion modeling of the smelter plume, higher concentrations of lead in the soil should have been found south of the smelter, but the sampling results indicated otherwise. This is most likely due to the removal of soil and the placement of clean gravel and vegetation in the utility areas located across the Ismailia Canal to the south of the smelter.

There are other sources of lead contamination in the area. Sampling indicated that one of these sources is the El-Mahy smelter east of the Awadulla site.

Surface water and groundwater samples taken within a 1-km radius of the Awadulla smelter indicate that groundwater lead concentrations generally exceed GOE Law 48/82 and WHO drinking water standards for lead with one sample exceeding standards for chromium. These levels are consistent with lead levels found during the PA of the site. There was also a marked difference in lead content between filtered and non-filtered samples; this should be further investigated since the unfiltered sample analyses are the appropriate data for heavy metal content. As for surface water, the lead, due to its weight, most likely has been tied up with sediment that has settled to the bottom of the nearby Ismailia canal.

7. Recommendations for future work

The Awadulla family replaced the smelter and changed it into a showroom. Where the hazardous soil and equipment were buried was never known. The smelter site was remediated but important guidelines were not met. The school was renovated properly and there was a felt enhancement of the neighborhood.

This work goes a long way toward defining which areas near the Awadulla lead smelter may require remediation. At this time, concentrations of lead in soils and dust have only been compared to guidelines developed by Rhode Island. These may or may not be applicable to Egypt. A draft risk assessment has been written for the potential for lead exposure to nearby residents. Based on the results of the health risk study, the GOE will be able to set up its own soil cleanup standards and the most appropriate remediation method for the polluted area could be implemented.

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