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Assessment of The Current Practices of eWaste Management in Alexandria, Egypt (Case Study: Waste from Personal Computers)

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Abstract: E-waste is one of the fastest growing waste streams in the world. Decision- and policy-makers in Egypt have not yet tackled the issue of e-waste management. Recently, this management has been recognized as a serious issue due to numerous environmental concerns such as a) e-waste quantity generated at an alarming rate, b) pollution of air and groundwater, c) resource consumption, d) health and environmental hazards associated with informal e-waste recycling, and e) illegal trans-boundary movement of this e-waste. This study was carried out in Alexandria aiming at assessing the current practices adopted in the management of one type of e-waste, that is waste resulting from obsolete personal computers (PC-waste). To achieve this aim, information was collected from 40 PC-waste stakeholders. Furthermore, Toxicity Characteristic Leaching Procedure (TCLP) was performed on 10 discarded Printed Wire Boards (PWBs) to determine whether they should be considered as hazardous waste or not. Results of the study revealed that 55% of PC-waste were reused especially in PC repairing and refurbishing centers, that the major means of disposing PC-waste was by selling it to scrap dealers (50% of the respondents), followed by throwing it with municipal solid waste (MSW) (35% of the respondents), and finally by applying a "Producer Take-Back" system especially for large e-waste generators (15% of the respondents). PC-waste was collected by scrap dealers using trucks or donkey carts. Informal recycling was taking place to reclaim steel, plastic and aluminum. Fortunately, no intense material recovery from PC-waste was encountered in Alexandria. All the remaining fractions from PC-waste were found to be thrown with MSW to be directed to the landfill. As for the PWBs, they were found to exhibit toxicity due to high lead levels and therefore, they should be considered hazardous waste D008. Finally, the study concluded the complete absence of any legislation or infra-structure to deal with e-waste management and recommended a framework for an action plan to be taken by policy-makers in Egypt.

Key words: E-waste; computer; waste management; TCLP; PWBs; Hazardous waste; e-waste recycling

INTRODUCTION

Waste Electrical and Electronic Equipment (WEEE) or E-waste is one of the fastest growing waste streams in the world. E-waste refers to electronic equipment that is no longer usable or wanted. It encompasses a broad and growing range of devices, including computers, televisions, cellular phones, personal stereos, digital cameras, and electronic games. Today, when an electronic item breaks, it is often

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perceived to be more cost-effective to discard it and replace it with a new, more modern item instead of having it repaired. Such "high obsolescence rate" causes more and more e-waste to end up in the waste stream.[1,2]

As in the majority of African countries, decision- and policy-makers in Egypt have not yet tackled the issue of e-waste management. No report has been found stating the quantity of e-waste generated, collected, or recycled, their item-wise characteristics (hazardous or non-hazardous) or the environmental impacts associated with their management. Recently, e-waste management has been recognized as a serious issue due to numerous environmental concerns that can be summarized in terms of a) e-waste quantity generated at an alarming rate, b) pollution of air and groundwater, c) resource consumption, d) health and environmental hazards associated with informal e-waste recycling, and e) illegal trans-boundary movement.[3]

First, and as regards to the generation rate: In developed countries, e-waste equals 1% of total solid waste on an average and is expected to grow to 2% by 2010. In the United States, it is reported that approximately 500 million computers became obsolete between 1997 and 2007. In European Union, it is estimated that the total amount of e-waste generated ranges from 5 to 7 million tons per annum or about 14 to 15 kg per capita and is expected to grow at a rate of 3% to 5% per year. In developing countries, it ranges from 0.01% to 1% of the total municipal solid waste generation.[4]

The second and greatest concern is associated with groundwater and air pollution. The Environmental Protection Agency (EPA) estimates that, in 2005, only 12.5% of the e-waste generated in the United States was collected for recycling.

