A SURVEY OF MERCURY POLLUTION FROM FLUORESCENT LAMPS DISPOSAL IN SELECTED SITES IN NAIROBI

BY:

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DECLARATION

This thesis is my original work and has not been presented for award of a degree in any University.

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DEDICATION

I dedicate this work to Humankind.

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ABREVIATIONS

BAT- Best Available Technology

BEP- Best Environmental Practices

CFL- Compact Fluorescent Lamps

EMCA -The Environment Management and Coordination Act

EPA- U.S Environmental Protection Agency

ESM- Environmentally Sound Management

FSCF- Potential Source Contribution Function

IEA- International Energy Agency

IMERC- Interstate Mercury Education and Reduction Clearinghouse

LRTAP Convention- Long Range Transboundary Air Pollution

MEA- Multilateral Environmental Agreements

NEMA- National Environment Management Authority

NWT- Northwest Territories of Canada

OECD- Organization for Economic Cooperation and Development

OSPAR- Convention for the Protection of the Marine Environment of the North-East Atlantic

SAICAM-Strategic Approach to International Chemical Management

SCHER- European Scientific Committee on Health and Environmental Risks

SCENIHR- Scientific Committee on Emerging and Newly Identified Health Risks

UNEP-United Nations Environmental Programme

UNIDO- United Nations Industrial Development Organization

UV-Ultraviolet

WHO- World Health Organization

ABSTRACT

The high cost of electricity has necessitated most households to opt for fluorescent bulbs as opposed to the normal incandescent lamps. The disposal of phosphor and particularly the toxic mercury in the tubes is an environmental issue of concern. Government regulations in many areas require special disposal of fluorescent lamps separate from general and household wastes. Kenya however, lacks such regulations.

A source specific environmental risk analysis was performed in selected sites within Nairobi with high fluorescent bulb usage, to ascertain the local levels of mercury in ambient air. These were Times Tower building and the Sunken Car Park. Passive sampling of ambient air using 0.1% potassium permanganate in 1N sulphuric acid as the dissolving solution was carried out in the selected sites over April to June 2010. Cold vapour atomic absorption spectroscopy was used to determine ambient air mercury contamination levels.

The results obtained for both Times Tower and the Sunken Car Park indicated mercury levels above the average permissible concentrations for occupational (0.05 mg/m^3) or continuous environmental exposure (0.015mg/m^3) (WHO, 1976). The results obtained at Times Tower, (1.3440 mg/m^3) for the month of April prior to sensitization confirms high mercury air contamination associated with lack of sensitization. After sensitization on the need to separately dispose the dead lamps, there was an overall decrease of 5.72 times. The Sunken Car Park where dumping was uncontrolled was used as a reference. The mercury concentration decreased by 1.09 times over the study period. This was attributed to the fact that no sensitization was done for those responsible for the disposal of the florescent bulbs and garbage.

The impact of sensitization was evidenced by the sharp drop in mercury concentrations at Times Tower holding ground in the subsequent months of study. This shows that mercury pollution can be controlled through awareness and proper disposal procedures.

CHAPTER 1

1.0: INTRODUCTION

The high cost of electricity has necessitated most households to opt for fluorescent bulbs as opposed to the normal incandescent lamps. Recently, the Government of Kenya, through the Kenya Power and Lighting Company campaigned for the enhanced replacement of incandescent lamps with energy-saving fluorescent bulbs (compact fluorescent lamps) and distributed over one million free fluorescent lamps to households This was in an effort to reduce the rising costs of providing electricity(Kumba & Muiruri, 2010).. Compact fluorescent lamps (CFL) have emerged as a potent alternative of incandescent lamps due to lower power consumption and longer life,life lasts 8–10 times longer compared to an incandescent bulb (Mantho, 2008). The longer life may also reduce lamp replacement costs, providing additional saving especially where hired labour is costly. Therefore, fluorescent bulbs are widely used in households, businesses and institutions. Compared with an incandescent lamp, a fluorescent tube is a more diffuse and physically larger light source (IMERC, 2008). A 23 Watt CFL produces same luminous efflux as a 100 Watt bulb. CFL consumes 2–5 times less power; 100W incandescent bulb converts only 2.6% of power to white light whilst a CFL converts 6.6–8.8% of input power to white light (Mantho, 2008). About two-thirds to three-quarters less heat is given off by fluorescent lamps compared to an equivalent rating of incandescent lamps. All these advantages lead to reduction in the cost of energy consumption (IMERC, 2008)

However, fluorescent lamps have a down side. They emit UV radiation and pollute the environment with mercury and phosphors when broken or at end of their life cycle (Ahlbom et al, 2008) .A typical 4 ft (fluorescent lamp) contains about 12 milligrams of mercury (IMERC, 2008). A broken fluorescent tube will release its mercury content. 99% of the mercury is typically contained in the phosphor, especially on lamps that are near their end of life cycle (IMERC, 2008). Safe cleanup procedures of broken fluorescent bulbs differs from cleanup of conventional broken glass or incandescent bulbs. Once broken, the room/ area must be evacuated immediately, air conditioner switched off and all windows opened. Cleaning equipment that includes hard cardboards, soapy wet wipes and sealable container should be assembled. The cleaner must wear protective gear which includes gloves, mask and overall. All particles should be carefully collected and placed in the sealable container. The affected area should be wiped with the soapy wet wipes which are then placed in the container, Once satisfied that the area is free of any particles, the protective gear should also be placed in the into the container. The bag should be sealed, properly stored away from other refuse awaiting proper disposal; The room should continue to be aerated for another 15-30 minutes before occupation (Ceaser, 2010; US-EPA, 2011). The disposal of phosphor and particularly the toxic mercury in the tubes is an environmental and health issue (Muchiri, 2010; US-EPA, 2011)

With the increased use of energy-efficient fluorescent bulbs, the disposal of such items pose a potentially serious source of mercury contamination. Although the amount of mercury used in each bulb is small, the cumulative impact of the disposal of millions of such bulbs in the future needs to be addressed by national and municipal governments. Mercury is toxic in all its forms, exhibiting adverse health and environmental effects depending on the chemical species, dose received, and period of exposure(UNEP,2009).. It is a potent neurotoxin and may result in nervous system disorders, reproductive and developmental problems, kidney damage, and other health effects (UNEP,2009).. Once released into the environment, mercury becomes part of a biogeochemical cycle contaminating soil, air, groundwater and surface water where it accumulates and moves foot and 5000 four-foot fluorescent bulbs (Obingo, 2010). When the bulbs burnt out (20, 000 lamps burn out annually), they are mixed with other refuse awaiting disposal (Mureithi, 2010).With the increased importation of fluorescent (KRA, 2009), it is therefore prudent to set up collection points for these lamps, separate from other garbage to prevent a looming environmental disaster. Figure 1 shows increase in compact florescent lamps for the period 2005-2009.

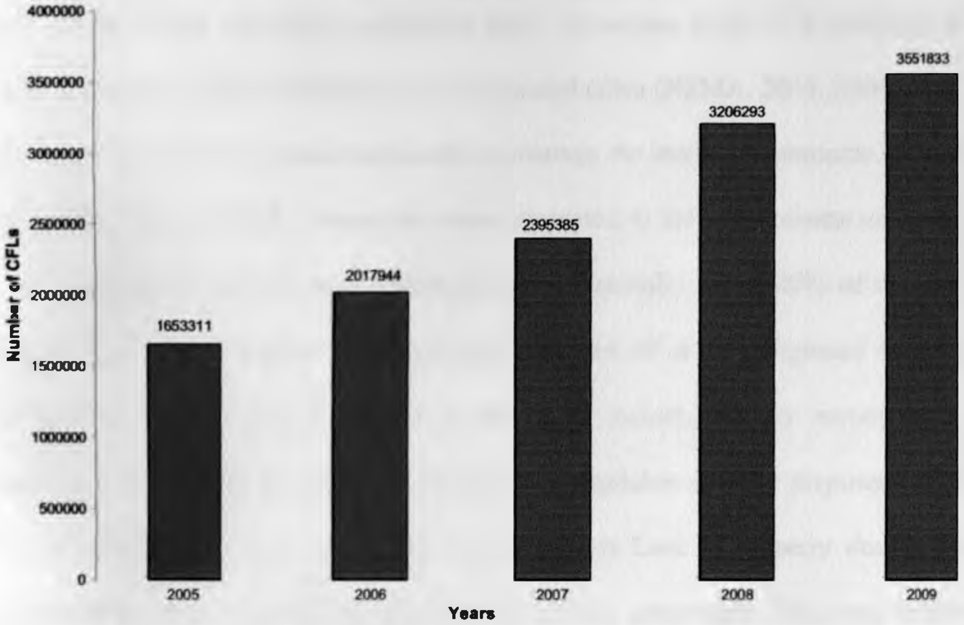


Figure 1: *Compact Fluorescent Lamps Imports to Kenya For the Period 2005 to 2009*

(Source: Kenya Revenue Authority, Customs Services Department)

The current constitution of Kenya, Chapter 4; Bill of rights, Part 2-Rights and fundamental freedoms; sub-section 52 stipulates that every person has the right to a clean and healthy environment, which includes the right (a) to have the environment protected for the benefit of present and future generations through legislative and other measures, particularly those contemplated in Article 69; and (b) to have obligations relating to the environment fulfilled under Article 70 (GOK, 2010). Furthermore, the existing up the food chain (UNEP,2009). Solid waste management in urban areas, including environmentally and socially acceptable collection, treatment and disposal is a challenge for most developing and transitional countries. While appropriate technological solutions are often available, they cannot be applied without instituting cost-effective arrangements, which would ensure effectiveness and financial sustainability (UNEP, 2009). In most developing countries local governments provide solid waste management services (GOK, 2002). As urban populations grow, it became more of a challenge to handle increasing quantities of waste in more congested cities (NEMA, 2003, 2004, 2005, and 2006). Local authorities have been unable to manage the increasing amounts of solid wastes (GOK, 2002) 21% of municipal waste generated in the urban centre emanates from industrial areas and 61% from residential areas. Generally, about 40% of the total waste generated in urban centres is collected and disposed off at the designated disposal sites. The rest of the waste, composed of chemicals including heavy metals, salts, detergents and medical waste was either dumped in unsuitable areas or disposed off in rivers that traverse the urban centres and other wetlands Lack of properly designated sanitary landfills led to disposal of wastes in low income settlements. This was further aggravated by lack of enforcement of standards (NEMA, 2003, GOK, 2002) The mode of waste transportation was not regulated and lacked coordination (NEMA, 2003). The disposal of the fluorescent bulbs complicated the already bad situation. The disposal of phosphor and particularly the toxic mercury in the tubes is an environmental issue. Government regulations in many areas, such as the United States of America and European Union require special disposal of fluorescent lamps separate from general and household wastes (US-EPA, 2011). However, Kenya lacks such regulations for disposal of toxic wastes. Furthermore, lack of awareness on the dangers posed by mercury poisoning and injury from broken glass by consumers aggravates the situation. For instance, the tallest and largest building in the country, Times Tower uses 50,000 two-environmental Act, Environmental Management and Coordination Act (EMCA) of 1999 underscores the right of every person in Kenya to a clean and healthy environment and commit each and every one of us to safeguard and enhance the environment.

