AMERICAN UNIVERSITY OF BEIRUT

MAPPING & CHARACTERIZING BATTERY WASTE MANAGEMENT FACILITIES IN LEBANON

by
YARA YARINK BOU RACHED

A thesis
submitted in partial fulfillment of the requirements
for the degree of Master of Science in Environmental Sciences
to the Department of Environmental Health
of the Faculty of Health Sciences
at the American University of Beirut

Beirut, Lebanon
January 2024

AMERICAN UNIVERSITY OF BEIRUT

MAPPING & CHARACTERIZING BATTERY WASTE MANAGEMENT FACILITIES IN LEBANON

by

YARA YARINK BOU RACHED

Approved by:

Dr. Hassan Dhaini, Associate Professor — Advisor
Department of Environmental Health

Dr. Mohamad Abiad, Professor — Co-Advisor
Department of Nutrition and Food Sciences

Dr. Mey Jurdi, Professor and Chairperson — Member of Committee
Department of Environmental Health

Dr. Lilian Ghandour, Associate Professor — Member of Committee
Department of Epidemiology and Population Health

Date of thesis defense: January 23, 2024

AMERICAN UNIVERSITY OF BEIRUT

THESIS RELEASE FORM

Student Name: Bou Rached Yara Yarink
Last First Middle

I authorize the American University of Beirut, to: (a) reproduce hard or electronic copies of my thesis; (b) include such copies in the archives and digital repositories of the University; and (c) make freely available such copies to third parties for research or educational purposes:

- ☐ As of the date of submission
- ☒ One year from the date of submission of my thesis.
- ☐ Two years from the date of submission of my thesis.
- ☐ Three years from the date of submission of my thesis.

Yara Bou Rached 6 February 2024

Signature Date

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude and appreciation to all those who have supported and contributed to the successful completion of this thesis paper on the Mapping & Characterizing of Battery Waste Management Facilities in Lebanon.

First and foremost, I would like to thank my supervisor, Dr. Hassan Dhaini, for his guidance, expertise, and invaluable feedback throughout the research process. His continuous support and encouragement have been instrumental in shaping this study.

Furthermore, I would like to extend my thanks to the professionals and experts in the field of Nutrition and Food Sciences, Dr. Mohamad Abiad, the field of Environmental Health, Dr. Mey Jurdi and the field of Epidemiology & Population Health, Dr. Lilian Ghandour, who generously shared their knowledge and insights during the data collection and analysis process. Their expertise has greatly enriched this study and provided a real-world perspective on the topic.

I am also grateful to the faculty members of the American University of Beirut for providing me with a beneficial learning environment and access to various resources that aided in conducting this research. Their commitment to academic excellence has been truly inspiring.

I would also like to express my sincere gratitude to Arc-En-Ciel (NGO) for their generous support and financial assistance in funding my research project. Their contribution has played a crucial role in the success of my study.

I would additionally like to acknowledge the assistance of my friends and family who have stood by me throughout this academic journey. Their unwavering support, understanding, and encouragement have been crucial in overcoming challenges and maintaining motivation.

Lastly, I would like to express my gratitude to all the participants who willingly took part in the questionnaires and interviews for this research. Their contributions played a pivotal role in gathering valuable data and enhancing the credibility of this study.

This thesis paper would not have been possible without the collective effort of all these individuals, and for that, I am sincerely thankful.

ABSTRACT

OF THE THESIS OF

Yara Yarink Bou Rached for Master of Science in Environmental Sciences
Major: Environmental Health

Title: Mapping & Characterizing Battery Waste Management Facilities in Lebanon

The aim of this study is to investigate the occupational exposure of battery recyclers to heavy metals and the resulting environmental pollution caused by these recycling facilities in Lebanon. The study utilized soil and water analysis for the heavy metals Lead (Pb), Cadmium (Cd) and Mercury (Hg) in the vicinity of three identified battery recycling facilities in Lebanon, as well as two structured questionnaires, one addressed to the managers of the facilities and the other to the workers, to assess waste management practices and determine the extent of exposure and contamination at the workplace. The results of the metal analysis indicated a significant increase in exposure levels and environmental contamination of Lead (Pb), and the results of the questionnaires further revealed several mishandling practices, highlighting the need for improved management practices and further investigation by designated authorities. This research provides valuable insights on the impact of battery recycling on both workers and the environment and offers recommendations for an improved occupational safety. Overall, this study contributes to a deeper understanding of the potential risks associated with battery recycling facilities in Lebanon and the need for more sustainable practices in the industry.

TABLE OF CONTENTS

ILLUSTARTIONS

Figure

TABLES

Table

ABBREVIATIONS

ATSDR	Agency for Toxic Substances and Disease Registry
BBB	Blood Brain Barrier
BLL	Blood Lead Level
Ca	Calcium
Cd	Cadmium
CDC	Center for Disease Control
CNS	Central Nervous System
EFSA	The European Food Safety Authority
EPA	Environmental Protection Agency
ESMAP	Energy Sector Management Assistance Program
Hg	Mercury
IARC	The International Agency for Research on Cancer
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
IRENA	International Renewable Energy Agency
LEAF	The Laboratories for the Environment, Agriculture and Food
LME	London Metal Exchange
LoQ	Limit of Quantification
Mt	Metallothionein
Nd	Not Detected
NGO	Non-Governmental Organization
NHANES	National Health and Nutrition Examination Survey
NIEHS	National Institute of Environmental Health Sciences
OSHA	Occupational Safety and Health Administration
Pb	Lead
pH	Potential Hydrogen
PPE	Personal Protective Equipment
PV	Photovoltaic
QSE	Quality, Safety & Environment
SS	Soil Sample
UCd	Urinary Cadmium
ULAB	Used Lead Acid Battery
UNDP	United Nations Development Programme
UPS	Uninterruptible Power Supply
WHO	World Health Organization
WS	Water Sample

CHAPTER 1

INTRODUCTION

Battery recycling facilities play a major role in helping reduce environmental pollution. Although these facilities are crucial for the proper disposal of hazardous materials, the process of recycling used batteries can also release harmful chemicals into the environment, which may lead to a variety of adverse health effects and negative environmental impacts (Adie, Afu, Olim, Beshel, & Ofem, 2022; Cook, 1977; Hsiao, Wu, Lai, & Kuo, 2001a; Krishna & Govil, 2005).

To better understand those effects, it is necessary to study the process of battery recycling and to characterize released pollutants. Previous reports indicate the release of toxic metals, such as lead (Pb), mercury (Hg) and cadmium (Cd), and other pollutants of concern (Kumar et al., 2022; Li et al., 2019; Neesanan et al., 2011; Onianwa & Fakayode, 2000).

1.1. Problem Statement

Lebanon is witnessing severe social, environmental, and economic crises that have tremendously affected the quality of life and the population's health. At the forefront of these crises are the solid waste and energy crises, which have become one of the major issues facing the country (Human Rights Watch, 2017). The solid waste crisis emerged in 2015, when the closure of the Naameh sanitary landfill led to a major accumulation of uncollected garbage, particularly in Beirut and Mount-Lebanon (Al Sayah, 2022). In parallel, the energy crisis was amplified by the severe economic and financial crisis that the country is facing, the deteriorating infrastructure, and the growing energy demands (Human Rights Watch, 2017). The situation is further exacerbated by the Syrian refugee's crisis, the political instability, and the general mismanagement in the public sector. These challenges have led to frequent power outages, affecting both residential and commercial sectors, and hindering the country's ability to attract foreign investment and promote economic growth (Human Rights Watch, 2017). Following the Port of Beirut explosion in August 2020, power blackouts reached 22 hours daily, hence imposing on many businesses to switch to private off-grids, UPS systems and battery usage (Human Rights Watch, 2021).

As fuel and electricity demand heavily weigh on Lebanon's economy, this demand also outpaces the power generation capacity. Accordingly, the International Renewable Energy Agency's (IRENA) report of 2020 recommends using new tools for small-scale applications, such as batteries. Therefore, the use of batteries is on the rise and is expected to maintain an increasing pattern, especially that the Ministry of Education and Higher Education in addition to many others, have called for the development of Photovoltaic (PV) systems based on backup battery storage (IRENA, 2020). This advanced form of potential grid provision would provide dynamic charging and better flexibility to the grid (ESMAP, 2020). As much as this approach would be efficient in alleviating the current electricity shortage, there is a need for appropriate management and efficient strategies in managing battery waste (Azzi, 2017).

Battery wastes in Lebanon end up either dumped with municipal waste at a landfill, thrown at sea, or taken by scavengers or metal dealers (Azzi, 2017). This practice pollutes the environment, leading to water and soil contamination, and adverse health effects.

1.2. Significance and Objectives of the study

This study aims to map battery waste management facilities in Lebanon and assess their environmental impact. More specifically, this study aims to:

1. Identify battery waste management facilities in Lebanon on a national scale
2. Understand the dynamics of battery waste management system and assess practices in the country
3. Measure levels of heavy metal pollution in the vicinity of identified sites

To the best of our knowledge, this is the first study in Lebanon to address the occupational exposure and pollution levels associated with the heavy metals lead (Pb), cadmium (Cd) and mercury (Hg) in (1) Beirut, (2) Tripoli and (3) Bekaa.

Our results would provide baseline data on the quality of water and soil in areas near battery recycling facilities and would set the basis for future research. In addition, the study would provide info on battery recycling facilities' malpractices, and their potential impact on health and the environment, which will inform policymakers and help in formulating an intervention in the future. Through highlighting areas where improvements are needed, results will help promote sustainable practices within the battery recycling industry, provide evidence for local authorities to push for the safe disposal and treatment of batteries, and ensure that battery recycling facilities are operating in an environmentally responsible manner. This can ultimately reduce pollution levels, increase resource recovery, and improve the overall sustainability of battery recycling operations (Meso, 2021).

CHAPTER 2

BACKGROUND INFORMATION

2.1. Battery Waste Recycling Principles

Battery recycling processes are many and have developed over time. Initially, the recycling process involved manual dismantling of batteries, followed by separation of lead (Pb) and sulfuric acid components. Pb is then melted and reused to create new batteries, while acid is disposed (Li, Liu & Han, 2016). Pb-acid batteries were the first types of batteries to be recycled, since 1912 (Li, Liu & Han, 2016). The recycling of used Pb-acid batteries was a success story for the recycling industry with up to 98% of the used lead-acid batteries (ULABs) able to be recycled (Li, Liu & Han, 2016). In many developing countries, battery recycling workers still dismantle retired batteries manually and heat them to remove combustible material, which exposes them to the inhalation of dust and fumes, especially in the absence of proper ventilation (Shah et al., 2012).

In the 20th century, the demand for Pb batteries grew rapidly due to the increase in automotive applications, hence the emergence of industrial-scale lead batteries recycling facilities (Li, Liu & Han, 2016). Some of these facilities used more advanced and efficient methods such as the hydraulic press technique to crush and separate Pb and sulfuric acid components, while others relied on more improved processes involving physico-chemical treatment to increase their yield (Li, Liu & Han, 2016). Among these physico-chemical treatments, the most commonly used in battery recycling are hydrometallurgy and pyrometallurgy. The pyrometallurgical process is the dominating Pb recycling technique nowadays (Ballantyne et al., 2018). The latter consists of breaking the battery and separating lead paste, lead grids, sulfuric acid, and polypropylene plastic (Ballantyne et al., 2018). The lead grids are then passed directly into a refining operation to remove alloy impurities, followed by smelting of the entire mixture to reduce the Pb-containing compounds to metallic Pb. Then, smelting occurs at temperatures ranging from 1100-1300 ^{o}C (Ballantyne et al., 2018). Hydrometallurgy on the other hand, consists of using an aqueous solution to extract the metal from its ore, allowing the separation of different metallic fractions. The process is then followed by purification and recovery of the metal (Ballantyne et al., 2018).

Other recycling principles have also been employed for battery recycling such as the wet recovery technology, the chemical precipitation method, the dry recovery technology, and others (Li et al., 2019). However, as much as these processes have been developed over time to improve the recovery and utilization of metal components of waste batteries and protect the environment, they still generate dust and vapors containing metals and trace elements including cadmium (Cd), nickel (Ni), lead (Pb), and mercury (Hg) (Li, Liu & Han, 2016).