The other 87.5% went to landfills and incinerators despite the fact that hazardous chemicals in them can leach out of landfills into groundwater and streams, or that burning the plastics in electronics can emit dioxin. Studies reported that about 70 percent of the heavy metals in landfills, including lead, mercury, and cadmium, come from discarded electronic equipment. Since it has become common knowledge that all landfills leak, and even the best "state of the art" ones are not completely sealed throughout their lifetimes, a certain amount of chemical and metal leakage occurs. The situation is far worse for older or less stringently controlled dump sites.(5,6)

A typical computer monitor or TV contains 4-8 pounds of lead, and consequently, discarded monitors and televisions are characterized as hazardous waste according to EPA standards. As they break down in a landfill, they can leach toxic chemicals into groundwater. Now with LCDs (liquid crystal display) dominating the TV market, together with the increasing use of laptops and other flat panel computer displays, the mercury contamination problem is faced, since mercury lamps are used to light these screens. Milligrams of mercury are used in each LCD, but mercury is so toxic that as little as one gram of airborne mercury deposited per year to a 20-acre lake is enough to maintain mercury contamination at a level where the fish are unsafe to eat.(7)

Third, the production of electric and electronic devices is a very resource-intensive activity. The environmental burden due to the production of electrical and electronic products ("ecological baggage") exceeds by far the one due to the production of other household materials. A United Nations study found that the manufacturing of a computer and its screen takes at least 240 kg (530 pounds) of fossil fuels, 22 kg (48 pounds) of chemicals and 1.5 tons of water.(8)

Besides, many valuable materials are used in the manufacture of electronic equipment: In 1998, over 112 million pounds of materials were recovered from electronics, including steel, glass, and plastic, as well as precious metals such as gold, silver, palladium, and platinum. Reusing and recycling the raw materials from end-of-life electronics conserves natural resources and avoids the air and water pollution, as well as greenhouse gas emissions that are caused by manufacturing new products.(9)

However, the e-waste recycling process may also constitute an environmental and occupational hazard in itself if carried out in unorganized or informal way: In many developing countries, e-wastes are collected, manipulated, and dismantled to extract their content of valuable materials for resale. Such dismantling is a relatively new phenomenon, resulting in individuals exposing themselves to toxic substances.(10)

Many studies reported the negative impacts resulting from informal e-waste recycling on both the surrounding environment and health of workers and inhabitants: In one e-waste processing region in China, more than 80% of the children have lead poisoning, the water is unsafe to drink, and the workers have extraordinarily high levels of toxic fire retardants in their bodies. Air around e-waste recycling areas in Guiyu, China, contains the highest levels of dioxins ever recorded. Excessive releases of metals, from primitive e-waste processing, in 2 rivers within Guiyu has also been proved. Furthermore, poly-aromatic hydrocarbon concentrations in the Guiyu soil were found to be affected by the primitive e-waste recycling activities.(11,12)

Lastly, as the recovery of metals from E waste is a profitable business, it has resulted in trans-boundary and global trade: Large volumes of e-waste from developed countries end up in container vessels to developing nations, where the computers and TVs are dismantled and materials are scavenged in dangerous conditions. Exports to these countries are often disguised as second-hand computer donations towards bridging the digital divide or simply as metal scrap. Although re-use in the developing countries is a good way to lengthen a product's life span, it means that a vast amount of equipment will soon be added to the waste stream. Rich countries, dumping their old devices in developing countries - sometimes legally as "charity", sometimes illegally as waste - are thus liberating themselves of the waste disposal problem. A recent report found that 70% of electronic waste collected at recycling units in New Delhi (India) was actually exported from developed countries.(8,13)

The Basel Convention on the Control of the Trans-boundary Movement of Hazardous Waste and Their Disposal was adopted in 1989 and entered into force in 1992. It was created to prevent the economically motivated dumping of hazardous wastes from richer to poorer countries. The Basel Ban Amendment, adopted in 1995, has prohibited all exports of hazardous wastes. Thus, the export of e-waste as has been witnessed in China, India, and Pakistan is in violation of the Basel Amendment.(14)

As defined by the United Nation Environment Program (UNEP), the three major components of e-waste management system are:

1. E -waste collection and transportation system.
2. E-waste treatment system (including material recovery).
3. E-waste disposal system.

E-waste collection system consists of producer/retailer take back system, municipal collection system, and recycler’s/dismantler’s collection system. Each of these agencies should have its own e-waste collection and storage centers.