Waste Management regulations (Legal Notice No. 121) Fourth Schedule *(Regulation 16)* defines wastes considered hazardous and the levels of mercury and mercury containing products constituting hazardous wastes (EMCA-WM, 2006). However, regulations pertaining to disposal of mercury and mercury- containing products have not been formulated. The EMCA (Air Quality) Regulation 2008 (draft) mentions mercury vapour as a pollutant but does not specify tolerance limits for industrial, residential, rural or controlled areas.

The National Energy Policy of 2005 only addresses the provision of adequate, reliable, cost effective and affordable energy supply to meet development needs, while protecting and conserving the environment but fails to propose regulation on their disposal (Ministry of Energy, 2005).

Consequently, in this study a survey was conducted on mercury pollution level due to fluorescent bulb disposal. The findings of this study will be shared with the policy makers to enable them enact laws that shall institute recycling measures by fluorescent lamps manufacturers/distributors and appropriate disposal procedures of spent fluorescent bulbs.

CHAPTER 2

2.1: LITERATURE REVIEW

2.1.1: Working Principles of Fluorescent Lamps

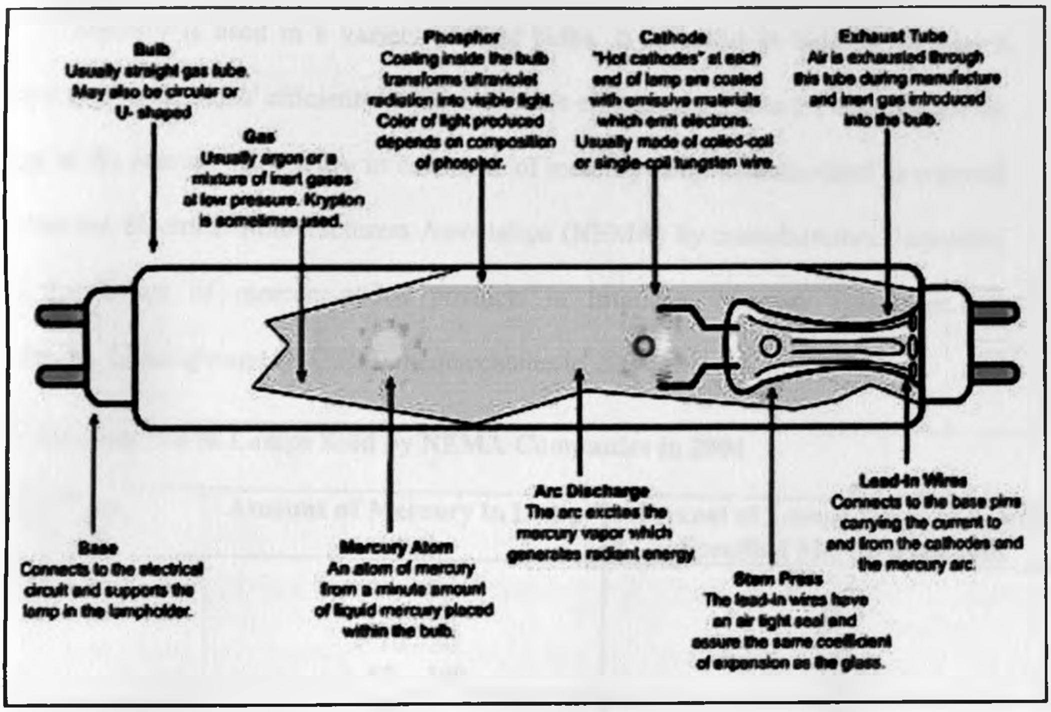


Figure 2.1: Illustration of the components of a fluorescent lamp and how they work. (Photo Source: Northeast Lamp Recycling, Inc)

A fluorescent lamp tube is filled with a gas containing low pressure mercury vapour and noble gases at a total pressure of about 0.3% of the atmospheric pressure (Ahlbom et al, 2008; US-EPA, 2011). The lamp generates light from collisions in a hot gas ('plasma') of free accelerated electrons with atoms– typically mercury – in which electrons are excited to higher energy levels and then fall back while emitting at two UV emission lines (254 nm and 185 nm). The thus created UV radiation is then converted into visible light by UV excitation of a fluorescent coating on the glass envelope of the lamp. The chemical composition of this coating is selected to emit in a desired spectrum.. This ionization can only take place in intact light bulbs (Ahlbom et al, 2008; US-EPA, 2011)

2.1.2: Types of Mercury Lamps

Mercury is used in a variety of light bulbs. It is useful in lighting because it contributes to the bulbs' efficient operation and life expectancy. Table.2.1 summarizes the range in the amount of mercury in each type of mercury lamp manufactured as reported to National Electrical Manufacturers Association (NEMA) by manufacturers, importers, and distributors of mercury-added products in Interstate Mercury Education and Reduction Clearinghouse (IMERC) member states in 2004 in U.S.A.

Table2.1: Mercury Use in Lamps Sold by NEMA Companies in 2004

Lamp Type	Amount of Mercury in Lamp (mg)	Percent of Lamps Production with Specified Mercury Amount
Fluorescent	0 - 5	12
	> 5 - 10	48.5
	> 10 - 50	27
	> 50 – 100	12.5
CFL (Compact Fluorescent lamps)	0 - 5	66
	> 5 - 10	30
	>10 – 50	4
Metal Halide (MH)	>10 - 50	24
	> 50 - 100	40
	> 100 - 1,000	35
Ceramic Metal Halide	0 - 5	17.6
	> 5 - 10	46.8
	> 10 – 50	35.6
High Pressure Sodium	>10 – 50	97
Mercury Vapor	>10 - 50	58
	> 50 - 100	29
	> 100 - 1,000	12
Mercury Short-Arc	> 100 - 1,000	65
	> 1,000	23

(Source: IMERC 2004)

Types of fluorescent lamps include:

1) Linear fluorescent, U-tube, and Circline lamps used for general illumination purposes. They are widely used in commercial buildings, schools, industrial facilities, and hospitals (SCHER, 2010; IMERC, 2008).

2) Bug zappers contain a fluorescent lamp that emits ultraviolet light, attracting unwanted insects (SCHER, 2010; IMERC, 2008).

3) Tanning lamps use a phosphor composition that emits primarily UV-light, type A (non-visible light that can cause damage to the skin), with a small amount of UV-light, type B (SCHER, 2010; IMERC, 2008).

4) Black lights use a phosphor composition that converts the short-wave UV within the tube to long-wave UV rather than to visible light. They are often used in forensic investigations (SCHER, 2010; IMERC, 2008).

5) Germicidal lamps do not use phosphor powder and their tubes are made of fused quartz that is transparent to short-wave UV light. The ultraviolet light emitted kills germs and ionizes oxygen to ozone. These lamps are often used for sterilization of air or water (SCHER, 2010; IMERC, 2008) .

6) High output fluorescent lamps (HO) are used in warehouses, industrial facilities, and storage areas where bright lighting is necessary. High output lamps are also used for outdoor lighting because of their lower starting temperature, and as grow lamps. They operate the same way as fluorescent lamps, but the bulbs are designed for much higher current arcs. The light emitted is much brighter than that of traditional fluorescent lamps. However, they are less energy-efficient because they require a higher electrical current (SCHER, 2010; IMERC, 2008) .

7)Cold-cathode lamps are small diameter, fluorescent tubes that are used for backlighting in liquid crystal displays (LCDs) on a wide range of electronic equipment, including computers, flat screen TVs, cameras, camcorders, cash registers, digital projectors, copiers, and fax machines. They are also used for backlighting instrument panels and entertainment systems in automobiles. Cold-cathode fluorescent lamps operate at a much higher voltage than conventional fluorescent lamps, which eliminates the need for heating the electrodes and increases the efficiency of the lamp 10 to 30 percent. They can be made of different colors, have high brightness, and long life (SCHER, 2010; IMERC, 2008) .

8) Compact fluorescent lamps (CFL) use the same basic technology as linear fluorescent lamps, but are folded or spiraled in order to approximate the physical volume of an incandescent bulb. Screw-based CFLs typically use “premium” phosphors for good color, come with integral ballast, and can be installed in nearly any table lamp or lighting fixture that accepts an incandescent bulb. Pin-based CFLs do not employ integral ballasts and are designed to be used in fixtures that have separate ballast. Both screw-based and pin-based CFLs are used in commercial buildings. Residential use of these types of bulbs is growing because of their energy efficiency and long life (SCHER, 2010; IMERC, 2008).

9) High intensity discharge (HID) is the term commonly used for several types of lamps, including metal halide, high pressure sodium, and mercury vapor lamps. HID lamps operate similarly to fluorescent lamps. An arc is established between two electrodes in a gas-filled tube, causing a metallic vapor to produce radiant energy. HID lamps do not require phosphor powder, however, because a combination of factors shifts most of the energy produced to the visible range (IMERC, 2008). In addition, the electrodes are much closer together than in most fluorescent lamps; and under operating conditions the total gas pressure in the lamp is relatively high. This generates extremely high temperatures in the tube, causing the metallic elements and other chemicals in the lamp to vaporize and generate visible radiant energy (IMERC, 2008). HID lamps have very long life. Some emit far more lumens per fixture than typical fluorescent lights. Like fluorescent lamps, HID sources operate from ballasts specifically designed for the lamps type and wattage being used. In addition, HID lamps require a warm-up period to achieve full light output. Even a momentary loss of power can cause the system to "re-strike" and have to warm up again – a process that can take several minutes (SCHER, 2010). The names of the HID lamps (i.e., metal halide, high pressure sodium, and mercury vapor) refer to the elements that are added to the gases that are generally xenon or argon and mercury in the arc stream. Each element type causes the lamp to have somewhat different color characteristics (SCHER, 2010; IMERC, 2008).

a) Metal halide lamps (MH) use metal halides such as sodium iodide in the arc tubes, which produce light in most regions of the spectrum. They provide high efficacy, excellent color rendition, long service life, and good lumen maintenance, and are commonly used in stadiums, warehouses, and any industrial setting where distinguishing colors is important(IMERC, 2008). They are also used for the bright blue-tinted car headlights and for aquarium lighting (SCHER, 2010. Low-wattage MH lamps are available and have become popular in department stores, grocery stores, and many other applications where light quality is important. Of all the mercury lamps, MH lamps should be considered a complete system of lamp, ballast, igniter, fixture, and controls. The amount of mercury used in individual MH lamps ranges from more than 10 mg to 1,000 mg, depending on the power level. About one-third of these lamps sold in the U.S. contain greater than 100 to 1,000 mg of mercury (SCHER, 2010; IMERC, 2008)·

b) Ceramic metal halide lamps (CMH) were recently introduced to provide a high quality, energy efficient, alternative to incandescent and halogen light sources. Many are designed to be optically equivalent to the halogen sources they were designed to replace. They are used for accent lighting, retail lighting, and are useful in high volume spaces, with ceiling heights of 14-30 feet. The arc tube is made of ceramic. CMH lamps provide better light quality, better lumen maintenance, and better color consistency than MH lamps at a lower cost. CMH lamps contain less mercury than MH lamps. The majority contain from greater than 5 mg to 50 mg of mercury (SCHER, 2010; IMERC, 2008).

c) High pressure sodium lamps (HPS) are a highly efficient light source, but tend to look yellow and provide poor color rendition. HPS lamps were developed in 1968 as energy-efficient sources for exterior, security, and industrial lighting applications and are particularly prevalent in street lighting. Standard HPS lamps produce a golden (yellow/orange) white light when they reach full brightness. Because of their poor color-rendering their use is limited to outdoor and industrial applications where high efficacy and long life are priorities. HPS lamps generally contain 10 to 50 mg of mercury. A small percentage contains more than 50 mg of mercury (SCHER, 2010; IMERC, 2008).

d) Mercury vapor lighting is the oldest HID technology. The mercury arc produces a bluish light that renders colors poorly. Therefore, most mercury vapor lamps have a phosphor coating that alters the color and improves color rendering to some extent. Mercury vapor lamps have a lower light output and are the least efficient members of the HID family. They were developed to overcome problems with fluorescent lamps for outdoor use but are less energy efficient than fluorescents. Mercury vapor lamps are primarily used in industrial applications and outdoor lighting (e.g., security equipment, roadways, and sports arenas) because of their low cost and long life (16,000 to 24,000 hours). These lamps represent a diminishing market, and their use will continue to bottle/cup decorating, and converting/coating applications. These specialized lamps contain 100 to 1,000 mg of mercury (SCHER, 2010; IMERC, 2008).