2.2. Battery Toxic Components

The components of batteries could be many, particularly including heavy metals such as nickel, cadmium, mercury, lead as well as acid. These heavy metals are known for their ability to penetrate the food chain and bioaccumulate in the human body (Baloch et al., 2020). Studies have shown that improper disposal of Ni-Cd batteries can contaminate the soil and surrounding crops (Dorris, Atieh & Gupta, 2002). Additionally, several studies reported an elevation in blood lead levels (BLLs) among workers involved in battery recycling activities (Ahmad et al., 2014; Baloch et. al, 2020;

Shah et al., 2012). Workers in developing countries are more at risk due to the lack of laws and regulations that protect workers' health on-site, poor supervision and training, and low literacy rate (Champion, Khaliq, & Mihelcic, 2022). Moreover, a community-driven research approach conducted in Los Angeles showed that children living near battery recycling facilities have higher levels of Pb measured in their teeth, than in other neighborhoods. This was later explained by the contamination of air and soil (Johnston et al., 2019).

Heavy metal exposure can be highly dangerous for human health. Exposure to heavy metals can cause a range of health problems, from minor skin irritations to more serious health issues such as organ damage, nerve damage, and even cancer (WHO, 2007). Furthermore, heavy metals can enter the body through inhalation, ingestion, or dermal contact, and can accumulate in the body over time, leading to long-term health problems (WHO, 2007). The toxicity of Lead (Pb), Cadmium (Cd) and Mercury (Hg) are discussed in the following sections.

2.2.1. Toxicity of Lead (Pb)

Generally, lead (Pb) exposure can occur either through consuming polluted food and water or through paint, batteries, welding, and ceramics. However, the most important exposure is believed to be at the workplace (Alessio, 1988). Exposure to Pb has increased due to the increase in water and air pollution, however, the major exposure route remains throughout the recycling process (Kumar, Rahman, Islam, Hashem, & Rahman, 2022). People working in industries involved in activities related to battery recycling, mining, or smelting are being significantly exposed to these heavy metals for an extensive period of time (Gil et al., 2011). Occupationally, Pb is either inhaled or ingested by workers on-site, particularly in the case of manufacturing or recycling of Pb-acid batteries (Hsiao, Wu, Lai, & Kuo, 2001a). Additionally, poor personal hygiene and improper handwashing among workers, specifically before eating, has been shown to lead to an increased exposure by ingestion (Alessio, 1988). Previous studies found an increased blood lead levels (BLLs) in workers of a battery facility that was associated with the ‘lead loadings on lips’ theory resulting from poor personal hygiene, smoking while working, and other forms of direct exposure via hand to mouth activity (Hwang et al., 2000).

The high exposure to Pb can lead to damages in the nervous, hepatic, renal, reproductive and hematological system, due to the ability of Pb to alter the synthesis of heme in the body and therefore the lifespan of erythrocyte (Ahmad et al., 2014; NIEHS, 2012). Studies have shown that the elevated levels of Pb in the blood of children of developing countries had irreversible damages to the brain, altered growth and delayed puberty, particularly among children who had deficiencies in essential elements such as iron or calcium (Bellinger, 2008; Canfield et al., 2003; Gulson et al., 2004; NIEHS, 2012). In addition, results of a case-control study conducted in a group of Chinese males showed that the risk of having abnormal sperm quality was higher in the high BLL group in comparison with the control group (Ren et al., 2020). Epidemiological studies have also shown an increased association between elevated BLLs, lead nephropathy, and glomerular and tubular changes in the kidneys (Adham, 1997; Cardenas et al., 1993; Goyer et al., 1989; Hommond, Lerner & Gartside, 1980; cited in Rastogi, 2008).

Once Pb gets absorbed into the body, it binds to calcium (Ca) channels and gets transported inside the body where it deposits in the bony matrix. Under conditions where bone physiology is undergoing a period of change, such as during pregnancy, growth, aging, and osteoporosis, Pb is released from the bone mineral matrix, and binds to Ca channels again, where it gets transported to the brain (ATSDR, 2020). Pb is then capable of crossing the Blood Brain Barrier (BBB) through Ca channels where it leads to neuropathy at the level of the central nervous system (CNS), in addition to cognitive impairment (ATSDR, 2020). Pb can also restrain the synthesis of hemoglobin and reduce the lifespan of erythrocytes, subsequently leading to increased risk of anemia (Dongre et al., 2011; Taylor et al., 2016). The primary screening process to assess Pb in the human body is the blood, especially since Pb can enter the body either via inhalation or ingestion and its half-life in the blood can reach up to 40 days, after which Pb accumulates in the metaphyseal region of the bony matrix where its half-life can reach up to 20 years (ATSDR, 2010; Rabinowitz, 1991; Skerfving & Nilsson, 1992). IARC has classified lead and inorganic lead compounds in Group 2B as a possible carcinogen to humans (IARC, 2018).

2.2.2. Toxicity of Cadmium (Cd)

Cadmium is a toxic metal that can be released into the environment from different human activities such as the incineration of electronic waste, the use of phosphate fertilizers, contaminated water, the production or recycling of Ni-Cd batteries and other industrial sources (ATSDR, 2023). Moreover, people can be exposed to cadmium through consuming cadmium-contaminated fruits and vegetables, and also through tobacco smoking (WHO, 2007).

For acute exposure to cadmium, the principal effects include a series of gastrointestinal disturbances and negative respiratory manifestations, such as bronchial or pulmonary irritations (Kobayashi, Suwazono, Dochi, Honda, & Kido, 2009;

Lauwerys, Buchet, Roels, & Bernard, 1982). On the other hand, chronic cadmium exposure can primarily affect the kidneys, lungs, and bones (Kobayashi et al., 2009). Following absorption, Cd binds to plasma proteins and gets transported to the liver where it induces metallothionein (MT) (ATSDR, 2012). Metallothionein (a small cysteine-rich protein that plays important roles in metal homeostasis and protection against heavy metal toxicity, DNA damage, and oxidative stress) binds to Cd forming the metallothionein-cadmium (MT-Cd) complex. This complex will be transported from the liver to the kidneys where it accumulates (ATSDR, 2012). Once the renal pool of MT is saturated, MT-Cd will be broken down by lysosomes inside the kidney's tubular tissues, and divalent Cadmium (Cd2+) is released attacking segments of the kidneys' proximal tubules and causing injuries (ATSDR, 2012; Prozialeck & Edwards, 2012). Cd is excreted out primarily in urine; however, its excretion rate is low, because Cd remains tightly bound to MT (ATSDR, 2012). Therefore, cadmium levels in the urine are considered a strong biomarker of long-term exposure to cadmium (Vacchi-Suzzi, Kruse, Harrington, Levine, & Meliker, 2016).

In a study conducted on workers of a Ni-Cd battery recycling facility, blood and scalp hair samples were analyzed for Cd in exposed workers at the facility and a control group; results showed that the average concentrations of Cd in biospecimens from the workers were 3-fold higher as compared to the control subjects (Baloch et al., 2020). In another study conducted on battery recyclers in France, Cd urinary concentrations reached 27.6 µg/g creatinine in workers involved the direct treatment of batteries (Hanser, Melczer & Remy, 2022). Many other studies have emphasized on the occupational exposure of workers to cadmium and its negative health effects (Alli, 2015; Baloch, Kazi, Baig, Afridi, & Arain, 2020; Gil et al., 2011). Cadmium and cadmium compounds have been classified as Group 1 carcinogens by the International Agency for Research on Cancer (IARC, 2018). The World Health Organization (WHO) and the European Food Safety Authority (EFSA) have set a urinary cadmium level (UCd) of 5.24 μg/g creatinine as a threshold ((EFSA, 2011); WHO, 2007). As for the Occupational Safety and Health Administration, it has set the cadmium standard level to be less than 3.0 μg/g creatine (OSHA, 2012). The biologic half-life of cadmium in the kidney is estimated to be between 6 -38 years while the half-life of cadmium in the liver is 4 -19 years (ATSDR, 2012). These long half-lives reflect long-term storage of Cd in these organs and a slow excretion rate.

2.2.3. Toxicity of Mercury (Hg)

Although mercury exists naturally, it is also a man-made contaminant (Rice, Walker, Wu, Gillette, & Blough, 2014). Mercury (Hg) constitutes another metal that is hazardous to human health and its primary exposure occurs in the workplace from smelting operations and can lead to high intensity Hg vapor inhalation (ATSDR, 2015). At the workplace, workers may be exposed to Hg through using or breaking battery products containing mercury or through the inhalation of inorganic mercury compounds or toxic vapors formed from mercury vaporization (Ye et al., 2016). In a study conducted on a facility treating alkaline batteries in France, elevated urinary Hg in workers was reported to be associated with inadequate recycling practices (Hanser et al., 2022). Additionally, studies have confirmed that chronic exposure of workers to mercury vapor over longer periods of time can lead to damage to the lining of the lungs and mouth (ATSDR, 2015).

Another route by which people can get exposed to mercury is through its organic form that is methylmercury (MeHg), via fish consumption, dental fillings, or from improper disposal of medical wastes (ATSDR, 2015). Organic Mercury can cross the blood-brain barrier and target the central nervous system and its side effects can be manifested by tingling sensations, muscle weaknesses and slurred speech (Ye et al., 2016). Absorbed mercury may be converted to its inorganic form and damage the kidneys, leading to necrosis of the proximal tubule, and can damage the stomach and intestine (ATSDR, 2015), while the remaining Hg can enter the BBB and will be trapped in the brain for a long period of time (ATSDR, 2015). Mercury toxicity can also lead to negative health effects on the endocrine and the reproductive system, in addition to impaired neurological development in children (Rice et al., 2014). The average biological half-life of inhaled mercury is approximately 60 days in the human body (Rice et al., 2014).

2.3. Differences in Metals Toxicokinetic

These heavy metals have different absorption rates by the body, which is highly dependent on the route of exposure. Inhalation is reported to be the fastest way the human body absorbs these heavy metals (WHO, 2006). Pb is also shown to be absorbed through dermal exposure, whereas Cd absorption via dermal route seems to be minimal (WHO, 2006). Hg vapor has a high absorption by inhalation, at a rate of approximately 80%, given its high volatility, and shows a high systemic diffusion into various body organs (ATSDR, 2015; Ye et al., 2016). The acceptable blood lead level is less than 5 μg/dl, whereas that of blood mercury level is less than 10 μg/dl (CDC NHANES, 2014;

NIEHS, 2012). Although Cadmium exposure is better determined via urine, the acceptable blood level of cadmium is 0.03–0.12 µg/dl (WHO, 2006).

2.4. Impact on the Environment

Previous studies have reported that in industrial areas, the release of heavy metals is very high in nearby soil and vegetation when compared to other non-industrial areas (Krishna & Govil, 2005; M. Li, Luo, & Su, 2007). Heavy metal toxicity can affect plant growth through altering photosynthesis activity and damaging the root system (Shah, Ahmad, Masood, Peralta-Videa, & Ahmad, 2010). In this case, soil is a root cause not only because it allows plant growth but also because it constitutes a transmitter to many pollutants to surface water or groundwater. According to a study conducted in a lead battery factory in China, the shorter the distance to the factory, the higher the lead levels in surrounding soil and vegetation (Zhang et al., 2016). Another study showed that lead contaminated soils may be transported inside the home once it attaches to the shoes or pets and thus can be a moving contaminant (Johnston, Franklin, Roh, Austin, & Arora, 2019). On the other hand, a correlation was found between increased soil Pb levels in areas near a recycling facility and increased BLLs in children playing near this facility (Neesanan et al., 2011). In another study attempting to highlight the exposure risk arising from lead and cadmium in the top soil and vegetation around a battery recycling factory located near households in West Africa, high concentration levels of lead and cadmium were observed (Onianwa & Fakayode, 2000). Another study presented circumstantial evidence that Pb in environmental samples had an important influence on human uptake, and showed an elevated lead levels in soil of about 18 times compared to other non-battery facilities (Yeh et al., 1996).