Concerning e-waste treatment, the major treatment techniques are decontamination and disassembly followed by shredding of different fractions. E-waste fractions emitted after shredding go for metal recovery. The remaining of e-waste fractions are disposed off either in landfills or incinerated.(15)

The challenges facing the developing countries in e-waste management include: an absence of infrastructure for appropriate waste management, an absence of legislation dealing specifically with e-waste, and an absence of any framework for end-of-life (EOL) product take-back. A scientific, safe and environmentally sound management system, including policies and technologies, needs to be developed and implemented.(4)

In Alexandria as well as in all parts of the world, computers have become the most common and widely used gadget in all kinds of activities ranging from schools, residences, offices to manufacturing industries. E-waste components in computers could be summarized as circuit boards containing heavy metals like lead and cadmium; batteries containing cadmium; cathode ray tubes with lead oxide and barium; brominated flame retardants used on printed circuit boards, cables and plastic casing; poly-vinyl chloride (PVC) coated copper cables and plastic computer casings that release highly toxic dioxins and furans when burnt to recover valuable metals; and mercury switches; mercury in flat screens; and poly-chlorinated biphenyl's (PCB's) present in older capacitors and transformers. Furthermore, the plastic, glass, and metal constituents of used computers pose an environmental concern due to their unlimited lifetime in the landfill environment.(16)

Therefore, the following study was carried out to assess the environmental impact of the current practices adopted in the management of e-waste resulting from personal computer (PC-waste) in Alexandria.

Objectives of the study:

1- To collect and analyze data necessary for understanding the current status of PC-waste management in Alexandria: waste collection/transportation system, treatment system as well as disposal system.

2- To determine whether Printed Wire Boards (PWBs) resulting from discarded computer should be considered as hazardous waste or not.

MATERIAL AND METHODS

1. Trying to approach the current practices of PC-waste management in Alexandria, the following study was conducted.

The study sample consisted of 40 PC-waste stakeholders: 20 PC-waste generators in addition to 10 PC-waste collectors and 10 PC-waste recyclers (No PC-waste treatment sector was found in Alexandria).

PC-waste generators were selected randomly so as to present the two most common PC-waste generator sectors: large PC consumers (business, commercial, and educational), and PC repairing/refurbishing centers. Other PC-waste generators include PC manufacturing companies (that discard defective items under guarantee in addition to items that fail the quality tests), and individual households. The former do not exist in Alexandria, and the latter have the practice of storing the obsolete PC or PC components at home for indefinite period of time or to pass the old ones to relatives having kids that want to download and play on-line games.

Therefore, the randomly selected waste generators were limited to 10 large PC consumers and 10 PC repairing/refurbishing centers as previously mentioned. These generators gave the research team some names and addresses of PC-waste collectors, which, by their turn, provided the research team with names and addresses of

PC-waste recyclers. Data were collected using two questionnaire forms:

- The first was addressed to PC-waste generators focusing on the computer parts that are discarded as waste, their quantities, and the way of getting rid of these parts.
- The second was addressed to PC-waste collectors and recyclers focusing on the methods adopted for the collection/transport, recycling, recovery, and disposal of waste resulting from obsolete computers.

1. ***Printed wire boards (PWBs)*** were found to be disposed off in the sanitary landfill in Alexandria. Trying to determine whether waste PWBs are considered toxicity characteristic (TC) hazardous waste or not, the Toxicity Characteristic Leaching Procedure (TCLP) was performed on 10 waste PWBs, according to the method described by the EPA. Following the protocol, the TCLP is an extraction process that includes placing 25 gm of size-reduced PWBs into a 600-ml beaker, and adding 500 ml leaching solution (an acetic acid–based simulated leachate fluid of pH 2.9). Mixing by hand stirring was done frequently, for 18 hours due to the absence of magnetic stirrer. The extracts were then filtered on acid-washed filter paper. This was followed by digestion of the filtrate with HNO_3, and analysis of lead and cadmium in the digested sample using atomic absorption spectrophotometer. A blank sample containing the leaching solution was performed parallel to the PCBs samples.(17)

In the TCLP, if the concentration of certain pollutants in the leachate exceeds a standard level regulated by the EPA, it is a TC hazardous waste. This regulatory level is 5 mg/L for lead and 1 mg/L for cadmium.(18)

RESULTS AND DISUSSION

1. Current practices of PC-waste management in Alexandria:

a) E-waste generation from discarded computers:

- Concerning the 10 PC consumers, the study sample included one bank, two hospitals, an educational institute affiliated to Alexandria University, two commercial centers, a private company for trade and distribution, a telecommunication company, one private school and an international organization.