2.1.3.: Sources of Mercury in the Environment

Mercury occurs naturally in forms that are volatile, hence continuously evaporates into the atmosphere, from both soils and water. The presence of mercury-rich rocks and soils can lead to elevated mercury levels across wide areas. The weathering of rocks, volcanic activity and forest fires all contribute to the natural emission of mercury into the air. Natural sources contribute less than 50% of the total emissions (UNEP, 2002).

Mercury is a naturally occurring metal with atomic number 80. The metallic mercury is a shiny, silver-white, odorless liquid at typical ambient temperatures and pressures. It has a relative molecular mass of 200.59, a melting point of -38.87^{0}C, a boiling point of 356.72^{0}C, and a density of 13.534 g/cm^3 at 25^{0}C (WHO 2003). When heated, it gives off a colorless and odourless mercury vapour (ASTDR, 1999) .

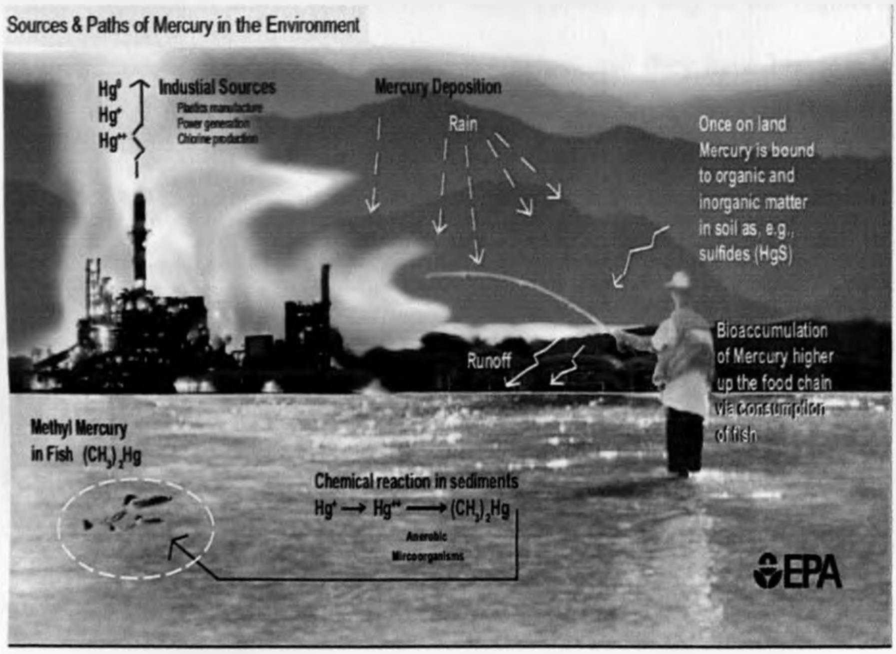


Figure 2.2: Sources and Paths of Mercury in the Environment (Source: STAR, 2002)

decline because their ballasts have been banned under the Energy Policy Act of 2005 (EPACT). They generally contain between 10 and 100 mg of mercury. A small portion contains greater than 100 mg of mercury (SCHER, 2010; IMERC, 2008).

e) Mercury short-arc lamps are spherical or slightly oblong quartz bulbs with two electrodes penetrating far into the bulb so that they are only a few millimeters apart. The bulb is filled with argon and mercury vapor at low pressure. Wattage can range from under a hundred watts to a few kilowatts. With the small arc size and high power, the arc is extremely intense. Mercury short-arc lamps are used for special applications, such as search lights, specialized medical equipment, photochemistry, UV curing, and spectroscopy. They contain relatively larger amounts of mercury, typically between 100 mg and 1,000 mg. About a quarter of these lamps contain more than 1,000 mg of mercury (SCHER, 2010; IMERC, 2008).

f) Mercury xenon short-arc lamps operate similarly to mercury short-arc lamps, except that they contain a mixture of xenon and mercury vapor. However, they do not require as long a warm up period as regular mercury short-arc lamps, and they have better color rendering. They are used mainly in industrial applications. They can contain between 50 mg and 1,000 mg of mercury. A small percentage of these lamps contain more than 1,000 mg of mercury (SCHER, 2010; IMERC, 2008).

g) Mercury capillary lamps provide an intense source of radiant energy from the ultraviolet through the near infrared range. These lamps require no warming-up period for starting or restarting and reach near full brightness within seconds. They come in a variety of arc length, radiant power, and mounting methods, and are used in industrial settings (i.e., for printed circuit boards), for UV curing, and for graphic arts. UV curing is widely used in silk screening, CD/DVD printing and replication, medical manufacturing, The vapor pressure of mercury metal is strongly dependent upon temperature, and it vaporizes readily under ambient conditions. Its saturation vapor pressure of 14 mg/m^3 greatly exceeds the average permissible concentrations for occupational (0.05 mg/m^3) or continuous environmental exposure (0.015mg/m^3) (WHO, 1976). Elemental mercury partitions strongly to air in the environment and is not found in nature as a pure, confined liquid. Most of the mercury encountered in the atmosphere is elemental mercury vapor (ASTDR, 1999).

Mercury has several forms and can exist in three oxidation states: Hg^0 (metallic), Hg^+ (mercurous), and Hg^{2+} (mercuric-Hg (II)). The properties and chemical behavior of mercury strongly depend on the oxidation state. Mercurous and mercuric mercury can form numerous inorganic and organic chemical compounds. However, mercurous mercury is rarely stable under ordinary environmental conditions. Mercury is unusual among metals because it tends to form covalent rather than ionic bonds. Most of the mercury encountered in water/soil/sediments/biota (all environmental media except the atmosphere) is in the form of inorganic mercuric salts and organomercurics. Organomercurics are defined by the presence of a covalent C-Hg bond. The presence of a covalent C-Hg bond differentiates organomercurics from inorganic mercury compounds that merely associate with the organic material in the environment but do not have the C-Hg bond. The compounds most likely to be found under environmental conditions are the mercuric salts $HgCl_2$, $Hg(OH)_2$ and HgS, the methylmercury compounds, methylmercuric chloride (CH_3HgCl) , methylmercuric hydroxide (CH_3HgOH); and, in small fractions, other two organomercurics (i.e., dimethylmercury and phenylmercury) (Langford, 1999).

Mercury compounds in the aqueous phase often remain as undissociated molecules, and the reported solubility values reflect this. Solubility values for mercury compounds which do not disassociate are not based on the ionic product. Most organomercurics are not soluble and do not react with weak acids or bases due to the low affinity of the mercury for oxygen bonded to carbon. CH_3HgOH, however, is highly soluble due to the strong hydrogen bonding capability of the hydroxide group. The mercuric salts vary widely in solubility. For example $HgCl_2$ is readily soluble in water, and HgS is as unreactive as the organomercurics due to the high affinity of mercury for sulfur (Langford & Ferner, 1999). The most common methylmercury, is produced mainly by microscopic organisms in the water and soil. More mercury in the environment can increase the amounts of methylmercury that these small organisms make. Metallic mercury is used to produce chlorine gas and caustic soda, and is also used in thermometers, dental fillings, and batteries. Mercury salts are sometimes used in skin lightening creams and as antiseptic creams and ointments (US-EPA, 2008)

2.1.4: Behaviour of Mercury in the Environment

Mercury is a persistent, mobile and bioaccumulative element in the environment and retained in organisms. Because mercury is an element; it cannot be converted to a non-mercury compound. Mercury is emitted into the atmosphere from a number of natural and anthropogenic sources. It can then be deposited in the vicinity of the emission source(s) or subjected to long-range atmospheric transport followed by deposition in ecosystems remote from the source(s). In contrast to most of the other heavy metals, mercury and many of its compounds behave exceptionally in the environment due to their volatility and capacity for methylation (UNEP, 2007).

Mercury in the aquatic environment is changed to various forms, mainly methylmercury. Once mercury enters into the environment, mercury permanently exists in the environment by changing its chemical forms depending on the environment. Fig. 4 shows the mercury species and transformation in the environment (UNEP, 2007).

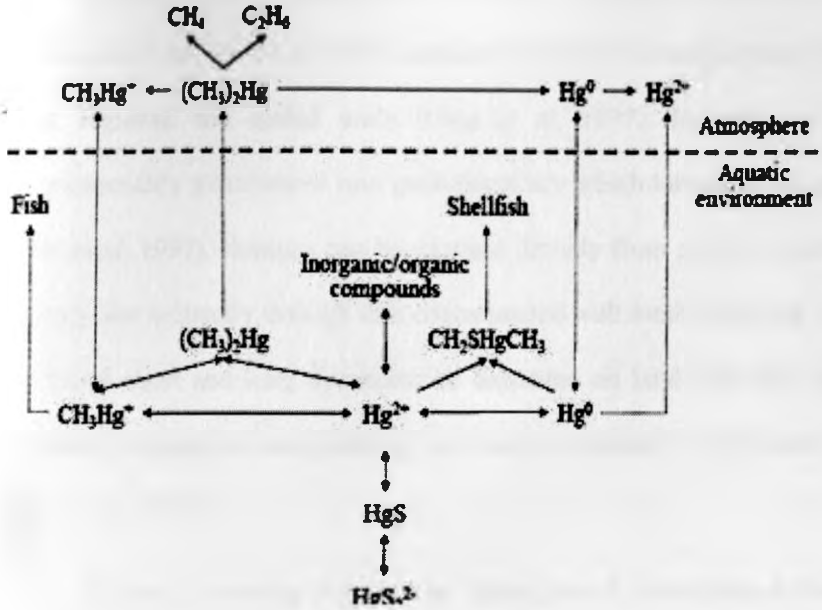


Figure 2.3: *Mercury species and transformation in the environment.*(Source: UNEP, 2007)

Mercury in the atmosphere is broadly divided into gaseous and particulate forms. Most of mercury in the general atmosphere is in gas form (95% or more). Gaseous mercury includes mercury vapour, inorganic compounds (chlorides and oxides), and alkyl mercury (primarily methylmercury). However, 90-95% or more of the gaseous mercury is mercury vapour (Japan Public Health Association, 2001).