Moreover, Pb can get adsorbed into soil and dissolved in water, leading to a significant alteration in the soil acidity and alkalinity, thereby affecting and endangering the growth of crops and the survival of aquatic organisms (H. Li et al., 2019). In a study conducted on soil and groundwater at two scrap iron and metal recycling facilities, pH levels of soil had reached a value of 3.5. This was presumably caused by the acid's leakage from the car batteries, and this low pH value has been shown to facilitate the migration of the metals into the depth of the soil and eventually reach groundwater (Jensen, Holm, & Christensen, 2000). Other studies have shown that food and vegetables are the main exposure pathways of metals from agricultural soils to the human body (Huang, Zhou, Sun, & Zhao, 2008). In conclusion, all these studies emphasize the concerns raised by the environmental pollution caused by battery recycling facilities and the need to address these problems to limit people's exposure to the toxic effects of these heavy metals.

2.5. Battery Recycling Facilities in Lebanon

The increase in the fleet of private cars in Lebanon has created an increased demand for Pb-acid batteries and the recycling of used batteries (Baaj, 2020). Lebanon has a very weak infrastructure and a limited institutional capacity to properly manage batteries and capture the values by reusing (repairing) and recycling (UNDP, n.d). Due to weak law enforcement in the country, most of this waste ends up in the hands of informal scrap-dealers or, in most cases, mixed up with regular municipal waste. Additionally, battery waste is expected to increase with the growing demand for solar panels that Lebanon is recently witnessing (Vizoso & Murr, 2022). Photovoltaic cells use different types of batteries including lead-acid batteries, lithium-ion batteries, Nickel-cadmium (NiCd) batteries, Nickel-metal hydride (NiMH) batteries and Sodium-sulfur (NaS) batteries, but the most commonly used type is Pb-acid battery because they are much less expensive and have a well-established manufacturing infrastructure (Chakraborty et al., 2022). The battery life spans of solar panels can vary from a few months to several years but will need to be changed evidently (Jossen, Garche, & Sauer, 2004). A few local NGOs are collecting batteries from households and institutions, but most do not possess a treatment process, or their service coverage and capacity are limited and thus do not reach a significant scale yet. Most recycling facilities in Lebanon treat only Pb batteries (Vizoso & Murr, 2022). More than 90 percent of the weight of lead-acid batteries can be recycled, and the recovered lead is sold according to its weight in fresh USD (Vizoso & Murr, 2022). Unlike lead-acid batteries, there are no recycling facilities in Lebanon that treat other types of batteries such as lithium-ion and Nickel-cadmium batteries (Vizoso & Murr, 2022).

CHAPTER 3

MATERIALS AND METHODS

3.1. Study Area

Upon inquiry, three major battery recycling facilities were identified to be active and serving Lebanon, one located in the capital city Beirut, another one in Tripoli, Northern Lebanon, and a third one located in the Bekaa, East of Lebanon (Fig.1).

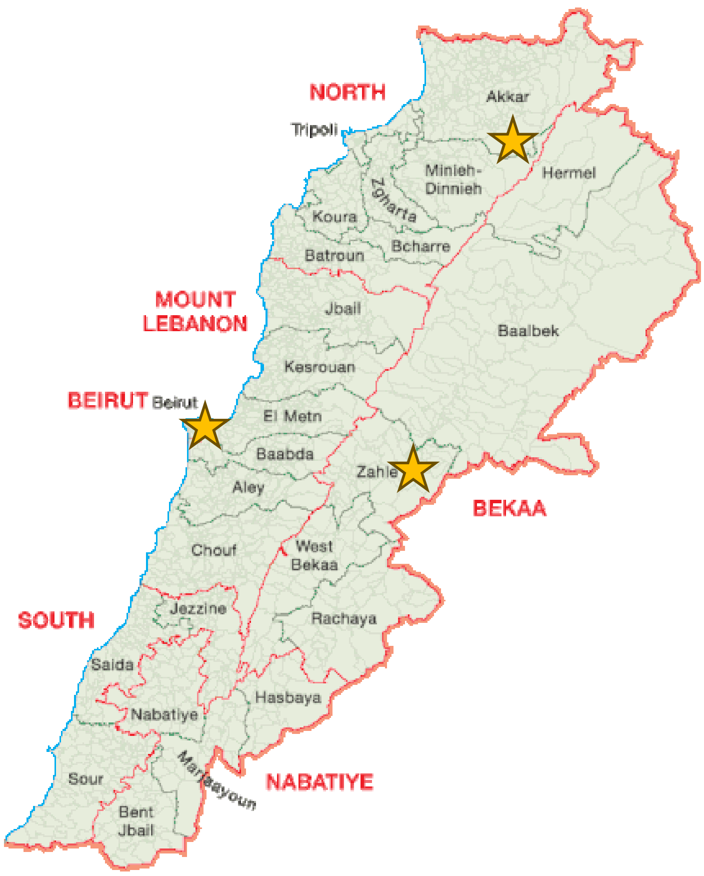

Figure 1. Lebanon Map showing the locations of the three recycling facilities. Retrieved from https://images.app.goo.gl/T2jJtM1KJe16TsyZ9.

3.2. Data Collection

Data was collected from all available workers, above 18 years of age, who worked at the facility on a full-time basis (8h/day), 5 days a week for the past 6 months and who volunteered to participate in this study. In addition, data was collected from managers of each facility.

For this purpose, two different structured questionnaires were used for data collection (Appendix A & B) - the first one targeting managers assessed practices related to facility characteristics, battery disposal and management procedures, and other legal requirements (Appendix A), and the second one targeting workers collected information (sociodemographic questions, job related questions, battery waste management practices, in addition to questions related to their medical history) (Appendix B). These questions were also administered to understand the measures taken by the facilities to decrease the occupational exposure of the workers to hazardous chemicals and to determine the safety of the workers during these activities.

All participants were assured of the anonymity of their identity and responses, and that their responses would not affect their work. Informed consent was obtained from all participants in this study. Ethical approval was obtained from the Institutional Review Board (IRB) at the American University of Beirut (AUB) prior to starting data collection (Appendix D).

Additionally, a workplace inspection for each of the targeted facilities was conducted according to a developed checklist (Appendix C), to characterize disposal methods and protective measures required. To be able to validate questionnaires, we first piloted the questionnaires internally and then proceeded to data collection once we insured that research protocols are well followed.

3.3. Environmental Sampling

Upon our visit to the three facilities, we began by inspecting the facility's boundaries and determining the direction of its operations. Accordingly, we were able to determine the areas that are mostly affected by the facilities' activities. We were able to collect two water samples and one soil sample from the Beirut facility, in addition to five soil samples from the Bekaa facility, amounting to eight environmental samples in total.

For the Beirut facility, we identified surrounding land areas that could have been impacted and sampled them. As for the Bekaa facility, and since no soil was identified onsite, we collected five soil samples in the vicinity of the facility, at 3, 5, 7, 9, and 11 meters from the facility. No soil samples were collected from the Tripoli facility.

As for water sampling, we obtained two water samples from the Beirut Facility, one sample collected from a water hose that supplies the facility, and another sample from the water tank which serves as a wastewater container. The container is supplied from discharges of activities of the industrial machine that breaks down the batteries and was therefore a potential indicator of the levels of contaminants resulting from the recycling process. No water samples were collected from the Tripoli or Bekaa Facility.

Accordingly, areas for soil sampling were located based on identified disposal locations for both solid and liquid wastes. Liquid samples of storage tanks used for recycling purposes as well as sub-surface soil within facilities and in their vicinities, were collected in plastic sampling tubes and labeled. Both water and soil sampling tubes were filled to the shoulder. Two grab sub-surface soil samples were obtained from the Beirut facility and five from the Bekaa facility from the surface layer at a moderate depth of 25-50 cm from the surface (EPA, 2017). Both water and soil samples were returned to the American University of Beirut's LEAF on ice and refrigerated at 4°C until processed. Additionally, we made sure that all tools were clean and free of rust before collecting the samples, and gloves were worn before and after sampling to prevent any contamination by hand.

3.4. Laboratory Analysis

3.4.1. Digestion and Heavy Metals Quantification

Collected water samples were analyzed for Pb, Hg, and Cd using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). The ICP-MS allows for a rapid and highly accurate testing of heavy metals with a low limit of quantification (LoQ). Soil samples were acid digested in a microwave-assisted digestor at 200 ^{o}C under high pressure before running them on the ICP-MS, to examine Pb, Cd and Hg levels. Briefly, 0.5g of collected soil was added to a microwave vessel and digested using 2mL concentrated nitric acid, 6mL concentrated hydrochloric acid, and 1mL concentrated hydrofluoric acid. Samples were then digested for around 30 minutes, reaching a maximum temperature of 200 ^{o}C using an Anton Paar Multiwave Microwave. After cooling, the samples were placed into metal-free Polypropylene (PP) tubes and filled up to a volume of 50mL using deionized water for dilution. Before being run on the ICP-MS, digested samples were filtered using a 0.45 µm filter. For soil, the LoQ were: 5 mg/Kg for Pb, and 0.5mg/kg for Cd and Hg. For water samples, the LoQ were: 5 ug/L for Pb, 0.5 ug/L for Cd and Hg.

When measuring heavy metals on the ICP-MS quantitatively, an 8-point calibration curve was created, using one standard for Pb and Cd and another standard for Hg. These were prepared on the day of analysis and run before the samples. Water and soil samples were also tested for pH values to check for any acid contamination. To test for the pH, 1g of each sample was inserted in 5 mL of deionized water, shaken well, and left for an hour. After an hour, the pH was tested using a pH meter.

3.4.2. Quality assurance/Quality control (QA/QC)

The ICPMS runs 1% nitric acid washes between each sample to ensure no cross contamination occurs between samples. Several washes were conducted at the beginning and end of each run to ensure a clean system. Metal free plastic tubing was used for the storing of the samples and the preparation of the standards. The vessels used were cleaned between each run, before running the digestion usings just acids and deionized water. One-time use disposable plastic pipettes were additionally utilized. All plastics used for analysis were rinsed twice with deionized water prior to usage. For the water, the quality control performed were a sample duplicate, a sample spiked (to check for any interference and recovery), a blank (deionized water) and a standard certified reference material (CRM). For the soil, the quality control performed were a blank (deionized water), a blank spiked (deionized water with 50ppb of Cd and Pb and 3ppb Hg), a certified reference (0.5g), a sample duplicate and a sample spiked.

3.5. Data Analysis

Since the sample size is too small, we opted for qualitative analysis. For the questionnaires, we were able to identify themes within the collected data and report on them (e.g.: adequate ventilation system, proper air monitoring, available wastewater treatment, etc.…). These themes were therefore compared between the three different recycling facilities and findings were then interpreted to draw associated conclusions and insights about each facility, and about the whole recycling process in Lebanon as well. As for environmental samples, water samples at the Beirut facility were compared between each other, one serving as a control and another as a potential indicator of contamination. Soil samples at the Bekaa facility were compared based on their distance from the facility and were then compared with the only soil sample from the Beirut facility. All environmental samples were subsequently compared with WHO guidelines for heavy metals in soil and Jordanian Standards for permissible limits of heavy metals in water.

CHAPTER 4

RESULTS AND DISCUSSION

4.1. Inspection Results

During the inspection of each battery recycling facility, several key aspects were evaluated to ensure compliance with regulatory standards, optimal performance, and employee safety, among which were (1) facility characteristics, (2) environmental compliance and (3) the occupational exposure of their workers. All three inspected facilities process lead-batteries, mostly automotive, collected from garages or scrapyards and batteries are received completely drained from their acid. Even though all three facilities process acid-drained batteries, only the facility in Bekaa reported that it often receives batteries full of acid and that it is equipped with the right machinery to drain it.

4.1.1. Facility Characteristics (refer to table 1)

All floors were clean and dry upon our entry to the recycling facilities and there were minimal signs of spills or leakage (refer to figure 2 & 3). The lighting was adequate in both the Bekaa and the Beirut facility, however it was very dim in the Tripoli facility and not adequate for normal work routine. Both the temperature and the humidity were not adequately controlled in the Beirut and Tripoli facilities, where the only ventilation system visible was a fan at the Beirut site (refer to figure 4), and none at the Tripoli site. Although the Bekaa facility does not have a proper ventilation system installed, the temperature and humidity were properly controlled. No safety signs were posted where there are spills in the three facilities, however, flammable materials and tools used onsite were properly stored away.