Information collected by 100% of the study sample revealed that *ALL* computer components can be discarded as e-waste when they become out of order after the necessary maintenance has been done. For example, monitors, CPU (central processing unit), keyboard, mouse, printers, and scanners. When the respondents were asked about any trial to reuse any still-functioning part of the obsolete PC, only 1 out of the 10 PC consumers (10% of the study sample) stated that personnel in the IT center are used to do so.

As for the quantity of e-waste generated from obsolete PC, this could not be obtained from anyone of the respondents, either because they considered this as confidential information (60% of the study sample), or because they do not have any idea about such quantity (40% of the study sample).

Finally, as far as the method of disposing such e-waste type was concerned, the study reported a system of "Producer Take-back" among 3 out of 10 of the study sample (30%). In this system, e-waste is taken back directly by the producer company; this usually operates on the principle of "new equipment replacing the old ones". Half of the study sample (5/10) reported arranging auctions for scrap dealers to pick-up obsolete PC components. The rest (20%) of the study sample stated throwing every obsolete e-waste component with the municipal solid waste (MSW).

- Concerning the 10 PC repairing/refurbishing centers, and in contrast to the PC consumers, 100% of them reported reusing the still-functioning e-waste components (which is logic as far as they will gain profit from them). Example of reused e-waste, cables, plastic casing, chips, lamps, drives, RAMs, processors, modems, video and sound cards, printing cartridges,…,etc.

The end-of-life (EOL) components were reported to be disposed with the MSW by 50% of the respondents, while the other half stated they sell them to scrap dealers at no pre-determined price.

Similarly to the PC consumers, quantities generated of these EOL components could not be determined by anyone of the study sample. They all (100%) assumed having no idea about it.

Combining the results obtained from the 20 PC-waste generators, two figures could be obtained showing a preliminary estimate of:

a) the percentage reuse of e-waste resulting from PC (Figure1), and

b) the means of disposing e-waste resulting from PC (Figure 2).

As obvious from the figures, reuse was found to be adopted by 55% of the e-waste generators, and disposal was found to occur through one of the following 3 ways: 15% taken back by the producer company, 50% sold to scrap dealers, and 35% thrown with the MSW.

Following this finding, the research team was directed to scrap dealers to obtain more information about the management of this type of e-waste resulting from obsolete PC.

b) PC-waste management (collection, recycling, treatment, and disposal):

As previously mentioned, the e-waste collection system adopted for obsolete PC was found to be a recycler collection system: i.e., collection of PC-waste was done by the scrap dealers who purchase e-waste in bulk quantities from the first level generators. Having limited capacity for dismantling, they were just involved in trading of the collected e-waste with recyclers to carry out the dismantling operations.

Collection and transport of e-waste were found to take place using trucks or donkey-carts with no special sites for such e-waste collection and storage. This was found to be in contrast to the majority of collection schemes in Europe where a municipal e-waste collection system exists: In this collection mechanism, consumers and/or businesses can leave e-waste at municipal sites where a number of sorting containers and/or pallets are provided according to the e-waste scope and logistical arrangements with recyclers and transporters. This collection mechanism is usually free for household e-waste, although charges sometimes apply for commercial companies.[15]

Next, and concerning the PC-waste recyclers, all of them (100% of the study sample) reported dismantling of the PC-waste to the following elements:

- Cathode ray tube (CRT) to be sold to TV repairing shops,
- Plastic cases housing the CPU, aluminum sheets, glass, and ferrous scrap to be sent to recycling plants.

No material recovery from the PC-waste was encountered during the study. All of the recyclers/dismantlers (100% of the study sample) ignored knowing anything about any precious element in the PC-waste components. This was found to be completely in contrast to the material recovery that takes place in countries such as China, India, Viet Nam, and Pakistan where workers (working with few health and safety precautions) in e-waste yards use acid bath and open burning to reclaim minimal valuable materials such as gold and copper.[10]

Finally, the PC-waste fractions remaining after recycling were found to be landfilled with the MSW. This was also in contrast to the system applied in developed countries where e-waste has to be treated prior to landfill using the following 3 levels of treatment: First, e-waste should be decontaminated by manual dismantling to remove mercury switches, CRT, batteries, and capacitors to be sent to hazardous waste landfill or to special treatment facilities. Second, the decontaminated e-waste should be subjected to size reduction by hammering or shredding, followed by special treatment processes such as electromagnetic separation to get ferrous metal, eddy current separation to get non-ferrous (Cu and Al) and precious metal (silver, gold, and palladium), and density separation to get plastic. Third, recycling is applied to sorted plastic and ferrous metals, while non-ferrous metals are subjected to smelting, and precious metals are subjected to refining. Finally, incineration is done for energy recovery from plastic mixed with brominated flame retardants, after ensuring proper air emission control system.(15)