In the aquatic environment under suitable conditions, mercury is bioconverted to methylmercury by the process called methylation (Wood 1974). Methylmercury is bioaccumulated within organisms from both biotic (other organisms) and abiotic (soil, air, and water) sources and biomagnified on the food chain. Therefore, methylation is the source of mercury exposure to human and it is chronic exposure to human health through consuming fish and seafood (UNEP, 2007).

2.1.5: Toxicity of Mercury

Mercury is well-documented as a toxic, environmentally persistent substance that demonstrates the ability to bioaccumulate and to be atmospherically transported on a local, regional, and global scale (Glen *et al*, 1997). In addition, mercury can be environmentally transformed into methylmercury which biomagnifies and is highly toxic (Glen *et al*, 1997). Humans can be exposed directly from products containing elemental mercury and indirectly through fish contaminated with methylmercury. Airborne mercury can travel short and long distances; be deposited on land and water resources locally, nationally, regionally, and globally; and lead to elevated methylmercury levels in Fish (Glen *et al*, 1997)

Mercury poisoning is known as hydrargaria or mercurialism (Barry, 1964). It is caused by exposure to mercury and its compounds. Exposure can occur from breathing contaminated air, or from improper use or disposal of mercury containing objects such as mercury spills and fluorescent light bulbs. People may be exposed to mercury in any of its forms under different circumstances. The factors that determine how severe the health effects are from mercury exposure include, the chemical form, dosage, age of the person exposed (the fetus is the most susceptible), duration of exposure, the route of exposure - inhalation, ingestion, dermal contact and health of the person exposed (ASTDR, 1999).

Elemental (metallic) mercury primarily causes health effects when it is inhaled as a vapor where it may be absorbed through the lungs. These exposures can occur when elemental mercury is spilled or products that contain elemental mercury break and release mercury to the air, particularly in warm or poorly-ventilated spaces (US-EPA 2008).Elemental mercury vaporizes at room temperature and is highly absorbed through inhalation (80%)(ASTDR 1999). Its lipid-soluble property allows for easy passage through the alveoli into the blood stream and red blood cells. Once inhaled it is converted into an inorganic divalent form by catalase in the erythrocytes. Small amounts of non-oxidized elemental mercury continue to persist and account for the central nervous system toxicity(ASTDR 1999). It penetrates the central nervous system where it is ionized and trapped, attributing to its significant toxic effects. Elemental mercury is not well absorbed by the gastro intestinal tract and therefore, when ingested, is only mildly toxic. Symptoms include tremors; emotional changes (e.g., mood swings, irritability, nervousness, and excessive shyness); insomnia; neuromuscular changes (such as weakness, muscle atrophy, twitching); headaches; disturbances in sensations; changes in nerve responses; performance deficits on tests of cognitive function(ASTDR 1999). At higher exposures there may be kidney effects, respiratory failure and death (STAR, 2000). Acute exposure caused by inhalation of elemental mercury can lead to pulmonary symptoms. Initial signs and symptoms include fever, chills, and shortness of breath, metallic taste and pleuric chest pain (Barry, 1964). Chronic and intense acute exposure causes cutaneous and neurological symptoms such as tremors, gingivitis, insomnia, shyness, memory loss, emotional instability, depression, anorexia, vasomotor disturbances, uncontrolled perspiration and blushing (Barry, 1964).

Inorganic mercury, found mostly in the mercuric salt form is highly toxic and corrosive (Barry, 1964). It gains access to the body orally or derrmally and is absorbed at a rate of 10% of that ingested. Clarkson (1989) reported absorption in dogs to be 40 % via inhalation. Absorption of Hg2+ through the gastrointestinal tract varies with the particular mercuric salt involved. Absorption decreases with decreasing solubility (ASTDR, 1999). It has a non-uniform mode of distribution secondary to poor lipid solubility characteristics and accumulates mostly in the kidneys, causing significant renal damage. Despite the poor lipid solubility, central nervous system penetration, slow elimination and chronic exposure may also lead to toxicity (Barry, 1964). Increases in intestinal pH, a milk diet (relevant to neonates), and increases in pinocytotic activity in the gastrointestinal tract (as occurs in neonates) have all been associated with increased absorption of Hg^{2+}(ASTDR.1999). Long term dermal exposure may also lead to toxicity (Barry, 1964). Symptoms of high exposures to inorganic mercury include: skin rashes and dermatitis; mood swings; memory loss; mental disturbances; and muscle weakness (ASTDR, 1999). The reported half-life of inorganic mercury in blood is about 20 to 66 days. Ionic mercury is excreted primarily in the faeces. However, ionic mercury can also be excreted via breast milk (ASTDR.1999). Renal excretion is considered insufficient and attributes to its chronic exposure and accumulation within the brain, causing central nervous system effects (Barry, 1964).

Organic mercury is found in three forms: aryl and short and long chain alkyl compounds (ASTDR 1999). They are absorbed more completely from the gastro-intestinal tract because they are lipid soluble and are mildly corrosive. Once absorbed, the aryl and the long chain alkyl compounds are converted to inorganic forms and possess similar toxic effects as inorganic mercury(Langford, 1999). The short chain mercurials are readily absorbed in the Gastro-Intestinal tract (90-95%) and remain stable in their initial forms (ASTDR 1999). Alkyl organic mercury has high lipid solubility and is distributed uniformly throughout the body, accumulating in the brain, kidney, liver, hair and skin. They also cross the blood brain barrier and placenta and penetrate erythrocytes, attributing to neurological symptoms, teratogenic effects and high blood to plasma ratio, respectively (Langford, 1999).

Methylmercury has a high affinity for sulfhydryl groups which attributes to its effects on enzyme dysfunction. Choline acetyl transferase which is involved in the final step of actylcholine production is inhibited, leading to acetylcholine deficiency, contributing to the signs and symptoms of motor dysfunction (Barry, 1964). Methylmercury combines with cystein to form a methylmercury-cysteine conjugate. A methylmercury-cysteine conjugate can pass through not only the blood-brain barrier but also the placenta via an amino acid transporter. Methylmercury can enter the brain where it is oxidized and accumulated and eventually causes chronic exposure and, depending on the level of exposure, can lead to adverse human health effects (ASTDR 1999). Because methylated Hg (methyl-Hg) in the aquatic environment accumulates in animal tissues up the food chain, persons can be exposed by eating freshwater fish, seafood, and shellfish. Exposure of childbearing-aged women is of particular concern because of the potential adverse neurologic effects of mercury in foetuses (Barry, 1964). Methylmercury has a relatively long biological half-life in humans; estimates range from 44 to 80 days. Excretion of methylmercury occurs primarily via the faeces, in hair, with less than one-third of the total excretion occurring through the urine. Methylmercury is also excreted through human milk but at much lower levels (ASTDR, 1999; WHO 2004)

2.1.6: Human Exposure

Mercury is well-documented as a toxic, environmentally persistent substance that demonstrates the ability to bioaccumulate and to be atmospherically transported on a local, regional, and global scale. In addition, mercury can be environmentally transformed into methylmercury which biomagnifies and is highly toxic (Glen et al, 1997, ASTDR, 1999). Humans can be exposed directly from products containing elemental mercury and indirectly through fish contaminated with methylmercury. Airborne mercury can travel short and long distances; be deposited on land and water resources locally, nationally, regionally, and globally; and lead to elevated methylmercury levels in fish (Glen et al, 1997). . Consumption of rice, maize, soyabean, broomcorn and vegetables grown in soils contaminated by smelting activities contribute to mercury exposure (Na Zheng et al, 2007). Although less common, humans can also be exposed to elemental mercury vapor. Exposure to mercury vapor can occur through inhalation and eye or skin contact. This exposure can occur when elemental mercury is released during production of mercury products or when products that contain elemental mercury break and release mercury to the air, particularly in warm or poorly-ventilated indoor spaces (ASTDR 1999; STAR, 2000). Exposures to elemental mercury from spills and breakage can result in significant exposures to elemental mercury, particularly when the quantity of mercury is large. Certain products that require maintenance (e.g., recalibration or refilling), can create potential exposure to elemental mercury vapor STAR, 2000). Inhalation of elemental mercury vapor is the main source of occupational exposure to mercury. Industries that use elemental mercury in their processes have had the largest occupational mercury exposure. Workers may also transport mercury home on contaminated clothing and shoes. Products containing mercury may also be broken during transport and disposal, resulting in mercury release and exposure. Persons living near mercury production, use, and disposal sites may be exposed to mercury that has been released from these sites to the surrounding air, water, and soil (ASTDR 1999; STAR, 2000) .Other possible routes of exposure to various forms of mercury include dermal exposure and breast- feeding (ATSDR, 1999; UNEP, 2002)

2.1.7: Manifestation of Mercury toxicity

2.1.7.1: : Minamata Disease

Minamata disease, which is a typical example of the pollution-related adverse effects to human health and the environment, was officially reported in 1956 around Minamata Bay, Kumamoto, Japan, and reccurred in 1965 in the Agano river basin, Nigata, Japan. The causal substance was methylmercury which was produced as a by-product of acetaldehyde discarded from Chisso Corporation into Minamata bay and from Showa Denko Company into the Agano river basin. Methylmercury released from both factories had been bioaccumulated and biomagnified heavily in fish and seafood which were the main source of food for local people (Japan Ministry of the Environment, 2002).

The signs and symptoms of the Minamata disease patients were sensory disturbance in the distal portions of four extremities, ataxia, concentric contraction of the visual field, etc. At the end of March 2006, 2,955 Minamata disease patients had been certified. The lessons learned from Minamata disease was that the environment should never be compromised for economic gains. (UNEP 2007)

2.1.7.2: Mercury Poisoning in Iraq

Methylmercury and ethylmercury poisonings have occurred twice in Iraq following the consumption of seed grain that had been treated with fungicides containing alkyl mercury compounds. The first incident which occurred in the late 1950s, was caused by ethylmercury-treated grain, and adversely affected about 1000 people. In 1971, a larger number of people in Iraq were exposed to methylmercury when imported mercury-treated seed grains arrived after the planting season and were then used to make flour that was baked into bread Because most of the people exposed to methylmercury in this way lived in small villages in very rural areas (and some were nomads), the total number of people affected by the mercury-contaminated seed grains was not known. About 6,500 patients were hospitalized and 459 known deaths occurred, mainly due to failure of the central nervous system (UNEP, 2002).

Toxicity was observed in many adults and children who had consumed the bread over a three-month period. Fourteen Iraqi patients who developed ataxia and "pins and needles" and could not walk heel-to-toe were examined for impaired peripheral nerve function. The predominant symptom noted in adults was paresthesia, and it usually occurrs after a latent period of from 16 to 38 days. In adults, the symptoms were dose-dependent, and among the more severely affected individuals ataxia, blurred vision, slurred speech and hearing difficulties were observed (UNEP, 2002)..

The population group that showed the greatest effects was offspring of pregnant women who ate contaminated bread during pregnancy. Infants born to mothers who had eaten the bread exhibited symptoms ranging from delays in speech and motor development to mental retardation, reflex abnormalities and seizures. Some information indicated that male offspring were more sensitive than females. The mothers experienced paresthesia and other sensory disturbances but at higher doses than those associated with their children exposed *in utero.* (UNEP, 2002).