As for the storage area, no safe storage zone was noticeable in the Beirut and Tripoli facilities to prevent leakage by storm water runoff or soil contamination, and the containers were not adequately closed with lids and protected under roof nor were they leakproof or protective coated (refer to figure 5). However, the Bekaa facility had a proper storage area available and waste containers were adequately stored under roof.

Table 1. Facility Inspection Results.

Workplace Inspection Checklist	Beirut Facility (1)	Tripoli Facility (2)	Bekaa Facility (3)
Floors clean, dry & free from debris	Yes	Yes	Yes
Signs posted where there is hazardous material	No	No	No
Lighting Adequate	Yes	No	Yes
Temperature Adequate	No	No	Yes
Humidity Adequate	No	No	Yes
Signs of Container leakage	Yes	Yes	No
Tools safely stored	Yes	Yes	Yes
Flammable materials stored away	Yes	Yes	Yes
Adequate ventilation system	No	No	Yes
Safe storage area available	No	No	Yes
Hazardous substances properly stored	No	No	Yes
Labels warning on the containers	No	No	No
Containers with batteries closed with lids	No	No	No
Protective coated containers	No	No	Yes
Waste containers stored under roof	No	No	Yes
Emergency procedures displayed in the workplace	No	No	Yes
Walkways and aisle ways free of obstruction	Yes	Yes	Yes
First aid Provisions	Yes	No	Yes
Evacuation Signs	No	No	No
Extinguishers easily accessible	Yes	No	Yes
Employees trained on the use of extinguishers	Yes	No	Yes

Extinguishers free of corrosion and leakage	Yes	No	Yes
Extinguishers checked and maintained	Yes	No	Yes
Emergency eyewash in place	No	No	No
Bathrooms provided with soap/paper towel/tissues	No	No	Yes
Showers on site	No	No	No
Emergency shower	No	No	No
Eating areas separated from waste/hazardous material	No	No	Yes

Additionally, no emergency procedures were prominently displayed in the Beirut, Tripoli and Bekaa facilities, and no evacuation signs were visible in any. According to the managers of the Beirut and Bekaa facilities, first aid kits were available and stored at the managers' offices, and employees were well trained on their use. Fire extinguishers that are free of corrosion and regularly checked and maintained were easily accessible in the Beirut and Bekaa facilities, however no signs of any fire extinguishers or emergency preparedness equipment were seen at the Tripoli facility. Walkways and aisle ways were free of obstruction in all three facilities as seen in figure 2 and 3.

None of the three facilities had an emergency eyewash system in place or emergency shower. Only the Bekaa facility provided their workers with bathrooms, adequately equipped with soap and paper towels, and eating areas that were separated from the workplace.

Figure 2. The Beirut Recycling Facility.

Figure 3. The Tripoli Recycling Facility.

Figure 4. Ventilation System in the Beirut facility.

Figure 5. Storage Area in the Tripoli facility.

4.1.2. Environmental Compliance

All three facilities reported to adhere to environmental laws and regulations through environmental audits conducted by the Ministry of Environment. These facilities also hold permits for their industrial activities from the Ministry of Industry. The facility in Bekaa has its quality, safety, and environment (QSE) management system implemented and published on its website, stating that their operations fully meet the stringency of ISO 9001 and 14000 guidelines. The other two facilities claimed to follow basic safety guidelines in the workplace, such as the use of personal protective equipment (PPEs), and other requirements related to the documentation of incidents, the safe use and disposal of hazardous substances and the proper training of employees. These PPEs include industrial gloves and safety impermeable boots (refer to figure 6), however, employees were not issued with separate work clothing.

.

Figure 6. PPEs at the Beirut Facility.

The only respirator policy employed in the three facilities to reduce the exposure of workers to harmful substances is the use of industrial masks. Although the manager of the Beirut facility claims to have provided their employees with industrial masks, none of the employees were wearing them at the time of our visit (figure 6).

As for their disposal strategies, the Beirut and Tripoli facilities do not have any treatment system in place to treat the effluent water used during the recycling process, while the Bekaa facility claims to have a wastewater treatment system in place that allows the facility to re-use the same water for recurrent activities. The manager interviewed in the Bekaa facility claims that this system allows them to restrict the discharge of any contaminated wastewater. Additionally, this same treatment system is where the drained acid is discharged and recycled. Furthermore, all processes are ventilated into a baghouse with all fumes recycled and re-added to the furnace throughout the process, resulting in minimal waste.

Finally, all three facilities were located in an industrial zone, therefore there was no close contact with houses or occupied buildings. The three facilities did not have their own collection logistics as they are all supplied by a third party that transports and delivers the batteries to their facility. However, they all had a licensed open truck (refer to figure 7) for the transportation of batteries/compartment of batteries, which was not exclusively used for battery waste only, but also for other uses like the transport of paper residues to landfills at the end of the operation (figure 8). None of the three facilities had a closed truck that can prevent leakage and the direct exposure of waste to the sun.

Figure 7. Open Truck at the Beirut Facility.

Figure 8. Paper compartments resulting from the recycling process
(taken at the Beirut facility).

4.1.3. Occupational Health Measures

Workers' blood lead levels are never tested in the Beirut facility. The Tripoli facility claims to test them annually to check for the health of their workers and keep them documented in their files and stored at their offices, while the Bekaa facility checks them every 4 months. According to the managers, no irregular blood lead levels were ever noticed, however these documents were not shared with us, and managers of the Tripoli and Bekaa facilities reported that they do not submit these results to any authority. The managers of the three facilities stated that all employees undergo safety orientation that ensures that they are completely aware of the business operations and their responsibility within the company. Toolbox meetings that entail health and safety discussions are generally organized every 6 months in the Beirut and Bekaa facility, however no meetings are held at the Tripoli Facility. All incidents and accidents that happen onsite are documented and later investigated by the facility management and the insurance company. The three facilities, however, do not abide by any specific law related to the documentation of such incidents.

4.2. Assessment Managers Survey Results

Interviewed managers included amounted to three, one in each of the inspected facilities. We were additionally provided with the number of workers within each facility, ranging from 5-15 in Beirut, 15-20 in Tripoli, and more than 20 workers in the Bekaa facility.

According to all three managers, there are no recycling facilities in Lebanon that handle other types of batteries (such as portable or rechargeable batteries that are either lithium, Ni-Cd, alkaline or mercury containing batteries). The manager of the Tripoli facility claimed that they pay a fee of 900 (USD/ton) to their source for acquiring the old batteries. The manager of the Beirut facility claimed that the price of the used batteries fluctuates based on the international pricing of Pb and that it is usually between 960$ to 1000$ per ton. On the other hand, no price value was obtained from the manager of the Bekaa facility. Moreover, all three facilities agreed that the Pb resulting from the recycling process is sold based on the daily rate of the London Metal Exchange rate (LME) per USD/ton. Based on the LME rate, the pricing of Pb varies daily, and it fluctuates between 2018.75 to 2029.25 USD/ton (LME, n.d).

4.2.1. Dynamics of Battery Waste Management

According to the managers of the three facilities, the recycling process is similar in each facility and is divided into the following main steps (Figure 9):

Pre-Recycling: Collection & Transport

Metal collectors/ Scrapdealers	Dismantling of batteries & Acid Drainage	Occupational exposure to sulfuric acid	Intermediate storage	Transportation to the recycling facility

Preparation for Recycling/ Battery Treatment

Sorting drained batteries from non-drained ones	Possible acid leakage to surrounding soil or water	Occupational Exposure

Recycling: Battery Breakage via Industrial Machine & Components Separation

Lead paste	Polypropylene & Paper components	Dust Gas emission	Water waste	Occupational Exposure

Smelting of Pb in Rotary Furnace

Occupational Hazards	Furnace Gas emissions

Refining of Pb

Pb alloys	Pb ammunition	Pb sheets

Final End-products

Pb is sold based on LME rate	Plastic is sold	Paper components are discharged in landfill

Figure 9 Recycling Process Steps of Pb-acid batteries and Potential Exposure

The first step is the pre-recycling step, and it is usually outsourced to the metal dealers or scrapyard owners. This step consists of the collection, transport, acid drainage and storage of batteries until used Pb acid batteries (ULABs) reach the recycling facility. Hence, the existing infrastructure is based on the collectors' model which consists of metal scrapyard owners that collect the used batteries mostly from automotive parts. Metal scrapyard owners drain these batteries from their acid and store them before selling them to these recycling facilities. Some retailers also do intermediate storage. ULAB dealers can also include garages that have automotive batteries dropped at their facility in addition to Photovoltaic (PV) companies' owners. Upon receiving batteries to the recycling facility, all used lead batteries get packed in a loose and upright manner in front of the sorting machine. The Bekaa facility on the other hand, had a palletized and wrapped way of organizing the received batteries inside the facility. After receiving the batteries, they immediately get sorted via an industrial machine (figure 10). The Bekaa facility reports using an additional layer of sorting, where a supervisor checks on the batteries to insure prior drainage of acids and separate drained from non-drained ones.

The occupationally exposed participants are therefore involved in battery management or recycling activities, either in the pre-recycling phase (collection and transportation), or in the treatment phase (sorting, preparation for recycling or preparation for disposal), or during the recycling process (battery breakage, smelting, and recovery of metals) since these activities are likely to expose individuals to the heavy metals studied.

Once acid-drained batteries are sorted, recycling consists of battery breakage, and recovery of Pb and plastic compartments. In all three facilities, the battery breakage is conducted via an industrial machine that breaks all the components of the acid-drained lead batteries. All three managers agreed that the batteries are immediately broken upon arrival without any storage. After the breaking process, the lead is collected and channeled to closed furnaces for smelting and refining and then piped into casting molds (Fig. 11).

Figure 10. Industrial machine used to break the battery compartments.

Figure 11. Casting molds in which the smelted lead is placed.

The collection frequency of the three facilities is daily, and received batteries are sorted by date of receiving and not by size. When asked about the quantity of batteries recycled per month, the Bekaa facility had the highest number reaching an amount of 250 tons, followed by the Beirut facility with a total of 200 tons, and last the Tripoli facility with an approximate total of 100 -150 tons. The managers in Beirut and Bekaa stated that the amount of batteries is growing annually, especially because of the increased use of PV systems with a stated 5% increase at the Beirut facility and a 10% increase for the Bekaa site. The manager of the Tripoli facility, however, gave no opinion regarding an increase in the business.

After the disposal of the received batteries in the crushing machine, all the components of the batteries, including Pb, plastic, and paper are separated. The parts containing Pb are collected at the end of the machine while the plastic and paper are discharged into a large water tank inside the facility, where the separation of the plastics and paper happens (refer to Fig. 12). Separation happens on a gravity basis when the plastic components reach the surface of the well and are then collected and sold to plastic recycling facilities, and the paper that sinks to the bottom of the well is collected and transferred inside the furnace.

The non-metallic or the plastic pellets can be re-used in the manufacturing of new battery casings or other goods. The metallic elements or Pb can be re-used to make grid plates or alloys utilized to make a new lead battery (refer to Fig. 13) or Pb ammunition (refer to Fig. 14) or even lead sheets used in x-ray shielding at hospitals. The facility in Beirut claims to be the only one to manufacture lead sheets that are used in hospitals as radiation shielding sheets, additionally to the other types of lead end-products. On the other hand, the facility in Bekaa claims to be the only one to export Pb products abroad, to institutions using Pb alloys, either for the manufacturing of new batteries or other, and the plastic polypropylene in a wide variety of applications such as thermal paints, laboratory equipment, and automotive components.

The liquid tank with all the acid electrolyte, if any, is drawn off. No records of where the final disposal of this wastewater is happening in the Beirut and Tripoli facilities. However, the Bekaa manager claimed to have a wastewater treatment system (discussed earlier) that recycles all water that is drawn off from the industrial machine. This water is re-used for the same recycling activities, resulting in no water waste discharged outside of the facility.

The gas emissions and dust particles resulting from the furnace are managed by filters installed on these furnaces, abiding by the regulations of the Ministry of the Environment. The Beirut manager claimed installing a baghouse filter named UK filter bag 218 to control furnace emissions. No filter specs that allegedly control the furnace emissions were obtained from the managers of the Bekaa and the Tripoli facilities. Even though air pollution control technology is placed on the exit of each furnace, black smoke was still showing from the exhaust of the facilities.