2-TCLP test performed on PWBs:

According to the EPA, a waste is considered hazardous when it exhibits one or more of the following characteristics: Ignitability (Flashpoint <140° F), corrosiveness (aqueous pH <2 or >12.5), reactivity (normally unstable, undergoes violent changes without detonating, water reactive), or toxicity (exceeding the regulatory limits for contaminants under the TCLP analysis). These limits are presented in the EPA D-list.(18)

Printed wire boards (PWBs) form about 3% by weight of the total amount of electronic waste. Lead-based solder (typically a 60:40 ratio of tin to lead) is used to attach electrical components to PWBs. Typical PWBs have been reported to contain approximately 50 g of tin-lead solder per m^2 of PWB.(19)

When 10 waste PWBs were subjected to

the TCLP test for analyzing lead and cadmium concentrations in the extracts, the results illustrated in table 1 as well as in figures (3) and (4) were obtained: It was obvious that 100% of the samples exceeded the EPA regulatory level of 5 mg/L for Pb. The detected concentrations for lead were ranging from 6.5 mg/L to 19.75 mg/L with an average of 13.65 mg/L and a standard deviation of 4.36 mg/L. On the other hand, average, range, and standard deviation for Cd leaching were 0.012 mg/L, 0.008 – 0.017 mg/L, and 0.003 mg/L, respectively. This means that no one sample exceeded the 1 mg/L regulatory concentration for Cd.

This proves that PWBs exhibit toxicity due to high lead levels and would be considered hazardous waste D008. This was in accordance with previous and similar studies that reported high levels of lead leaching from PWBs in the TCLP test. A study in China reported the lead concentrations in the TCLP extracts of the majority of the PWBs to be ranging from 150 to 500 mg/L, which are 30–100 times the EPA regulatory level of 5 mg/L. Another one carried out in Florida reported a Pb concentration ranging from 100 to 200 mg/l in the TCLP extract of waste PWBs.[20-23]

The negative effects of lead are well established and recognized. Lead causes damage to the central and peripheral nervous systems, blood systems, kidney, and reproductive system in humans. Effects on the endocrine system have been observed and its serious negative effects on children's brain development are well documented. Lead accumulates in the environment and has high acute and chronic effects on plants, animals and micro-organisms.[24]

One criticism of the TCLP is that the conditions in the test are not representative of conditions inside most landfills. When PWBs were leached using TCLP leaching solution and another leaching solution consisting of a "real" leachate from "real" landfills, the results indicated that the extract from the latter case (landfill leachate) resulted in lower lead concentration than those from the former one (TCLP leaching solution). The greater lead concentrations measured using the TCLP can be attributed to two factors: The higher affinity of acetate ions in TCLP for lead resulting in better dissolution and complexation of the metal. Acetate, a component of the TCLP leaching solution, is at much higher concentration in the TCLP leaching solution that its concentration in the "real" landfill leachate. Second, pH plays an important role in the leachability of lead. The pH values for the landfill leachate were neutral, ranging from 6.5 to 8.2 (a typical pH for municipal solid waste landfills). This was in contrast to the acidic pH (2.9) of the TCLP leaching fluid.[25]

However, due to the unknown behavior of specific e-wastes in landfills, concerns about toxic materials have resulted in the precautionary measures adopted by the TCLP.

CONCLUSION

Based on the discussion of the results of this study carried out in Alexandria City, Egypt, the following could be concluded:

1. E-waste is a rapidly growing segment of the waste stream.
2. There is no special legislation or suitable infra-structure in Egypt to deal specifically with e-waste.
3. There is no accurate estimate of the quantity of e-waste generated and their classification in Egypt.
4. Means of disposing of e-waste resulting from obsolete computers in Alexandria was found to be as follows: 15% taken back by the producer company, 50% sold to scrap dealers, and 35% thrown with the MSW.
5. In Alexandria, the informal sector is engaged in e-waste management from the point of waste collection by scrap dealers, and continues by sorting and recycling steel, plastic, and aluminum till

the last stage of throwing the remaining items for disposal in landfill together with the MSW.