2.1.7.3: Environmental Pollution around Dandora Dump Site – Nairobi, Kenya

A dumping site (Dandora), located to the East of Nairobi served as the main dumping site for most of the solid waste from Nairobi area. Both informal settlements and the residential estates surround the dump. Over 2,000 tonnes of waste generated and collected from various locations in Nairobi and its environs are deposited on a daily basis into the dumpsite and what initially was to be refilling of an old quarry gave rise to a big mountain of garbage. Dumping at the site is unrestricted and industrial, agricultural, domestic and medical wastes (including used syringes) were strewn all over the dumping site. The Nairobi River also passes beside the dump site. Some of the waste from the dump ended up into the River thus extending environmental and health risks to the communities living within the vicinity as well as those living downstream who could be using the water for domestic and agricultural purposes(UNEP, 2007) . According to the case study, mercury concentration in the samples collected from the waste dump exhibited a value of 46.7 ppm while those collected along the river bank registered a value of 18.6 ppm. Both of these values greatly exceeded the WHO acceptable exposure level of 2 ppm (UNEP, 2007). The rest of the samples were inconclusive due to the fact that the analytical method used was only capable of detecting high levels of mercury (15 ppm and above). From the environmental evaluation conducted, it was determined that the dumpsite exposed the residents around it to unacceptable levels of environmental pollutants with adverse health impacts. A high number of children and adolescents living around the dumping site had illnesses related to the respiratory, gastrointestinal and dermatological systems such as upper respiratory tract infections, chronic bronchitis, asthma, fungal infections, allergic and unspecified dermatitis/pruritis – inflammation and itchiness of the skin (UNEP 2007).

2.1.8: Environmental Exposure

Environmental organisms can be exposed to mercury from products via airborne mercury which can travel short and long distances and be deposited on land and water resources locally, nationally, regionally, and globally. Methylmercury formed via microbial action can accumulate to elevated levels, including via biomagnifications, in environmental organisms (Glen et al, 1997; ASTDR 1999).

The majority of atmospheric anthropogenic emissions are released as gaseous elemental mercury. This is capable of being transported over very long distances with the air masses. The remaining part of air emissions are in the form of gaseous divalent compounds (such as $HgCl_2$) or bound to particles present in the emission gas. These species have a shorter atmospheric lifetime than elemental vapour and will deposit via wet or dry processes within roughly 100 to 1000 kilometres. However, significant conversion between mercury species may occur during atmospheric transport, which will affect the transport distance. The atmospheric residence time of elemental mercury is in the range of months to roughly one year. This makes transport on a hemispherical scale possible and emissions in any continent can thus contribute to the deposition in other continents (UNEP, 2007).

2.1.9: Previous Studies on Fluorescent Lamps Mercury Pollution

Aucott et al (2004) worked on the release of mercury from broken fluorescent bulbs. A Jerome 411 Gold Film Mercury Vapor Analyzer10 was used to detect mercury vapor released from the broken bulbs. This instrument detects elemental mercury vapor. They found that estimates of the amount of this mercury released when the bulbs were broken varied widely. A new method was developed to measure mercury released from broken bulbs. It was found that between 17% and 40% of the mercury in broken low-mercury fluorescent bulbs was released to the air during the two-week period immediately following breakage, with higher temperatures contributing to higher release rates. One-third of the mercury release occurred during the first 8 hours after breakage. Many fluorescent bulbs contain more mercury than the low-mercury bulbs tested; a typical bulb discarded in 2003 might have released between 3 and 8 mg of elemental mercury vapors over two weeks. Since about 620 million fluorescent bulbs were discarded annually in the U.S., these may have released approximately 2 to 4 tons of mercury per year in the U.S. Airborne levels of mercury in the vicinity of recently broken bulbs could exceed occupational exposure limits.

A material flow analysis, carried out with the use of data available in New Jersey, was instructive in placing mercury aspects of CFLs in perspective with other uses and releases of mercury. At 5 mg each, 300 million bulbs would add 1.5 tons, about 0.6 percent, to the total amount of mercury deposited in landfills each year. Based on this materials-accounting analysis, CFLs, even if used much more widely than presently, were not likely to contribute significantly to the anthropogenic releases of total mercury in the environment. (Aucott, 2009).

A study by Msuzu Asari et al (2008) on Life-cycle flow of mercury and recycling scenario of fluorescent lamps in Japan concluded that the amount of mercury flow originating from products was estimated to be about 10–20 tonnes annually, 5 tonnes of which was from fluorescent lamps. The use of fluorescent lamps for backlights had increased, and most fluorescent lamps were disposed off as waste. Only 0.6 tonnes of mercury, about 4% of the total, was recovered annually.

Two methods for the determination of mercury in fluorescent lamp cullet samples were developed by Dobrowolski et al, (1992). In the first, cold vapour atomic absorption spectrometry (AAS) was applied to samples that were digested to dissolve the attached, mercury-containing phosphor. In the second method, solid phosphor material stripped from the glass cullet was used in a solid sampling technique employing electrothermal atomic absorption spectrometry with a specially designed ring chamber graphite tube. The results for the determination of mercury by the two methods were comparable. The relative standard deviations were 3.2-3.5% for the cold vapour AAS technique and 8.5-9.9% for direct solid sampling AAS at mercury levels of about 1.5 and 2.5 pg g^{-1}, respectively. The proposed digestion procedure and mercury determination methods (especially the solid sampling AAS method) have been successfully applied to the rapid monitoring of the mercury level in fluorescent lamp cullet and facilitate its further use as recycled glass.

A study by Chang (2007) investigated the fate of mercury of Cold cathode fluorescent lamps (CCFLs), Ultraviolet lamps, (UV) and Super high pressure mercury lamp (SHPs) of high technology industry in Taiwan using Material Flow Analysis method. It was observed that 479,150,100 CCLFs, 551,500 UV lamps and 25,700 SHPs were produced locally or imported in 2004 which contained a total of 879 kg of mercury. On the contrary, 37,658,500 CCFLs and 65,000 UV lamps exported, contained total 59 kg mercury. It was also estimated that 165 kg mercury was wasted. Among this wasted mercury, 140 kg mercury, i.e., 4,833,300 CCFLs, 486,500 UV lamps, and 25,700 SHPs, were treated through the industrial waste treatment process, while 25 kg mercury was not recovered by the industrial waste treatment processes and might be harmful to the environment. The 140 kg treated mercury was contributed by 80 kg of domestic treatment (57%), 53 kg of overseas treatment (38%), and 7 kg of air emission (5%). Additionally, the mercury contained in CCFLs used as components of other industrial products were 662 kg, which constituted 463 kg for export and 199 kg for domestic sale. The study pointed out that Taiwan lacked a suitable policy on mercury waste management.

Khan et al (2010) studied techno-economic performance comparison of compact fluorescent lamps (CFL) with light emitting diodes (LED), electrode less fluorescent lamps (EEFL), fluorescent tubes, incandescent bulbs, photovoltaic (PV) and fiber optic lighting systems in view of worsening power and energy crisis in Pakistan. Literature survey showed 23W CFL, 21W EEFL, 18W fluorescent tube or 15W LED lamps emit almost same quantity of luminous flux (lumens) as a standard 100W incandescent lamp. All inclusive, operational costs of LED lamps were found 1.21, 1.62. 1.69, 6.46, 19.90 and 21.04 times lesser than fluorescent tubes, CFL, EEFL, incandescent bulbs, fiber optic solar lighting and PV systems, respectively.

However, tubes, LED, CFL and EEFL lamps worsen electric power quality of low voltage networks due to high current harmonic distortions (THD) and poor power factors (PF). Energy consumption, bio-effects, and environmental concerns prefer LED lamps over phosphor based lamps but power quality considerations prefer EEFL.

Costs of low THD and high PF CFL, EEFL and LED lamps may be five to ten times higher than high THD and low PF lamps. Choice of a lamp depends upon its current THD, PF, life span, energy consumption, efficiency, efficacy, color rendering index (CRI) and associated physical effects. This work proposed manufacturing and user level innovations to get rid of low PF problems. Keeping in view downside of phosphor based lamps the research concluded widespread adoption of LED lamps. Government and commercial buildings may consider full spectrum hybrid thermal photovoltaic and solar fiber optic illumination systems.

Jang, et al (2004) carried out Characterization and recovery of mercury from spent

fluorescent lamps. Series of mercury analyses from various parts of fluorescent lamps that were 26 mm in diameter and ranged from 600 to 1800 mm in length (T8) and lamps that were 38 mm in diameter and ranged from 600 to 2400 mm in length (T12) to determine the partitioning of mercury in five different components of new and spent fluorescent lamps – vapor phase, loose phosphor produced during breaking and washing steps, end caps, and the glass matrices. Glass samples were also obtained from two lamp recycling companies and

compared to glasses of tested lamps. Cold vapour atomic absorption spectrometry was used for the analyses. The following conclusions were drawn:

1. Through oxidative reactions with phosphor powder and penetration mechanisms, elemental mercury in vapor phase had been partitioned to other compartments such as end caps or glass matrices during the service although the partitioning was different depending on the lamp types.
2. Since the mercury-containing phosphor powders were mobile through air and liquid phases when lamps were broken, the detachability of mercury-containing phosphor powders might be an important factor of public health concerns. From detachability tests of mercury-containing phosphor powders, the mercury in phosphor powders of spent T12 lamps appeared to be more mobile than the spent T8 lamps.
3. Total mercury concentrations and the amounts of mercury varied significantly even among different lamps of the same model, which was in agreement with the results of other studies.
4. Mercury existed in the phosphor powder residue on the glasses at various levels, depending on the separation processes used by recyclers. The separation processes

employed by most lamp recyclers could remove the phosphor powder and mercury on lamp glasses completely.

Accordingly, when lamp glasses are recycled, the mercury residue on glasses volatilized and was emitted to the atmosphere.

5. Compared with the acid washing, the heating process was efficient for recovering mercury partitioned on the glass. The mercury concentrations after 1 hour of exposure at 100^0 C decreased to below approximately 4 lg/g. The remaining mercury was gradually volatilized

with an increase in temperature. Above 400^0 C, mercury was recovered almost completely, although some types of glass strongly complexed with mercury.

2.1.10: Mercury Waste Management

In mercury waste management partnership area, the Government of Japan is leading the initiative which was started in early 2008.The objective of the partnership area was to minimize and, where feasible, eliminate unintentional mercury releases to air, water, and land from waste containing mercury and mercury compounds by following a life cycle management approach which involves a cradle-to-reuse perspective to the mercury issue to identify mercury pollution prevention opportunities . Fostering cooperation on initiatives related to the finalization of the Draft Basel Technical Guidelines on Environmentally Sound Management of Mercury Waste Activities was a key objective for consideration.

Two projects are under implementation to develop waste management strategies for mercury. UNEP Chemicals-coordinated one includes Burkina Faso, Cambodia, Chile, Pakistan, and the Philippines; the one coordinated by Secretariat of the Basel Convention will include Argentina, Costa Rica, and Uruguay (UNEP, 2007).