Figure 12. Wastewater tanks inside the facility where the separation of plastic and water happens.

Figure 13. Pb alloys as a result of the recycling process.

Figure 14. Pb ammunition resulting from the recycling process.

4.3. Assessment Workers Survey Results

4.3.1. Sociodemographic (Table 2)

Interviewed workers amounted to a total of 8. A total of five workers from the Beirut facility were interviewed and three in the Beqaa facility. We were not able to interview any of the workers at the Tripoli facility as the supervisor of the facility claimed that it has been closed for a long time and upon our visit, no workers were seen at the workplace.

All workers involved in this study were male, 75% of them were married while the other 25% were single. 75% of them were aged between 35 to 50 years, while the remaining 25% were older than 50. When asked about their highest level of education, 25% of them answered that they have not been admitted to any school, 62.5% replied that they have been to elementary class while 12.5% of them had a high school degree. Regarding the tasks that these workers performed in the facility and among the ones that participated, 25% were responsible for collection/transport, 12.5% for sorting and the remaining 62.5% for smelting and refining. 37.5% of the workers have been in the facility for more than 20 years, 25% of them have been working from 10 -20 years, the other 25% between 5 to 10 years and 12.5% of them for a period of 1 to 5 years (refer to figure 15).

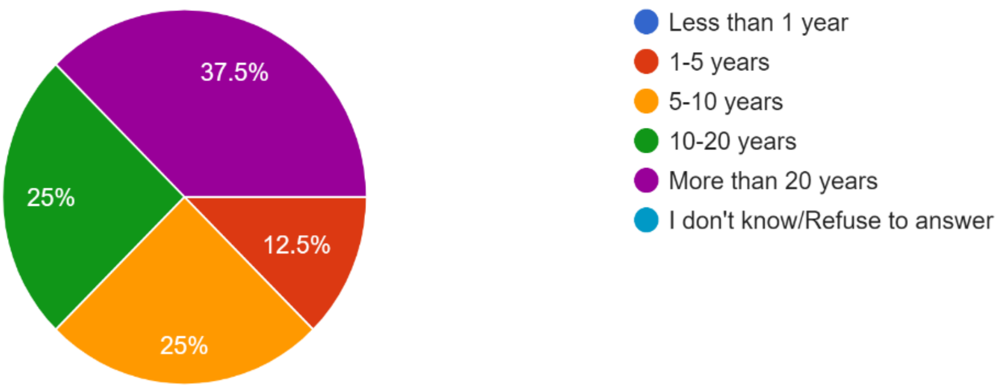

Figure 15. Estimated work time period of the workers in the three facilities.

None of the interviewed workers served at another battery management facility prior to their current job, and none of them consumed alcohol. When asked about their smoking habits, 50% of them smoked and the other 50% were non-smokers. Most of the smokers were heavy smokers consuming two packs a day, others claimed that they smoke Shisha regularly. 50% of them did medical checkups while the other 50% did not. Out of the eight workers interviewed, 75% of them reported wearing personal protective equipment in the workplace, while the other 25% that were involved in collection and transport did not. All workers considered that they get exposed to dust/fumes during the recycling process and that working in a recycling facility is somehow hazardous. All workers that participated in this research agreed that all batteries are broken via an industrial crushing machine and that no battery is being broken manually.

Table 2. Sociodemographic results of workers' questionnaires.

Variables	**n=8**	**%**
Gender		
Male	8	100
Female	0	0
Age (years)		
<18	0	0
Between 18-35	2	25
Between 35-50	4	50
>50	2	25
Marital Status		
Married	6	75
Single	2	25
Widowed	0	0
Divorced	0	0
Education		
No Education	2	25
Elementary	5	62.5
Highschool	1	12.5
Bachelor's Degree	0	0
Master's Degree	0	0
Smoking Status		
Yes	4	50
No	4	50
Alcohol Consumer		
Yes	0	0
No	8	100
Occupation within the facility		
Collection/ Transport	2	25
Sorting	1	12.5
Smelting & Refining	5	62.5
Regular Medical Checkups		
Yes	4	50
No	4	50

4.3.2. *Workers Medical History*

When asked about their medical history, three of them claimed to have problems related to high blood pressure and high cholesterol, while none of them were diagnosed with any kidney or lung problems such as COPD or difficulty breathing. None of them reported to have been diagnosed with cancer or other skin problems like eczema, and only one of them was diagnosed with diabetes. Additionally, none of them had a history of seizures or health problems such as osteoporosis or episodes of severe vomiting. Three out of ten claimed to feel numbness and fatigue and only one of them suffers from migraine and lack of sleep. Finally, none of the workers have had their blood metal levels checked, and they all report that they have not been diagnosed with any vitamin or mineral deficiency or any type of iron deficiency or anemia. Finally, they all confirmed that they do not take any vitamin/mineral supplements.

4.3.3. *Report on Battery Recycling Process*

Regarding the Beirut facility, all workers confirmed that the recycled batteries are packed in open air upon receiving them from the source, while all three workers at the Bekaa facility agreed that they are packaged before transferring them into the crushing machine. Additionally, when asked about the final disposal of the acid, all five workers from the Beirut facility agreed that they receive batteries drained from their acid, while the other three in Bekaa said that they sometimes receive some batteries with their acid to which they own a specific equipment to drain. They also agreed that this acid is discharged in a water treatment filter that filters all recycling activities that involve water inside the facility. The effluent water is therefore re-used inside the facility, while no treatment plan for the water at the Beirut facility has been confirmed by the workers. All workers at both facilities stated that they would be happy to be trained or given any technical support to reduce their exposure to hazards at the workplace.

4.4. Water and Soil Testing

Results of the heavy metals Lead (Pb), Cadmium (Cd) and Mercury (Hg) in the water and soil samples of the Beirut and Bekaa facilities in addition to their pH are summarized in Table 3. The different standards for permissible heavy metals in soils that are used for the comparative analysis are displayed in Table 5.

4.4.1. Heavy Metals and pH in soil

The soil sample collected from the Beirut facility, taken at approximately 2 meters near the disposal site of the furnace showed high levels of lead with a value of 39.0 g/Kg. As for the results of the soil sampling at the Bekaa facility, and since these samples were taken at the vicinity of the facility, and at different intervals, they were not as polluted with Pb as the one taken from the Beirut facility. Additionally, as expected, soil Pb levels decreased steadily with distance in the Bekaa facility (figure 16). However, soil sample 4 showed a Pb level that was higher than all other values taken at the Bekaa facility, despite its distance. This constitutes a potential indicator of previous contamination with Pb. When compared with the WHO standard limit for Pb in soil, all soil samples were higher than the permissible limit of 0.09-0.4g/kg. However, no comparison should be made between the soil samples taken at the Bekaa and the one in Beirut as they were all taken from different spots of the recycling facilities and cannot provide us with a critical analysis.

Cd levels in the soil sample of Beirut showed a significant level, which was higher than the WHO permissible limit for Cd in soil and was higher than the levels scored at the Bekaa facility. As for Cd results in the Bekaa, all soil samples exceeded the WHO limit value, and the values were irrespective of the distance in which the sampling occurred. Therefore, no patterns of association between levels of Cd and the distance from the facility can be concluded. As for Hg levels in soil samples of both facilities, no levels were detected as they were less than the LoQ for Hg.

Regarding the pH values of the soil in the vicinity of the Bekaa facility, sample 1 and 2 were neutral, while the pH of samples 3, 4 and 5 were alkaline. These pH values were taken at these specific spots to determine if any acid leakage is being discharged in the vicinity of the facility, or if any batteries were being drained from their acid in the vicinity. The results were negative for acid leakage as most of these pH were neutral to alkaline, showing no signs of acid leakage and confirming that no activity related to acid drainage is occurring. As for the soil sample of the Beirut facility, pH levels showed an alkaline milieu, additionally proving that no acid is being discharged near the furnace.

4.4.2. Heavy Metals and pH in liquid discharge

Starting with Pb, water sample 1 that was collected from the water tank inside the Beirut facility serving as a discharge from the crushing process of the industrial machine showed high levels of Pb with a value of 717 ug/L, whereas sample 2 that was collected from a water hose used inside the facility and which served as a control, had non-detectable levels of Pb. The water sample 1 exceeded by far the Jordanian Standard for water discharge to streams and indicates high contamination levels (WHO, 2006).

For Cd, water sample 1 exceeded the limits set by the Jordanian Standard but was not as high as the levels of Pb found in the same sample. However, Cd levels in water sample 2 were not detected showing no signs of potential contamination.

Hg water levels were not detected in both samples as they were less than the LoQ, therefore no quantitative value was obtained, and results could be not reported. As for pH values, water sample 1, scored the lowest pH with a value of 4.46, indicating a very acidic milieu (Table 4). Since water sample 1 serves as the tank water being discharged from the machine, and since the battery-breaking machine can generate acidic waste, the water can become highly contaminated by this waste leading to this observed drop in pH levels. This can also indicate that the batteries are not being 100% drained from their acid. This can be additionally confirmed by the pH results of water sample 2 that served as a control, which was slightly acidic but very close to neutral.

Table 3. Results of the water and soil samples[1,2].

Location	Matrix Type	Pb Levels (g/Kg)	Cd Levels (mg/Kg)	Hg Levels	pH
Beirut	WS1 [3,4]	717 ug/L	1.08 ug/L	Nd	4.46
	WS2 [3,4]	Nd	Nd	Nd	6.28
	SS1	39.0	3.68	Nd	7.73
Bekaa	SS1 (3m) *	4.33	2.12	Nd	6.69
	SS2 (5m) *	3.51	2.14	Nd	7.13
	SS3 (7m) *	2.98	1.73	Nd	7.51
	SS4 (9m) *	4.47	2.62	Nd	7.78
	SS5 (11m) *	2.77	1.69	Nd	7.84

*Sampling distance from the facility in meters

1 For water, LoQ is 5 ug/L for Pb, and 0.5 ug/L for Cd and Hg
2 For soil, LoQ is 5mg/kg for Pb, and 0.5mg/kg for Cd and Hg
3 Jordanian Standards for Pb in water discharge to streams is 0.0002 ug/L (WHO, 2006)
4 Jordanian Standards for Cd in water discharge to streams is 0.00001 ug/L (WHO, 2006)

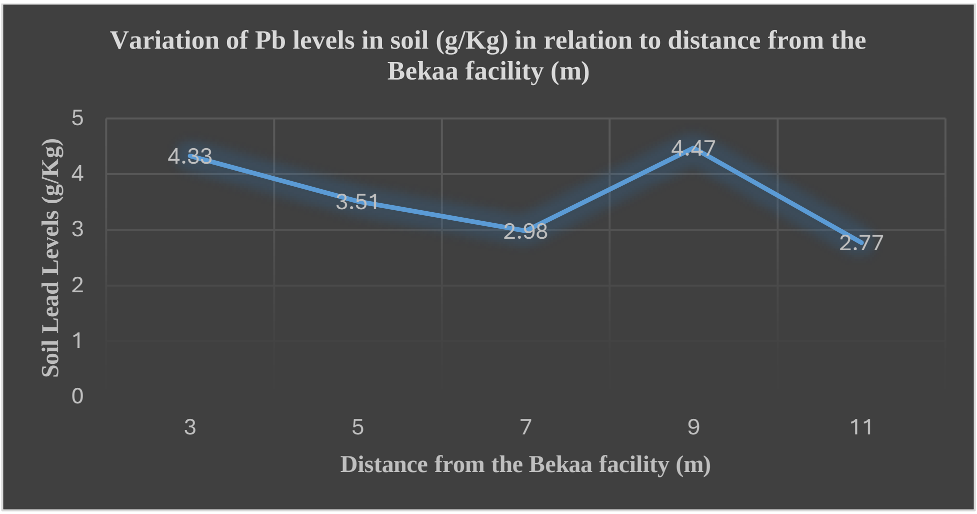

Figure 16. Variation of Pb levels in soil (g/Kg) in relation to distance from the Bekaa facility (m)

Table 4. Soil pH range, Retrieved from https://www.qld.gov.au/

pH <6.5	Acidic milieu
pH Between 6.5 to 7.5	Neutral milieu
pH >7.5	Alkaline milieu

Table 5 Heavy Metals Permissible soil limits as per different standards (Adie et al., 2022; Asemave & Anhwange, 2012 cited in Adie et al., 2022; Hong et al., 2014)

Standards/Guidelines	Pb (mg/kg)	Cd (mg/kg)	Hg (mg/kg)
WHO	90-400	0.002-0.5	1.0
EU	0.30	0.003	-
United States	50-300	1.6	0.5
Poland	70-150	1-3	5
Germany	100	1.5-3	2
Austria	100	5	5

4.5. Discussion

To the best of our knowledge, this is the first study to explore the occupational exposure and the level of environmental pollution caused by battery recycling facilities in Lebanon. In summary, the draining of acid occurs at scrap yards in most cases, and received batteries are acid-free. This greatly minimizes any acid leakage to the surrounding soil and water of the recycling facilities. However, acid leakage is occurring at scrapyards and is not being regulated by proper authorities. This improper draining and disposal of acid from lead-acid batteries can have severe consequences on the environment, causing harm to local ecosystems and potentially posing severe health risks to the public health.