6. Fortunately, no intense material recovery was encountered among e-waste recyclers in a way similar to what occur in China, Pakistan, or Viet Nam. However, the inefficient recycling processes result in substantial losses of material value.
7. Printed wire boards (example of e-waste resulting from discarded computers) are considered hazardous waste D008 according to the TCLP test specified by the EPA. If disposed off in a landfill, they can leach lead and cause ground water pollution.

RECOMMENDATIONS

1. Policy-makers in Egypt should address the e-waste problem by taking the following actions:

- Carrying out an e-waste inventory: Different methodologies are described in UNEP e-waste inventory assessment manual.(4)
- Determining the e-waste composition, recyclability, and hazardousness.
- Adding an article to The Law 4/94 explaining the policy to be adopted with e-waste management.
- Specifying the major stakeholders in e-waste management, and then focusing on knowledge transfer and skills upgrade of all involved stakeholders through trainings and seminars.
- Targeting mainly the existing informal recyclers allowing for their maximum but safe participation in future e-waste management by facilitating their evolution and integration in formal structures.
- Providing the necessary infra-structure for the proper management of e-waste. For example, convenient collection system (collection centers,

transportation vehicles), recycling centers (including material recovery), environmentally sound technology, trained manpower, and secure landfill for ultimate hazardous waste disposal.

2. Because of the small sample size and the application of random sampling procedure, findings of this study should be taken as preliminary results to be confirmed by larger scale studies in the future.

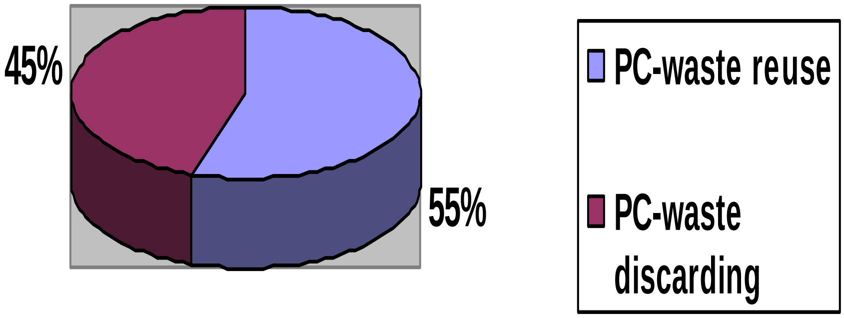

Figure (1): Percentage of reuse of e-waste resulting from personal computers (PC-waste) among PC-waste generators, Alexandria, Egypt, 2007.

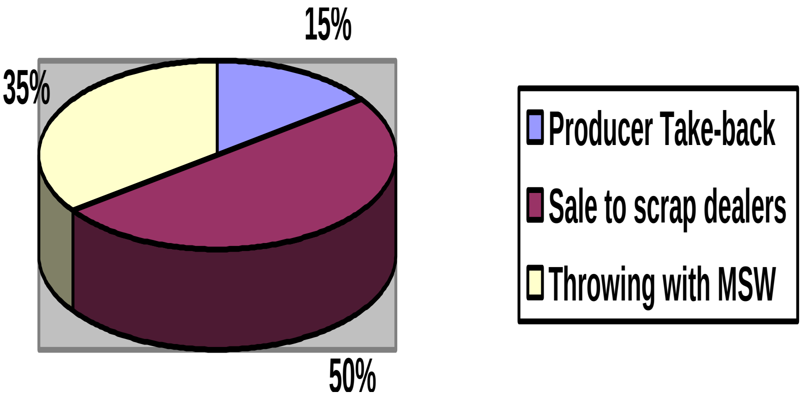

Figure (2): Means of disposing e-waste resulting from personal computers, Alexandria, Egypt, 2007.

Table 1: Lead and Cadmium concentrations in mg/L in the extracts obtained from TCLP carried out on 10 PWBs (Alexandria, 2007).