In order to reduce risk of mercury pollution to human health and the environment as well as the environmentally sound use of mercury-containing products, it was necessary to consider, introduce and fully implement Environmentally Sound Management (ESM) of mercury waste. Technical Guidelines on Environmentally Sound Management of Mercury Waste guides the environmentally unsound management of mercury waste to ESM. ESM of mercury waste means taking all practicable steps to ensure that mercury waste is managed in a manner which will protect human health and the environment against the adverse effects which may result from such waste. The criteria of ESM under the Basel Convention are to ensure that:

- Generation of mercury waste within it is reduced to a minimum, taking into account social, technological and economic aspects;
- Availability of adequate disposal facilities, for ESM of mercury waste, that shall be located, to the extent possible, within it, whatever the place of their disposal;
- Persons involved in the management of mercury waste within it to take such steps as are necessary to prevent pollution due to mercury waste arising from such management and, if such pollution occurs, to minimize the consequences thereof for human health and the environment;
- Transboundary movement of mercury waste is reduced to the minimum consistent with the environmentally sound and efficient management of such waste, and is conducted in a manner which will protect human health and the environment against the adverse effects which may result from such movement;
- International cooperation is implemented in activities among parties, interested organizations of both public and private sectors for information exchange and technical cooperation on ESM of mercury waste;
- Appropriate legal, administrative and other measures to prevent and punish conduct in contravention of the Basel Convention are implemented and enforced;

- Transboundary movement of mercury waste is strictly controlled under the Basel Convention (UNEP, 2007).

2.1.11: Legislation aimed to control Mercury Emission

Since mercury is persistent in the environment and the fact that it is transported over long distances by air and water, crossing borders and often accumulating in the food chain far from its original point of release (Glen et al,1997), a number of countries have concluded that national measures are not sufficient (UNEP 2007).. There are a number of examples where countries have initiated measures at regional, sub-regional and international levels to identify common reduction goals and ensure coordinated implementation among countries in the target area (UNEP 2007).

Three regional, legally binding instruments exist that contain binding commitments for parties with regards to reductions on use and releases of mercury and mercury compounds:

- LRTAP Convention on Long-Range Transboundary Air Pollution and its 1998 Aarhus Protocol on Heavy Metals (for Central and Eastern Europe and Canada and the USA);
- OSPAR Convention for Protection of the Marine Environment of the North-East Atlantic; and
- Helsinki Convention on the Protection of the Marine Environment of the Baltic Sea.

All these three instruments have successfully contributed to substantial reductions in use and releases of mercury within their target regions (UNEP 2007).

Six initiatives exist at regional or sub-regional levels that inspire and promote cooperative efforts to reduce uses and releases of mercury within the target area without setting legally binding obligations on the countries/regions participating. The initiatives are: the

Arctic Council Action Plan, the Canada-US Great Lakes Binational Toxics Strategy, the New England Governors/Eastern Canada Premiers Mercury Action Plan, the North American Regional Action Plan, the Nordic Environmental Action Programme and the North Sea Conferences(UNEP 2007). Important aspects of these initiatives are the discussion and agreement on concrete goals to be obtained through the cooperation, the development of strategies and work plans to obtain the set goals and the establishment of a forum to monitor and discuss progress. Although these initiatives are not binding on their participants, there is often a strong political commitment to ensure that the agreements reached within the initiative are implemented at national/regional level (UNEP 2007).

There are also a number of examples of national/regional initiatives being taken by the private sector in the form of voluntary commitments that can be seen as an adjunct to public sector initiatives and as having a good chance of success as they have, by definition, the support of the primary stakeholders. All these voluntary initiatives are valuable supplements to national regulatory measures and facilitate awareness raising, information exchange and the setting of reduction goals that benefit the target region (UNEP 2007).

The Waste & Resources Action Programme is pioneering a technique to recover mercury from LCD flat panel display shred, which can potentially be used for bulk scale commercial recycling (Business Wire, Mar. 16, 2010)

To control mercury emission, sector-specific legal regulations have been applied which deal with coal-fired power plants, waste incineration or cremation. In the EU Member States, emissions of mercury from major industrial sources (e.g. chlor-alkali plants) are subject to Directive 96/61/EC (IPPC). Special requirements for managing waste containing mercury and for protecting or monitoring the quality of soil, air, water, groundwater drinking water and food (e.g. fishery products) have been implemented (EC DG Environment, 2005).

The U.S. Environmental Protection Agency (US-EPA) recently settled with E.I. DuPont de Nemours and Company (DuPont) for the discharge of pollutants in violation of the Clean Water Act at its polymer fiber manufacturing facility in Kinston, N.C. Under the terms of the Consent Agreement and Final Order, DuPont paid a civil penalty of $59,000.The company discharged levels of mercury in excess of the total mercury limitation established in its National Pollutant Discharge Elimination System (NPDES) permit issued by the state of North Carolina during 8 months between September 2008 and March 2009 (US-EPA, June 15, 2010).

A Glasgow-based Waste Electrical and Electronic Equipment firm and its director fined £145,000 for exposing workers to toxic mercury fumes at its Huddersfield recycling plant. Five of the employees showed "extremely high levels" including a pregnant worker who was concerned that her unborn baby was at risk following the exposure which happened between October 2007 and August 2008.This breached Section 2(1) of the Health and Safety at Work Act 1974 and the Control of Substances Hazardous to Health Regulations 2002 (Materials Recycling_Week, Feb. 10, 2010).

2.1.12: International Fluorescent Lamp Recycle Initiatives

Proper disposal and recycling of fluorescent lamps is important because of their mercury content. If the bulbs break during use or are not properly collected and recycled at end of life, that mercury can enter the environment. Government agencies, utilities, manufacturers, retailers, and other organizations have implemented a number of initiatives to promote CFL recycling.

US has legislation requiring manufacturers to implement fluorescent lamp collection and recycling programs for consumers. A number of activities have been implemented in fluorescent lamp recycling. These include mail-back programmes which are advantageous in rural areas, where people may be far from a retail collection centre, there is access to a post office or mailbox (CFL recycle report). This help consumers properly recycle spent fluorescent lamps through the mail in pre-paid packages specifically designed for the product (Appell, 2007). Retail and wholesale-based collection programs involve utilization of designated collection programs at local retail stores and wholesale locations. The retail store, or other drop-off location, is responsible for ensuring that the bulbs dropped off by consumers are handled correctly, labelled and packed, and sent out for recycling. They include community drop-off locations and collection centres. Utility-sponsored programs involve manufactures, utilities, governments, and/or other organizations sponsoring special collection events for recycling fluorescent lamps. Often these events are hosted in conjunction with other community events (Appell, 2007).

The concepts of extended producer responsibility and manufacturer take-back initiatives are ongoing. Here the costs of recycling, including collection and transportation, are included in the overall product price and the consumer does not see them as a separate cost (Appell, 2007).

In April 2007, the Canadian federal government announced its intentions to ban the sale of inefficient incandescent light bulbs by 2012, in an effort to cut down on emissions of greenhouse gases and reduce other atmospheric pollution Initiatives include retail collection centres where customers can drop off bulbs for recycling free-of-charge. Also an outreach programme "Project Porchlight" is an energy efficiency lighting campaign. The goal of "Project Porchlight" is to provide a free CFL to every household in Canada. The program has been successful in educating the public on the energy efficiency of CFLs. Since 2005, the program has distributed more than two million CFL bulbs **(NEWMOA, 2009)**

"Project Porchlight" does provide customers with guidance on proper recycling and disposal options for CFLs **(NEWMOA, 2009)**

In Europe, Flourescent lamps are subject to subject to the requirements of the Waste Electrical and Electronic Equipment (WEEE) directive put forth by the countries in the European Union. The retail price of a CFL bulb includes the cost for recycling, and manufacturers are required to collect and recycle them. Manufacturers and retailers must also provide information to consumers about where they can recycle their CFLs. Some retailers have in-store collection facilities; however, most retailers rely on "Designated Collection Facilities." The designated collection facilities (also known as DCFs) are defined in the WEEE regulations as specific collection sites for receiving household electronic wastes, including CFLs recyclers **(NEWMOA, 2009)**

Australia has an ultimate goal to eliminate the use of incandescent light bulbs by 2015. Retail collection centres fitted with specially designed 'flashback' boxes for collection of spent fluorescent lamps and subsequent recycling by waste management companies have been set up. **(NEWMOA, 2009)**

In Asia, Taiwan has the highest rates of CFL recycling, with 87 percent of all fluorescent lamps recycled, due to a compulsory fluorescent lamp recycling program, which was launched in 2002 **(NEWMOA, 2009)** . The Taiwan Environmental Protection Administration (TEPA) implemented a mandatory fluorescent lamp recycling program under its *Waste Disposal Act.* Consumers can recycle their spent fluorescent lamps in any store in Taiwan that sells them. Store owners that fail to cooperate with the TEPA on the recycling project are fined. The collected lamps are sent to one of four approved mercury reclamation facilities. **(NEWMOA, 2009)**

In Japan, where 80 percent of households use CFLs, the recycling rate is less than 10 percent **(NEWMOA, 2009)**.

TCP, Inc., in collaboration with the Joint U.S.–China Cooperation on Clean Energy (JUCCCE) "China Green Lights for All" program, has launched China's first CFL recycling program for consumers in 2009. The program provided CFL recycling opportunities to millions of consumers free of charge. The program's goal is to collect more than two million CFLs every year **(NEWMOA, 2009).**

Hong Kong's Manufacturer-Funded Programs involving SUNSHINE Lighting Ltd. (a lamp manufacture in Hong Kong and China) piloted the first CFL recovery initiative to be available to the general public in Hong Kong. The program was called the "Save the Earth Energy Saving Lamp Recycling Campaign", and consumers were allowed to bring in their out-of-service CFLs to any Japan Home Centre (a local hardware store chain) for recycling

To encourage people to continue to use more energy efficient compact fluorescent lamps, SUNSHINE also provided $5.00 cash vouchers to use towards the purchase of new CFLs **(NEWMOA, 2009).**

2.1.13: The Kenya Situation

In its efforts to manage mercury pollution, Kenya set standards on environmental media. Drinking water should not contain more than 0.001mg/l. (KS03-459:1985) For foodstuffs, root tubers such as cassava should contain mercury not more than 0.001 ppm (KS05-1774:2002) On actions and regulations on products that contain mercuey, Kenya banned the importation, production and use of any cosmetic products containing mercury(KS03-1474: PART2), the total amount of heavy metals in finished products should not exceed 20ppm (KS03-1511: Clause 5.4) and mercury is no longer used in paint manufacture. Since 1986 no pesticide containing mercury has been imported in the country. The Kenya Bureau of Standards was given a full time involvement by the laws of Kenya (CAP 496) to ensure products evaluation and testing surveillance of imported products at points of entry and conduct regular market survey sampling (UNEP, 2008). The Constitution of Kenya (Aug 2010) and the Environmental Management and Coordination Act (EMCA) of 1999 both underscore the right of every person to a clean and healthy environment and commits each and every one of us to safeguard and enhance the environment. EMCA Waste Management regulations (Legal Notice No. 121) Fourth Schedule *(Regulation 16)* defines mercury wastes considered hazardous. However, regulations pertaining to disposal of mercury and mercury-containing products have not been formulated.

The research was intended to supply the necessary data to initiate the development of the relevant policy in regards to fluorescent bulb disposal. The study created awareness to all stakeholders on dangers and illnesses resulting from mercury exposure. In this study, I have carried out a source specific environmental risk analysis in identified high fluorescent bulb consumers within Nairobi in order to ascertain the local levels of mercury in ambient air. The selected areas were located away from other sources of mercury such as battery manufactures, thermometer manufactures/ consumers and hospitals. For comparison, an open dump site surrounded by buildings with high consumption of fluorescent lamps was also studied. Cold vapour atomic absorption spectroscopy was used to determine ambient air mercury contamination levels.