Additionally, although managers claim that no waste is resulting from this recycling process, as every battery component is recycled for reuse, in the Beirut and Tripoli facilities, no apparent wastewater treatment plan is being put in place and the final discharge of the tank water used for recycling facilities is still unknown and should be further investigated. As for the Bekaa facility, although its manager claimed to have a wastewater treatment plan in place, no further information or evidence was given and permission for inspection was not granted by the manager. This should be further investigated by proper authorities to make sure that all water pollutants are being properly treated.

No safety measures were put in place by the owners of the workshops to protect the workers from Pb exposure except for the provision of gloves and boots. Although PPEs are being provided for certain steps of the process, more specific equipment is needed to decrease the occupational exposure of the workers, like separate work clothing, industrial face masks, leakproof gloves, safety signs, first aid provisions and adequate washrooms.

The reported medical history of the workers shows no particular occupational illnesses. At the same time, it is important to emphasize that workers did not undergo blood monitoring and that fear that their responses might influence their work or relationship with their supervisor, might be undermining their answers.

Furthermore, the results of the inspection checklist revealed inadequate storage and handling of batteries in the Beirut and Tripoli facilities. Batteries were stacked in piles without any form of containment, increasing the risks of accidental leaks and spills, specifically if any of the batteries had remaining acid. This improper storage and handling of batteries can lead to several adverse effects, such as fires and explosions. Nevertheless, the lack of a ventilation system that could lead to the inhalation of dust and fumes by the workers is also one of the issues that need to be addressed in the Beirut and Tripoli facilities.

On the other hand, the inspection results found that the facilities' employees were adequately trained on the proper battery recycling procedures and safety protocols, indicating an adequate implementation of emergency preparedness and response protocols. Furthermore, the three facilities had proper communication between employer and employee, and employees were aware of the risks and hazards that they were exposed to, confirming that the supervisors of the facilities accurately presented their workers with the hazardous facts associated with their job.

Overall, the Bekaa facility had implemented efficient regulations in terms of actions put in place to ensure a proper working environment for the workers and in terms of mitigating the environmental impact of waste and hazardous substances disposal.

These actions include the adequate storage and handling of batteries, adequate wastewater management practices, proper training of the employees, proper documentation of accidents and incidents, adequate emergency preparedness and response and finally, proper air quality monitoring.

All environmental samples collected and tested for Pb and Cd were higher than the WHO permissible level of Pb in soil and water, which demonstrates that the activities of these facilities heavily impact the surrounding environment, even if precautionary measures are being taken into consideration. Additionally, even though these battery recycling facilities are situated in designated industrial zones, their activities can still have adverse effects on the environment and should be mitigated.

Furthermore, the water tanks that are contaminated mainly with lead and sulfuric acid, arise principally during lead recovery from scrap batteries or may result from the presence of acid in the batteries or from Pb not being 100% recovered. The resulting water is highly acidic and heavily laden with Pb and is being discharged randomly with no wastewater treatment plan at both the Beirut and Tripoli facilities. The acidic pH of water in the workshop further indicates that the batteries were not completely drained from their acid, and that some batteries that are being broken down by the industrial machine still contain remaining acid.

CHAPTER 5

LIMITATIONS, CHALLENGES, CONCLUSIONS & RECOMMENDATIONS

5.1. Limitations & Challenges

Several limitations and challenges were faced throughout the preparation and execution phases of this thesis work. One of the primary challenges was gaining access to the facilities themselves, as well as obtaining accurate and up-to-date information on their operations. The battery recycling facilities visited are private entities and some were hesitant to provide detailed information about their business and consequences of potential environmental impact outputs. Additionally, the reluctance of workers to provide candid responses in the presence of their supervisors and how their responses may be perceived by their superiors, might have impacted the validity of the collected data, and constitutes another limitation.

Another limitation that was encountered during the implementation of this study was during the data collection. For soil sampling, metals may be more ubiquitous in urban areas where construction, transportation, manufacturing, and fossil fuel combustion are more common. The results of soil analysis may be influenced by other activities or sources in the same industrial zone. Additionally, we were unable to collect environmental samples from all three facilities to be able to conduct a proper comparative analysis accordingly. As for assessing workers' exposure to hazardous substances through blood and urine samples, we were not able to obtain biospecimen samples due to the disaccord of the facilities' owners.

Furthermore, one significant limitation that has been encountered in our study is the failure to adequately address the context of the facility within the industrial zone in which it is located. By not accounting for the surrounding industrial facilities and their respective functions, it becomes challenging to assess the facility's environmental impact to be able to accurately evaluate the potential for mitigation measures. For this, a more critical analysis of the environmental footprints of the three facilities should be more efficiently addressed in future studies, particularly through mapping the surrounding facilities within the same industrial zone and their activities.

Another limitation of our study is studying the air quality within inspected facilities, which could have helped to better shed the light on the occupational exposure.

Finally, the rainy weather also constituted another challenge that we faced and may have altered our soil analysis at the Bekaa facility and therefore our results, as heavy metals may have eroded from the topsoil by rainwater while we targeted the sub-surface only.

5.2. Recommendations

At the regulatory level, it is evident that there is an urgent need for action to combat the polluting activities of scrapyards that dismantle batteries and drain the acid without any form of containment. These activities are not regulated by the ministry of environment and pose significant challenges to the environment and public health and for this, we recommend regulating this sector and enforcing the shutdown of scrapyards that engage in irresponsible battery acid drainage practices. Additionally, to effectively address the mismanagement practices of battery recycling facilities, a multi-faceted approach is needed. This includes implementing stricter regulatory measures and law enforcement related to the proper disposal of waste materials in accordance with local and international regulations. Furthermore, frequent inspection visits by the ministry should be scheduled in addition to regular monitoring and testing of wastewater and soil to ensure the facility’s compliance with environmental standards. This should be also coupled with raising awareness among end-users about the importance of battery recycling so that the end-user behavior is shaped to adopt right disposal practices (disposing the batteries correctly instead of hoarding them or disposing of them with other waste).

Although battery recycling facilities are a thriving business, as indicated by their large scale of operations and significant profits, yet, there is an apparent lack of adherence to pollution control measures, despite having the financial means to implement them. This may be attributed to the lack of law enforcement, which allows these facilities to operate without adhering to pollution control standards. Hence, there is a need to implement appropriate environmental control at the engineering level, for air, soil, and water pollution. For instance, in order to effectively capture and contain the hazardous heavy metals emissions caused during the breaking of batteries and the refining of Pb, we recommend the installation of adequate ventilation systems, such as central vacuum systems or dust collection systems. The central vacuum system offers a comprehensive solution for dust control, providing efficient suction and filtration capabilities at source. The US Occupational Safety and Health Agency (OSHA) recommends the use of laminar flow (supplied-air) island systems (SAI), that are designed to be installed above the crushing machine and the furnace, which are the two most polluting equipment at the facility. The SAI provides an envelope of clean air to the employee that remains in a stationary position above the machine for long periods of time. Many other types of vacuum systems can be employed in battery recycling facilities, such as the wet vacuum system and the High-Efficiency Particulate Air vacuum system (HEPA). Additionally, for effluent water control, we recommend the use of a combination of effluent water control technologies to effectively treat their wastewater discharge and minimize their environmental impact. These methods may include the chemical precipitation strategy that removes pollutants through sedimentation or filtration processes (Matlock, Howerton & Atwood, 2002). Another cost-effective mean is the ion exchange method that involves running the effluent water through ion exchange resins, selectively removing heavy metals (Al-Enezi, Hamoda & Fawzi, 2004; Arbabi, Hemati & Amiri, 2015).

At the same time, in case any of the batteries is collected with acid, the battery should be drained and prepared for recycling by trained and adequately protected personnel. This should also be implemented properly in scrapyards where no regulations are being followed. It is also important to stress the need to have an acid resistant floor, and proper leakproof containers to collect the acid and avoid its discharge to surrounding soil or water (Baloch et al., 2020). In operational areas, a ground cover should always be utilized to retain any leakage and direct it to a collecting container from where it can be removed (Gottesfeld & Pokhrel, 2011). Operational surfaces as well, should be resistant to chemicals and fire. If any, storage of waste batteries must take place in a covered place, on impermeable and acid resistant surface. As concrete is highly vulnerable to corrosion by acid, the floor should be covered with an acid-resistant epoxy coating (OSHA, n.d).

Battery storing containers should be leakproof, sheltered and not affected by ambient conditions such as sunlight, temperature, and water (Baloch et al., 2020;

OSHA, n.d). Additionally, and upon arrival, batteries should be arranged in a position that does not obstruct the doorway or any entrance passage. Containers must be clearly labelled regarding the nature of the waste and relevant danger symbols must be put in place. Managers as well as workers must be well-informed about the hazards and consequences of stacking batteries in a random hazardous manner, which can lead to several adverse effects, such as fires and explosions. For this, we recommend the use of safety signs and regular maintenance of fire extinguishers. Furthermore, transport vehicles should be sealed from under with stainless steel to prevent leakage and should be closed (Baloch et al., 2020; WHO, 2021).

At the occupational level, the use of industrial protective face masks by workers while on duty to prevent inhalation of heavy metal fumes is a must. Exposed workers should be trained on personal safety measures, including the importance of continuously washing their hands and face before eating at the workplace and changing their clothes at work before going home. Additionally, they should avoid wearing work clothes in their homes as Pb may be transported on the workers' clothes (Chiaradia, Gulson & MacDonald, 1997). In the recycling phase, workers may be exposed to lead acid batteries components that contain potentially combustible material, plastics, and Class 8 Corrosive Hazardous material such as sulfuric acid. Facilities should provide their workers with goggles, industrial gloves and masks, safety shoes and stress on the importance of wearing them (Danadevi, Rozati, Banu, Rao, & Grover, 2003; Hsiao, Wu, Lai, & Kuo, 2001b). Furthermore, workers should undergo regular biological monitoring for their body metals levels to make sure they are not excessively exposed.

Finally, and given the known health implications of elevated heavy metals levels in the environment, the high concentrations obtained from this study underline the need for further studies which should include a detailed assessment of BLLs of workers at the facilities to determine exposure risks. It also calls for a detailed examination of the waste management practices of battery recycling facilities in Lebanon to ensure environmental compliance and promote sustainable practices.

5.3. Conclusion

The battery recycling industry represents a critical sector where potential exposure to toxic and hazardous material is a reality and is of major concern to the environment and human health. Findings of this study have demonstrated that battery recyclers in Lebanon are at a high risk of exposure to heavy metals in their workplace. Through soil and water testing, it was additionally revealed that the levels of Pb, a highly toxic heavy metal, were significantly elevated in the vicinity of battery recycling facilities, indicating the potential for environmental contamination. The presence of these heavy metals in the workplace highlights the urgent need for stricter regulations and the enforcement of proper safety measures to be implemented in the battery recycling industry. To limit the diffusion of contamination, a range of preventive measures should be implemented, focusing on more efficient ways to capture these heavy metals and contain them in an environmentally friendly manner. It is imperative that steps are taken to protect the workers and the environment from the harmful effects of heavy metal exposure. Further research and continued monitoring are necessary to address this issue and ensure the well-being of all those involved in the battery recycling process.