Sample No.	Lead, mg/L	Cadmium, mg/L
1	13.5	0.0102
2	6.5	0.0098
3	11.75	0.0126
4	14.25	0.0147
5	16.75	0.0116
6	13.5	0.0084
7	7.75	0.0106
8	19.5	0.0167
9	19.75	0.0173
10	13.25	0.012
Average	**13.65**	**0.01239**
Standard Deviation	**4.36**	**0.0029**

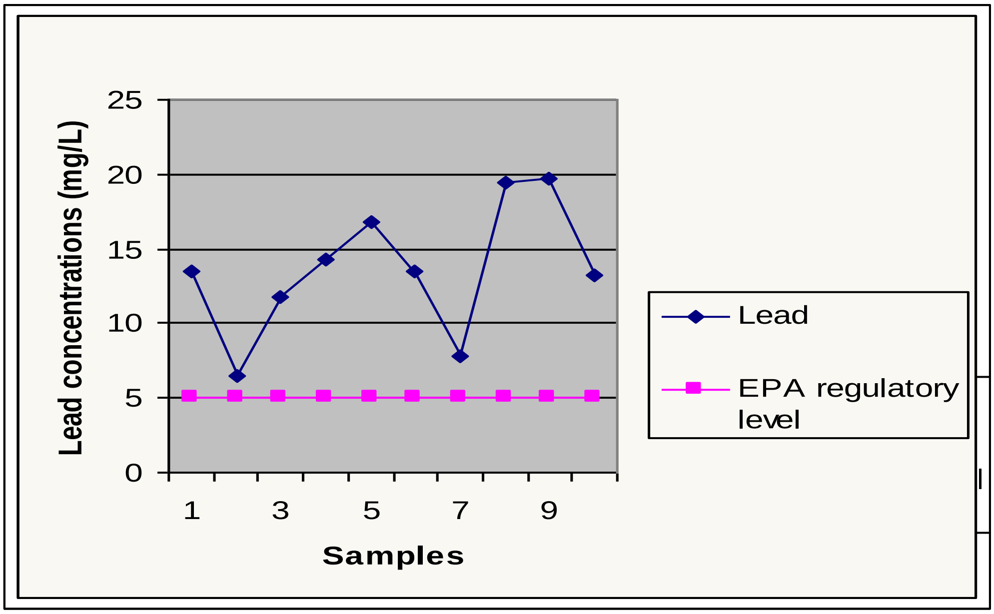

Figure (3): Lead concentrations in mg/L in the extracts obtained from TCLP carried out on 10 PWBs (Alexandria, 2007).

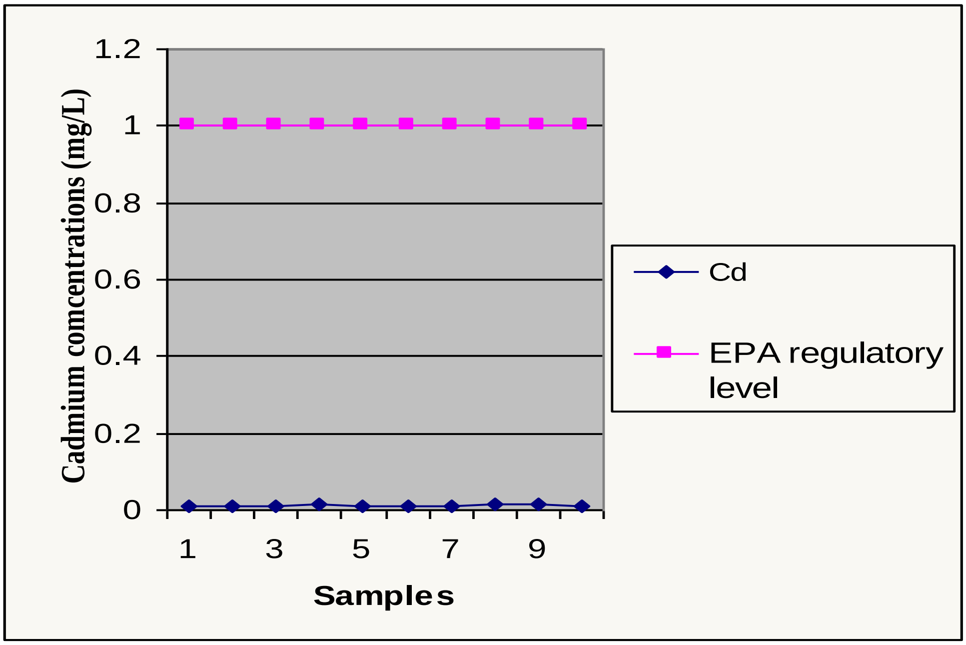

Figure (4): Cadmium concentrations in mg/L in the extracts obtained from TCLP carried out on 10 PWBs (Alexandria, 2007).

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