2.2: Problem Statement

With the advent of energy saving fluorescent lamps, regulations require special disposal of fluorescent lamps separate from general and household wastes. Kenya lacks such regulations Furthermore, lack of awareness on the dangers posed by mercury poisoning make the situation in Kenya more precarious.

Generally, about 40% of the total waste generated in urban centres is collected and disposed of at the designated disposal sites. The rest of the waste, composed of chemicals including heavy metals, salts, detergents and medical waste is either dumped in unsuitable areas or disposed off in rivers that traverse the urban centres and other wetlands. Some of the municipalities do not have designated disposal sites (NEMA, 2003).

The mode of waste transportation is also not regulated and lacks coordination. The disposal of the fluorescent bulbs and particularly the toxic mercury in the lamps is an environmental issue of concern. Exposure to mercury can occur from breathing contaminated air, or from improper use or disposal of mercury containing objects such as mercury spills and fluorescent light bulbs. Mercury is a powerful neurotoxin and causes a variety of health effects due to exposure. Chronic and intense acute exposure causes cutaneous and neurological symptoms such as tremors, gingivitis, insomnia, shyness, memory loss, emotional instability, depression, anorexia, vasomotor disturbances, uncontrolled perspiration and blushing (Barry, 1964) Those who are at most risk from mercury exposure are pregnant women and developing children (US-EPA, 2011).

The Constitution of Kenya (Aug 2010) and the Environmental Management and Coordination Act (EMCA) of 1999 both underscore the right of every person to a clean and healthy environment and commits each and every one of us to safeguard and enhance the environment. This has is not adhered to.

Since the case study on the Environmental Pollution around Dandora Dump Site – Nairobi, Kenya was done (UNEP, 2007), there has neither been follow-up nor mitigating efforts to rectify the situation. It is therefore imperative that relevant authorities should have policies/ regulations governing the safe disposal of the same based on factual scientific information.

To protect human health and the environment, mercury waste and waste containing mercury must be managed in an environmentally sound manner. Finding environmentally sound solutions for the management and storage of waste consisting of or containing mercury and mercury compounds is a key priority outlined by the UNEP Governing Council 24/3. The Basel Conference of Parties decision during its eighth session to include mercury waste as one of its strategic focus areas for the next biennium, the Draft Technical Guidelines (TG) on the Environmentally Sound Management (ESM) of Mercury Waste was developed as a collaborative effort between UNEP Chemicals and Secretariat for Basel Convention (SBC). It called for increased efforts to address the global challenges to reducing risks from mercury release (UNEP, 2007). The leading consensus from environmental organizations and government is that although fluorescents be recommended for business and residential use, they should be handled with care and managed properly to avoid breakage.

However, such policies/regulations must be supported with relevant scientific data.

The research was intended to supply the necessary data to initiate the development of the relevant policy in regards to fluorescent bulb disposal. The study will be used to create awareness to all stakeholders on dangers and illnesses resulting from mercury exposure.

2.3: Objectives of the Study

2.3.1.1: Overall Objective

The aim of the study was to determine whether selected sites with high consumption rates of fluorescent lamps have proper disposal procedures and if there is high mercury contamination associated with the same, with a view to inform policy makers on the need to regulate disposal of fluorescent lamps.

2.3.2: Specific objectives

- To evaluate the disposal procedures used in the selected sites with high fluorescent lamp consumption
- To determine mercury levels at the holding or dump sites at the selected facilities to determine the impact of sensitization on proper disposal of fluorescent lamps.
- To determine the impact of sensitization on proper disposal of fluorescent lamps.

CHAPTER 3

3.0: SAMPLING METHODOLOGY

3.1: Sampling Sites and study design

The study was designed to passively collect ambient air samples for determination of mercury concentrations, presumably solely from broken spent fluorescent lamps, over a three month period (April to June 2010). The sampling sites were selected based on high consumption of fluorescent lamps. The areas were located away from other sources of mercury pollution such as battery manufactures, thermometer manufactures/ consumers and hospitals .Disposal procedure of fluorescent lamps at the selected sites were observed. The selected sites were Times Tower building garbage holding facility located at the 1^0 17’ 26.32 S; 36^0 49’ 25.84 E and the open dump site at the Sunken Car Park.

Times Tower building has 38 floors and is the highest building in East Africa. An interview with the care-taker revealed that it has 50,000 two-foot and 5000 four-foot fluorescent bulbs. When burnt out (20,000 lamps annually), they were mixed with other refuse in disposal bins in each floor. The bins were emptied into the chutes that lead to the waste holding facility. In the process, the fluorescent lamps get crushed and release the mercury. The garbage was then disposed at the Dandora Dump site. Asked whether he knew that the fluorescent lamps contained mercury, the care-taker was neither aware that the fluorescent lamps contained mercury nor that mercury was poisonous, hence a special disposal procedure was necessary (Obingo, 2010).

The contracted waste disposal agent was also interviewed. They were not aware that the fluorescent lamps contain mercury. They were also not aware of its dangers or that the lamps required special disposal procedures (Mureithi, 2010). The first samples were taken before sensitization in April 2010, on alternating days totaling 15 days.

The caretaker and the contracted waste disposal company were advised to separate the fluorescent lamps from the rest of the wastes. To confirm whether they heeded the advice, monthly samples were taken on alternating days for another two months (i.e. May and June 2010).

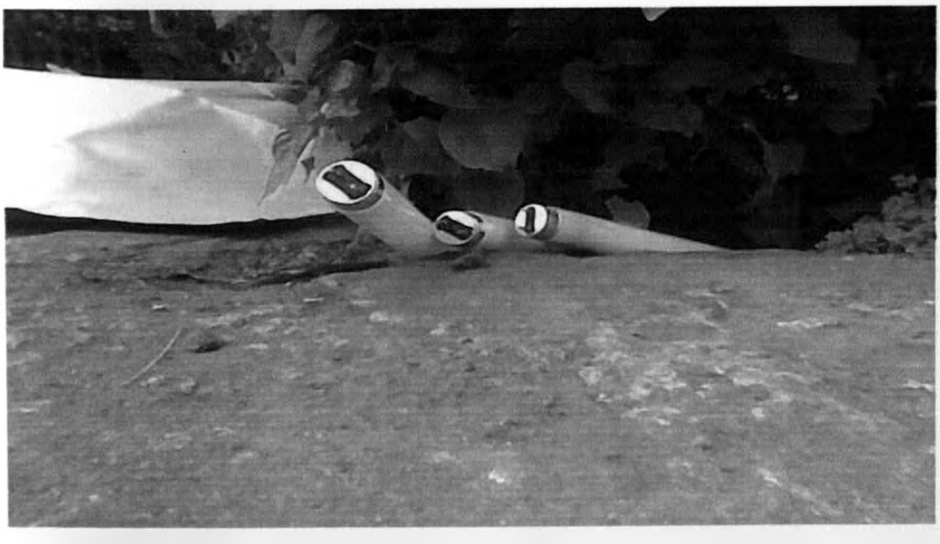
For comparison, sampling from an open dump site, was carried out. The Sunken car park dump site is located along Aga Khan Walk. The surrounding buildings are high fluorescent lamps consumers and temporarily, haphazardly dump their wastes at the site without any control measures in place. They were observed scattering wastes all over and sometimes dumping on the floor even when the bins were not full. Sensitizations could not be carried out under the circumstances. The Nairobi City Council then ferried the garbage to the Dandora dump site. Sampling was done on alternating days from April to June 2010.

Figure 3.1: Map of Nairobi


To Holiday Inn & Western Kenya
U.O.N
University Way
Globe Roundabout
Jevanjee Gardens
Koinange
Mbingu
Biashara
KILOME
Nairobi River
Central Park
City Market
MOI
RIVER
TOM MBOYA
LATEMA
KIRINYAGA
NGARIAMA
Kenyatta
G.P.O
Standard
TSAVO
ACCRA
KIMATHI
KAUNDA
WABERA
MAMA NGINA
DURUMA
RIVER
UHURU HIGHWAY
City Hall
City Hall Way
National Archives
Luthuli
CITY SQUARE
TAIFA
AGA KHAN
MOI
TOM MBOYA
RONALD NGALA
Uhuru Park
PARLIAMENT
K.I.C.C
Harambee
MFANGANO
MAKATI
RACECOURSE
Haile Selassie
Haile Selassie
Golf Course
To Carnivore, National Park, Giraffe Centre, Karen Blixen, etc.
MOI
STATION
Railway Station
SHOOR SAFARIS

Figure 3.2: Times Tower Waste holding Facility (April 2010)

A) Genral View



B) Close-up view

Figure 3.3: Sunken Car Park Dump Site. (April 2010)

3.2: Chemicals and Materials

An absorbing solution comprising 0.1% analytical grade (99.0% minimum assay) potassium permanganate from BDH and Analytical grade (0.5mol) 1N sulphuric acid (FIXANAL) from Sigma-Aldrich in plastic vials was used to trap mercury from the air. Analytical grade10% hydroxylamine hydrochloride from BDH was added drop wise to decolorize the potassium permanganate. Mercury Atomic Spectroscopy Standard solution from Fluka was used for making standard stock solution. 1 ml of the standard contained 1000ppm mercury. Analytical grade stannous chloride ($SnCl_2$), granulated tin (Sn (II) and Analytical grade 1N sulphuric acid were used to prepare the reductant. Laboratory distilled water was used in all dilutions. High purity argon gas purchased from BOC Kenya Limited was used as carrier gas in the cold vapour atomic absorption spectrometer to determine the mercury concentration.

3.3: Equipment and Apparatus

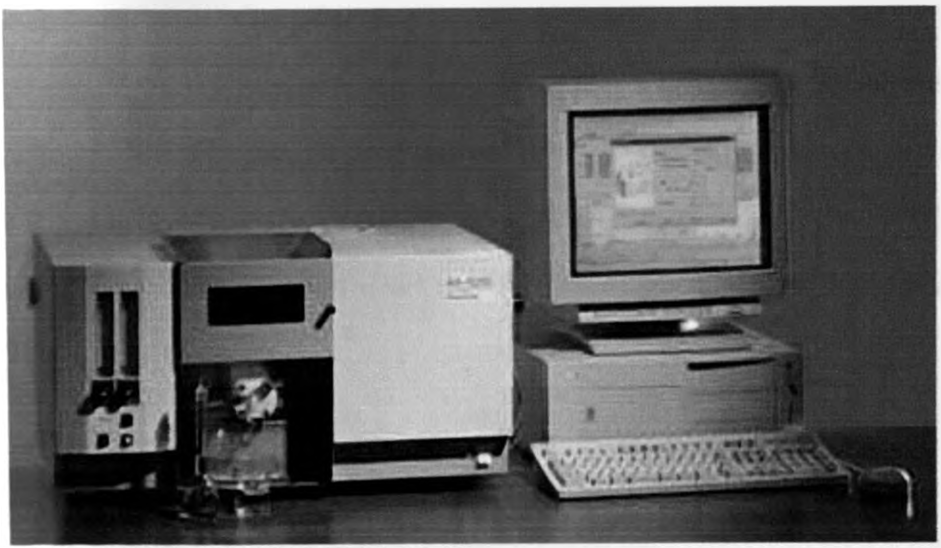


Figure 3.4: Shimadzu AAS 6200 with MVU-1A

Shimadzu AAS 6200 with MVU-1A from Japan was used for ambient air mercury concentration analysis. It has double-beam optics for superior baseline stability, D2 background compensation for matrix interferences as well as a 2-lamp turret for easy switching between elements, with lamp preheating. The MVU-1A enables determination of mercury with the cold vapour technique.