APPENDIX A

QUESTIONNAIRE FOR THE MANAGERS OF THE RECYCLING FACILITY

Appendix A- Questionnaire for the Manager of the Recycling Facility

Research Title: Battery Disposal Management in Lebanon: Environmental Pollution and Occupational Exposure

Date of the questionnaire: _______________

Location of the facility:

1) Beirut
2) Tripoli
3) Saida
4) Beqaa

Section No. and Title	Questions	Answers
I. Typology of the batteries and Facility Characteristics	1. Select all the type of batteries that are collected at the facility (Refer to Appendix F)	1) Lead batteries 2) Ni-Cd batteries 3) Mercury containing batteries 4) Lithium batteries 5) Alkaline batteries 6) Other, specify: 99) I don't know/ Refuse to answer
	2. Quantity of each class/type of batteries collected in tons/month	1) Lead batteries, Quantity: ______ 2) Ni-Cd batteries, Quantity: ______ 3) Mercury containing batteries, Quantity: ______ 4) Lithium batteries, Quantity: ______ 5) Alkaline batteries, Quantity: ______ 6) Other, specify:_____, Quantity: ______ 99) I don't know/ Refuse to answer
	3. Kind (usage) of batteries collected and recycled (More than one answers could be selected)	1) Car 2) Motorcycle 3) UPS-security 4) PV 5) Other, specify: 99) I don't know/ Refuse to answer
	4. Initial Source(s) of the batteries collected	1) Garages 2) Retailers

APPENDIX B

QUESTIONNAIRE SAMPLE FOR THE WORKERS

Appendix D – Questionnaire sample for the workers

Research Title: **Battery Disposal Management in Lebanon: Environmental Pollution and Occupational Exposure.**

Date of the Interview:/……/………...

Category	Questions	Answers
I. Sociodemographic Questions	1. Location	1) Beirut 2) Tripoli 3) Saida 4) Beqaa
	2. Sex	1) Male 2) Female
	3. How old are you? (Years)	
	4. What is your current marital status?	1) Married 2) Single 3) Widowed 4) Divorced 5) Separated 99) Refuse to answer
	5. What is your highest level of education?	1) No education 2) Elementary 3) Highschool /bac 4) Bachelor's degree 5) Master's level degree 99) Refuse to answer
	6. What tasks do you perform in this facility?	1) Treatment of the batteries 2) Recycling process 3) Collection and transport 4) Smelting 5) Refining 6) Others, specify: 99) Refuse to answer
	7. How long have you worked in this facility?	1)____(years)____(months)___(days) 99) I don't know/ Refuse to answer
	8. Did you work at another battery management facility before your current job?	1) Yes, specify: 2) No 99) Refuse to answer

APPENDIX C
INSPECTION CHECKLIST

Thesis Title: Battery Disposal Facilities: Environmental Pollution and Occupational Exposure

Workplace Inspection Checklist

Name of inspectors:
Date of inspection:
Location of inspection:

1) Beirut
2) Saida
3) Tripoli
4) Beqaa

I. General			
	Yes	**No**	**Comments**
Are floors clean, dry, free from debris, spills, acid residues or other hazards?			
Are signs posted where there are spills on the floor or hazardous material?			
Is the lighting adequate for normal work routine?			
Are temperature and humidity adequate?			
Is there any container that is leaking?			
Are tools safely secured and stored when not in use?			
Are flammable materials stored away from fire hazards and not accumulated throughout the warehouse?			
Is there an adequate ventilation system throughout the work area?			
Are there safety signs prohibiting eating or smoking on the worksite?			
Is there a regular communication between supervisor and employees regarding safety issues?			
Are incidents and accidents reported and documented properly?			
Is there an impermeable, leak proof and acid-resistant floor?			
II. Storage Area			

APPENDIX D
IRB APPROVAL LETTER

AMERICAN UNIVERSITY OF BEIRUT

Institutional Review Board
لجنة الأخلاقيات

APPROVAL OF RESEARCH

November 23, 2022

Hassan Dhaini, PhD
American University of Beirut
Email Address: hd24@aub.edu.lb

Dear Dr. Dhaini,

On November 23, 2022, the IRB reviewed the following protocol:

Type of Review:	Follow-up, Expedited
Project Title:	Battery Disposal Management in Lebanon: Environmental Pollution and Occupational Exposure
Investigator:	Dr. Hassan Dhaini
IRB ID	BIO-2022-0109
Documents reviewed:	Received on November 18, 2022: • The clean copy of the modified proposal • The clean copy of the modified *Application to Conduct Research on Human Subjects* form • The clean copies of the modified English and Arabic informed consent forms • The email confirmation to IRB Received on November 11, 2022: • The English oral consent form for managers • The Arabic oral consent form for managers • Letter for allocation of funds • The tracked copy of the modified *Application to Conduct Research on Human Subjects* form • The tracked copies of the modified English and Arabic informed consent forms • The tracked copy of the modified proposal • The point-by-point response to IRB Received on November 4, 2022: • The documentation of *Biomedical Basic Refresher* CITI training for Dr. Hassan Dhaini, Mohamad Abiad and Yara Bou Rached • The English and Arabic questionnaire for Recycling Facility • The English and Arabic questionnaire for scrapyards • The English and Arabic questionnaire for garage • The English and Arabic questionnaire for workers • The English and Arabic questionnaire for households

American University of Beirut
PO Box 11-0236, Riad El Solh, Beirut
1107 2020, Lebanon
T +961 1 35 00 00 – Ext 5445
irb@aub.edu.lb
www.aub.edu.lb/irb

1

REFERENCES

Adie, P., Afu, S., Olim, D., Beshel, S., & Ofem, V. (2022). Heavy Metals Concentration In Soils And Bioaccumulation In Earthworm (Lumbricus Terrestris) At Lemna Solid Wastes Dumpsite, Calabar, Cross River State. *Global Journal of Pure and Applied Sciences, 28*(2), 131-139.

Agency for Toxic Substance and Disease Registry ATSDR. (2010). What is the Biological Fate of Lead in the Body? *Environmental Health and Medicine Education*. Retrieved from https://www.atsdr.cdc.gov/csem/leadtoxicity/biologic_fate.html

Agency for Toxic Substance and Disease Registry ATSDR (2012). *Toxicological profile for Cadmium*. Retrieved from https://www.atsdr.cdc.gov/toxprofiles/tp5.pdf

Agency for Toxic Substance and Disease Registry ATSDR. (2015). *Mercury*. Agency for Toxic Substances and Disease Registry. Retrieved from https://www.atsdr.cdc.gov/sites/toxzine/mercury_toxzine.html#:~:text=Most%20of%20the%20metallic%20mercury,body%20in%20the%20exhaled%20breath.

Agency for Toxic Substance and Disease Registry ATSDR. (2020). Toxicological Profile for Lead. Agency for Toxic Substances and Disease Registry. Retrieved from https://www.atsdr.cdc.gov/toxprofiles/tp13.pdf

Ahmad, S., Khan, M. H., Khandker, S., Sarwar, A., Yasmin, N., Faruquee, M., & Yasmin, R. (2014). Blood lead levels and health problems of lead acid battery workers in Bangladesh. *The Scientific World Journal, 2014*.

Al-Enezi, G., Hamoda, M. F., & Fawzi, N. (2004). Ion exchange extraction of heavy metals from wastewater sludges. Journal of Environmental Science and Health, Part A, 39(2), 455-464.

Al Sayah, M. J., Der Sarkissian, R., & Abdallah, C. (2022). Review of recent events in Lebanon (2011–2020) and their effect on land degradation. *Nairobi, Kenya*.

Alessio, L. (1988). Relationship between “chelatable lead” and the indicators of exposure and effect in current and past occupational exposure. *Science of the Total Environment, 71*(3), 293-299. doi:https://doi.org/10.1016/0048-9697(88)90200-8

Alli, L. A. (2015). Blood level of cadmium and lead in occupationally exposed persons in Gwagwalada, Abuja, Nigeria. *Interdisciplinary toxicology, 8*(3), 146-150.

Arbabi, M., Hemati, S., & Amiri, M. (2015). Removal of lead ions from industrial wastewater: A review of Removal methods. environment, 4, 10.

Azzi, E. (2017). Waste Management Systems in Lebanon: The benefits of a waste crisis for improvement of practices. Retrieved from https://kth.diva-portal.org/smash/get/diva2:1139992/FULLTEXT01.pdf

Baaj, M. H. (2000). The public land transport sector in Lebanon. *Journal of Public Transportation*, *3*(3), 87-108.

Ballantyne, A. D., Hallett, J. P., Riley, D. J., Shah, N., & Payne, D. J. (2018). Lead acid battery recycling for the twenty-first century. *Royal Society open science,* 5(5), 171368.

Baloch, S., Kazi, T. G., Baig, J. A., Afridi, H. I., & Arain, M. B. (2020). Occupational exposure of lead and cadmium on adolescent and adult workers of battery recycling and welding workshops: Adverse impact on health. *Science of the Total Environment, 720*, 137549.

Bellinger, D. C. (2008). Very low lead exposures and children's neurodevelopment. *Current Opinion in Pediatrics, 20*(2), 172-177. doi:10.1097/MOP.0b013e3282f4f97b

Camfil Air Pollution Control. (n.d). A GUIDE TO DUST COLLECTION IN BATTERY MANUFACTURING. Retrieved from https://camfilapc.com/blog/battery-manufacturing/

Canfield, R. L., Henderson, C. R., Cory-Slechta, D. A., Cox, C., Jusko, T. A., & Lanphear, B. P. (2003). Intellectual Impairment in Children with Blood Lead Concentrations below 10 µg per Deciliter. *New England Journal of Medicine, 348*(16), 1517-1526. doi:10.1056/NEJMoa022848

CDC National Health and Nutrition Examination Survey (NHANES) (2014); summarized in Fourth National Report on Human Exposure to Environmental Chemicals

Chakraborty, M. R., Dawn, S., Saha, P. K., Basu, J. B., & Ustun, T. S. (2022). A comparative review on energy storage systems and their application in deregulated systems. *Batteries*, *8*(9), 124.

Champion, W. M., Khaliq, M., & Mihelcic, J. R. (2022). Advancing knowledge to reduce lead exposure of children in Data-Poor Low-and Middle-Income Countries. *Environmental Science & Technology Letters*, *9*(11), 879-888.

Chiaradia, M., Gulson, B. L., & MacDonald, K. (1997). Contamination of houses by workers occupationally exposed in a lead-zinc-copper mine and impact on blood lead concentrations in the families. Occupational and Environmental Medicine, 54(2), 117.

Cook, J. (1977). Environmental pollution by heavy metals. *International Journal of Environmental Studies, 10*(4), 253-266.

Danadevi, K., Rozati, R., Banu, B. S., Rao, P. H., & Grover, P. (2003). DNA damage in workers exposed to lead using comet assay. *Toxicology, 187*(2-3), 183-193.

Dongre, N. N., Suryakar, A. N., Patil, A. J., Ambekar, J. G., & Rathi, D. B. (2011). Biochemical effects of lead exposure on systolic & diastolic blood pressure, heme biosynthesis and hematological parameters in automobile workers of north karnataka (India). Indian journal of clinical biochemistry : IJCB, 26(4), 400–406. https://doi.org/10.1007/s12291-011-0159-6

Dorris, J., Atieh, B. H., & Gupta, R. C. (2002). Cadmium uptake by radishes from soil contaminated with nickel-cadmium batteries: toxicity and safety considerations. Toxicology Mechanisms and Methods, 12(4), 265-276.

EFSA. (2011). Statement on tolerable weekly intake for cadmium. *EFSA Journal, 9*(2), 1975. doi:https://doi.org/10.2903/j.efsa.2011.1975

Energy Sector Management Assistance Program (ESMAP). 2020. "Distributed Power Generation for Lebanon: Market Assessment and Policy Pathways. World Bank, Washington, DC. License: Creative Commons Attribution CC BY 3.0 IGO. Retrieved from https://openknowledge.worldbank.org/handle/10986/33788

EPA, U. (2017). Soil Sampling Retrieved from https://www.epa.gov/quality/soil-sampling

Gil, F., Hernández, A. F., Márquez, C., Femia, P., Olmedo, P., López-Guarnido, O., & Pla, A. (2011). Biomonitorization of cadmium, chromium, manganese, nickel and lead in whole blood, urine, axillary hair and saliva in an occupationally exposed population. *Science of the Total Environment, 409*(6), 1172-1180. doi:https://doi.org/10.1016/j.scitotenv.2010.11.033

Gottesfeld, P., & Pokhrel, A. K. (2011). Lead exposure in battery manufacturing and recycling in developing countries and among children in nearby communities. Journal of occupational and environmental hygiene, 8(9), 520-532.

Gulson, B. L., Mizon, K. J., Palmer, J. M., Korsch, M. J., Taylor, A. J., & Mahaffey, K. R. (2004). Blood lead changes during pregnancy and postpartum with calcium supplementation. *Environmental Health Perspectives, 112*(15), 1499-1507. doi:10.1289/ehp.6548

Hanser, O., Melczer, M., Remy, A. M., & Ndaw, S. (2022). Occupational exposure to metals among battery recyclers in France: biomonitoring and external dose measurements. *Waste Management,* 150, 122-130.

Hong, A. H., Law, P. L., & Onni, S. S. (2014). Environmental burden of heavy metal contamination levels in soil from sewage irrigation area of Geriyo Catchment, Nigeria. Civil and Environmental Research, 6(10), 118-124.

Hsiao, C.-Y., Wu, H.-D. I., Lai, J.-S., & Kuo, H.-W. (2001). A longitudinal study of the effects of long-term exposure to lead among lead battery factory workers in Taiwan (1989–1999). *Science of the Total Environment, 279*(1), 151-158. doi:https://doi.org/10.1016/S0048-9697(01)00762-8

Huang, M., Zhou, S., Sun, B., & Zhao, Q. (2008). Heavy metals in wheat grain: assessment of potential health risk for inhabitants in Kunshan, China. *Science of the Total Environment, 405*(1-3), 54-61.

Human Rights Watch. 2017. Lebanon: Waste Crisis Posing Health Risks. Retrieved from https://www.hrw.org/news/2017/12/01/lebanon-waste-crisis-posing-health-risks

Human Rights Watch. 2020. Lebanon in the Dark, Electricity Blackouts Affect Rights. Retrieved from https://www.hrw.org/news/2020/07/09/lebanon-dark

Hwang, Y.-H., Chao, K.-Y., Chang, C.-W., Hsiao, F.-T., Chang, H.-L., & Han, H.-Z. (2000). Lip Lead as an Alternative Measure for Lead Exposure Assessment of Lead Battery Assembly Workers. *AIHAJ - American Industrial Hygiene Association, 61*(6), 825-831. doi:10.1080/15298660008984593

IARC (2018) Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans. International Agency for Research on Cancer. https://monographs.iarc.fr/wpcontent/uploads/2018/07/List_of_Classifications.pdf

International Renewable Energy Agency IRENA. 2020. Renewable Energy Outlook: Lebanon. Retrieved from https://www.irena.org/publications/2020/Jun/Renewable-Energy-Outlook-Lebanon

Jensen, D. L., Holm, P. E., & Christensen, T. H. (2000). Soil and groundwater contamination with heavy metals at two scrap iron and metal recycling facilities. *Waste Management & Research, 18*(1), 52-63. doi:10.1177/0734242x0001800107

Johnston, J. E., Franklin, M., Roh, H., Austin, C., & Arora, M. (2019). Lead and arsenic in shed deciduous teeth of children living near a lead-acid battery smelter. *Environmental science & technology, 53*(10), 6000-6006.

Jossen, A., Garche, J., & Sauer, D. U. (2004). Operation conditions of batteries in PV applications. *Solar energy, 76*(6), 759-769.

Kobayashi, E., Suwazono, Y., Dochi, M., Honda, R., & Kido, T. (2009). Influence of Consumption of Cadmium-Polluted Rice or Jinzu River Water on Occurrence of Renal Tubular Dysfunction and/or Itai-itai Disease. *Biological Trace Element Research, 127*(3), 257-268. doi:10.1007/s12011-008-8239-z

Krishna, A., & Govil, P. (2005). Heavy metal distribution and contamination in soils of Thane–Belapur industrial development area, Mumbai, Western India. *Environmental Geology, 47*, 1054-1061.

Kumar, S., Rahman, M. A., Islam, M. R., Hashem, M. A., & Rahman, M. M. (2022). Lead and other elements-based pollution in soil, crops and water near a lead-acid battery recycling factory in Bangladesh. *Chemosphere, 290*, 133288. doi:https://doi.org/10.1016/j.chemosphere.2021.133288

Lauwerys, R., Buchet, J. P., Roels, H., & Bernard, A. (1982). [Cadmium toxicity: summary of personal studies]. *Toxicological European research. Recherche europeenne en toxicologie, 4*(1), 7-17. Retrieved from http://europepmc.org/abstract/MED/7051422

Li, H., Dai, J., Wang, A., Zhao, S., Ye, H., & Zhang, J. (2019). *Recycling and treatment of waste batteries.* Paper presented at the IOP Conference Series: Materials Science and Engineering.

Li, M., Liu, J., & Han, W. (2016). Recycling and management of waste lead-acid batteries: A mini-review. *Waste Management & Research*, 34(4), 298-306.

Li, M., Luo, Y., & Su, Z. (2007). Heavy metal concentrations in soils and plant accumulation in a restored manganese mineland in Guangxi, South China. *Environmental pollution, 147*(1), 168-175.

London Metal Exchange (LME). (n.d). The world centre for industrial metals pricing. Retrieved from https://www.lme.com/en/

Matlock, M. M., Howerton, B. S., & Atwood, D. A. (2002). Chemical precipitation of lead from lead battery recycling plant wastewater. Industrial & engineering chemistry research, 41(6), 1579-1582.

Meso, A. O. (2021). *Obstacles to Compliance With Regulatory Obligations Relating to the Recycling of Used Lead-acid Batteries in Kenya* (Doctoral dissertation, University of Nairobi).

National Institute for Environmental Health Services (NIEHS) (2012). National Toxicology Program NTP Monograph: Health effects of low-level lead. Research Triangle Park, NC: U.S. Department of Health and Human Services, National Institutes of Health.

Neesanan, N., Kasemsup, R., Ratanachuaeg, S., Kojaranjit, P., Sakulnoom, K., & Padungtod, C. (2011). Preliminary study on assessment of lead exposure in Thai children aged between 3-7 years old who live in Umphang district, Tak Province. *Journal of the Medical Association of Thailand= Chotmaihet thangphaet, 94*, S113-120.

Onianwa, P., & Fakayode, S. O. (2000). Lead contamination of topsoil and vegetation in the vicinity of a battery factory in Nigeria. *Environmental Geochemistry and Health, 22*, 211-218.

OSHA. (2012). Cadmium - Toxic and Hazardous Substances. Retrieved from https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.1027

OSHA. (n.d). Green Job Hazards. Retrieved from https://www.osha.gov/green-jobs/recycling/batteries

OSHA. (n.d). Engineering Controls. Retrieved from https://www.osha.gov/etools/battery-manufacturing/engineering-controls

OSHA. (n.d). Laminar Flow (Supplied Air) Islands. Retrieved from https://www.osha.gov/etools/battery-manufacturing/engineering-controls/laminar-flow-islands

Prozialeck, W. C., & Edwards, J. R. (2012). Mechanisms of cadmium-induced proximal tubule injury: new insights with implications for biomonitoring and therapeutic interventions. The Journal of pharmacology and experimental therapeutics, 343(1), 2–12. https://doi.org/10.1124/jpet.110.166769

Queensland Government. (2013). Soil pH. Retrieved from https://www.qld.gov.au/environment/land/management/soil/soil-properties/ph-levels#:~:text=6.5%20to%207.5%E2%80%94neutral,5.5%20are%20considered%20strongly%20acidic.

Rabinowitz, M. B. (1991). Toxicokinetics of bone lead. *Environmental Health Perspectives, 91*, 33-37. doi:doi:10.1289/ehp.919133

Rastogi S. K. (2008). Renal effects of environmental and occupational lead exposure. Indian journal of occupational and environmental medicine, 12(3), 103–106. https://doi.org/10.4103/0019-5278.44689

Ren, J., Cui, J., Chen, Q., Zhou, N., Zhou, Z., Zhang, G. H., ... & Cao, J. (2020). Low-level lead exposure is associated with aberrant sperm quality and reproductive hormone levels in Chinese male individuals: Results from the MARHCS study low-level lead exposure is associated with aberrant sperm quality. Chemosphere, 244, 125402.

Rice, K. M., Walker, E. M., Jr., Wu, M., Gillette, C., & Blough, E. R. (2014). Environmental mercury and its toxic effects. *J Prev Med Public Health, 47*(2), 74-83. doi:10.3961/jpmph.2014.47.2.74

Shah, Ahmad, N., Masood, K. R., Peralta-Videa, J. R., & Ahmad, F. u. D. (2010). Heavy metal toxicity in plants. *Plant adaptation and phytoremediation*, 71-97.

Shah, F., Kazi, T. G., Afridi, H. I., & Arain, S. S. (2012). Exposures of lead to adolescent workers in battery recycling workshops and surrounding communities. *Journal of Exposure Science & Environmental Epidemiology, 22*(6), 649-653.

Skerfving, S., & Nilsson, U. (1992). Assessment of accumulated body burden of metals. *Toxicology letters*, *64*, 17-24.

Taylor, K. W., Joubert, B. R., Braun, J. M., Dilworth, C., Gennings, C., Hauser, R., . . . Carlin, D. J. (2016). Statistical Approaches for Assessing Health Effects of Environmental Chemical Mixtures in Epidemiology: Lessons from an Innovative Workshop. *Environmental Health Perspectives, 124*(12), A227-A229. doi:doi:10.1289/EHP547

United Nations Development Program (UNDP). (n.d). SUSTAINABLE RECOVERY OF LEBANON FROM THE BEIRUT EXPLOSION. Retrieved from https://www.undp.org/lebanon/projects/sustainable-recovery-lebanon-beirut-explosion

Vacchi-Suzzi, C., Kruse, D., Harrington, J., Levine, K., & Meliker, J. R. (2016). Is Urinary Cadmium a Biomarker of Long-term Exposure in Humans? A Review. *Curr Environ Health Rep, 3*(4), 450-458. doi:10.1007/s40572-016-0107-y

Vizoso, J. C., Murr, Y. E. (2022). Privatizing the sun: The dark side of lebanon's "solar revolution". Retrieved from https://thepublicsource.org/lebanon-solar-privatization

WHO. (1996). *Trace elements in human nutrition and health*: World Health Organization. Retrieved from https://www.who.int/publications-detail-redirect/9241561734

WHO. (2006). *A compendium of standards for wastewater reuse in the Eastern Mediterranean Region*: World Health Organization. Retrieved from https://applications.emro.who.int/dsaf/dsa1184.pdf

WHO. (2007). *Health risks of heavy metals from long-range transboundary air pollution*. Copenhagen: World Health Organization. Regional Office for Europe.

WHO. (2021). *WHO guidance to reduce illness due to lead exposure.* World Health Organization. Retrieved from https://www.who.int/news/item/27-10-2021-who-guidance-to-reduce-illness-due-to-lead-exposure

Ye, B.-J., Kim, B.-G., Jeon, M.-J., Kim, S.-Y., Kim, H.-C., Jang, T.-W., . . . Hong, Y.-S. (2016). Evaluation of mercury exposure level, clinical diagnosis and treatment for mercury intoxication. *Annals of occupational and environmental medicine, 28*, 5-5. doi:10.1186/s40557-015-0086-8

Yeh, C.-Y., Chiou, H.-Y., Chen, R.-Y., Yeh, K.-H., Jeng, W.-L., & Han, B.-C. (1996). Monitoring lead pollution near a storage battery recycling plant in Taiwan, Republic of China. *Archives of environmental contamination and toxicology, 30,* 227-234.

Zhang, F., Liu, Y., Zhang, H., Ban, Y., Wang, J., Liu, J., . . . Zhu, B. (2016). Investigation and evaluation of children's blood lead levels around a lead battery factory and influencing factors. *International journal of environmental research and public health, 13*(6), 541.