Mettler Toledo AB201-S balance was used for weighing.

Glassware used included volumetric flasks (1000ml, 200ml, 100ml and 50ml), graduated pipettes (1ml, 5ml), for making standard, dissolving, decolourizing solutions and reductant; pipette droppers for decolourizing solution and 100mls glass vial with screw-type Teflon caps for the dissolving solution to trap mercury.

3.4: Field Sampling

Passive sampling was done on each site on every alternating day for three months (April, May and June 2010). 50 mls of the dissolving solution consisting of 0.1% potassium permanganate in 1N sulphuric acid solution was placed in open glass vials and placed on the floor of sampling sites at different locations, in triplicates for 24 hours (6.00 a.m- 5.00 a.m). Potassium permanganate oxidizes a wide variety of inorganic and organic substances. Potassium permanganate (Mn$^{7+)}$ is reduced to manganese dioxide (MnO_2) (Mn^{4+}) which precipitates out of solution (Hazen and Sawyer, 1992). All reactions are exothermic. Under acidic conditions the oxidation half-reactions are (CRC, 1990):

$$MnO_4^- + 4H^+ + 3e- \longrightarrow MnO_2 + 2H_2O$$

$$MnO_4^- + 8H^+ + 5e- \longrightarrow Mn^{2+} + 4H_2O$$

The vials were then capped, labelled appropriately with sample date and site, removed from sampling sites and stored under refrigeration (-20°C) awaiting analysis.

3.5: Sample Analysis

The samples mercury concentrations were determined by the cold vapor atomic absorption spectrometry (CVAAS) as outlined in the Mercury Analysis Manual (Ministry of Environment, Japan, 2004). The sample was reduced in the reaction vessel and the liberated mercury was transferred into the quartz cuvette. Using this method, a detection limit of 0.01 μg/L could be obtained.

3.5.1: Preparation of Standards

One milliliter (1 ml) of the Mercury Atomic Spectroscopy Standard was diluted to 1 litre (1000ml) to make the stock solution (1ml contained 1ppb mercury). Serial dilution solutions containing 0, 10, 20, 40, 60, 80, 100, 120, 160 and 180 ppb were made from the stock solution. The respective volumes were topped up with 1N sulphuric acid.

3.5.2: Preparation of the decolorizing solution

10 grams of analytical grade hydroxylamine hydrochloride ($NH_2OH.HCl$) was dissolved in 100ml distilled water to make a 10% solution. Hydroxylamine and its salts are commonly used as reducing agents in a myriad of organic and inorganic reactions due to their ability to donate nitric oxide (Cisnero et al, 2003).

3.5.3: Preparation of the Reductant

20g analytical grade stannous chloride ($SnCl_2$) was added to 40 ml IN Sulphuric Acid and warmed on a hot plate until it completely dissolved. The solution was made to 200mls with distilled water. A piece of granulated tin was added to reduce any Sn (IV) to Sn (II) until a clear solution was produced (Smith, 1975). Because of the extreme sensitivity for certain elements, the vapour generation technique is widely applied. It employs continuous flow technique in which samples and liquid reagents are pumped and allowed to mix. The gaseous reaction products are swept into an absorption cell located in the optical path of the atomic absorption spectrophotometer (Smith, 1975).

3.5.4: Quality Assurance and Quality Control

The quality control was performed by regular analyses of procedural blanks, blind triplicate samples, and by random analysis of standards to check the equipment performance.

3.5.5: Measurement

The sample flow rate was set at 1.5L/min while the wavelength was set at 253.7nm

First, a dissolving solution consisting of 0.1% potassium permanganate in 1N sulphuric acid was allowed to flow through in order to dissolve any atmospheric mercury from the system.

A blank solution consisting of 50ml 0.1% potassium permanganate in 1N sulphuric acid was then measured and its absorption recorded.

Then the standard series were run starting with least concentrated and their absorptions noted. The peristaltic pump maintained a constant flow of analytical solutions. The sample and the acid were first mixed before the stannous chloride entered the stream. Argon was then introduced into the liquid stream and the reaction proceeded while the mixture was flowing through the reaction coil. Vigorous evolution of hydrogen during the reaction assisted the stripping of the mercury vapour from the liquid into the argon. The gas was separated from the liquid in the separator. At this point, a second stream of argon was introduced to ensure that the gas stream was not saturated with water vapour. The gas stream passed from the separator into the flow-through cell. Two readings were taken for each standard and the average was determined.

Then drops of delourizing solution were added to the samples until they decolourized. The samples were measured and their absorptions noted.

A calibration curve for the standard series solution was drawn. The equation of the curve and the R^2 value were determined by Microsoft Excel. The concentrations of the samples were determined from the curve.

3. 6: Conversion from pbb to mg/m^3

The samples concentrations in ppb were converted to mg/m^3 using the expression: $mg/m^3 = 0.0409 \times ppb/1000 \times$ Molecular weight of mercury (200.59) (EAS 751:2010).

3.7: Statistical Analysis

The Mercury concentrations of the standards were statistically analyzed and the linear regression equation of the curve and the r^2 values determined, The mean, standard deviation and error values were also determined using Microsoft Excel.

CHAPTER 4

4.0: RESULTS AND DISCUSSION

The chapter summarizes the findings obtained from both sampling sites.

4.1: Quantification of Mercury in the Air

Cold vapour atomic absorption spectroscopy was used for quantitative determination of mercury in the air sampled around the selected sites. A calibration curve obtained from the standard solutions was made using the Microsoft Excel ,whose linear regression equation was $y = 0.01x - 0.0008$, with an r^2 value of 1. The calibration curve was used to quantify the concentration in parts per billion (pbb). The resultant concentrations were converted to $mg/m^{3.}$

Table 4.1: Mean Absorbance for Mercury Standards

Concentration (ppb)	**Absorbance (mean)**
0	0.000
10	0.0989± 0.0001
20	0.2041±0.0028
40	0.3976±0.0007
60	0.5937±0.0046
80	0.7952±0.0010
100	1.0021±0.0001
120	1.2002±0.0001
140	1.3989±0.0006
160	1.5978±0.0016
180	1.8001±0.0004

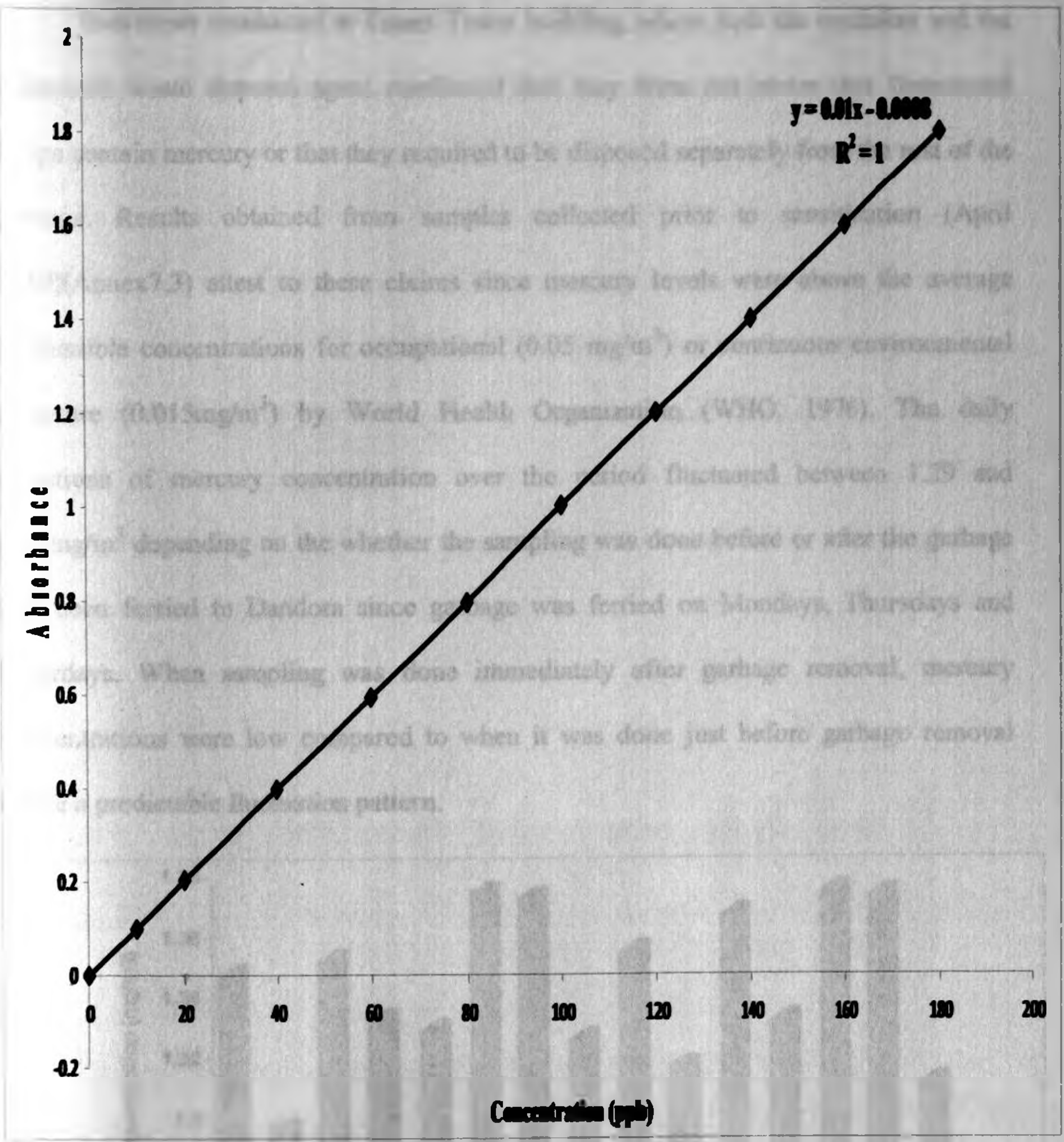


Figure 4.1: Mercury Calibration Curve

4.2: Times Tower Results for April 2010

Interviews conducted at Times Tower building, where both the caretaker and the contracted waste disposal agent confirmed that they were not aware that fluorescent lamps contain mercury or that they required to be disposed separately from the rest of the garbage. Results obtained from samples collected prior to sensitization (April 2010)(Annex7.3) attest to these claims since mercury levels were above the average permissible concentrations for occupational (0.05 mg/m^3) or continuous environmental exposure (0.015mg/m^3) by World Health Organization (WHO, 1976). The daily variations of mercury concentration over the period fluctuated between 1.29 and 1.37mg/m^3 depending on the whether the sampling was done before or after the garbage had been ferried to Dandora since garbage was ferried on Mondays, Thursdays and Saturdays. When sampling was done immediately after garbage removal, mercury concentrations were low compared to when it was done just before garbage removal hence a predictable fluctuation pattern.

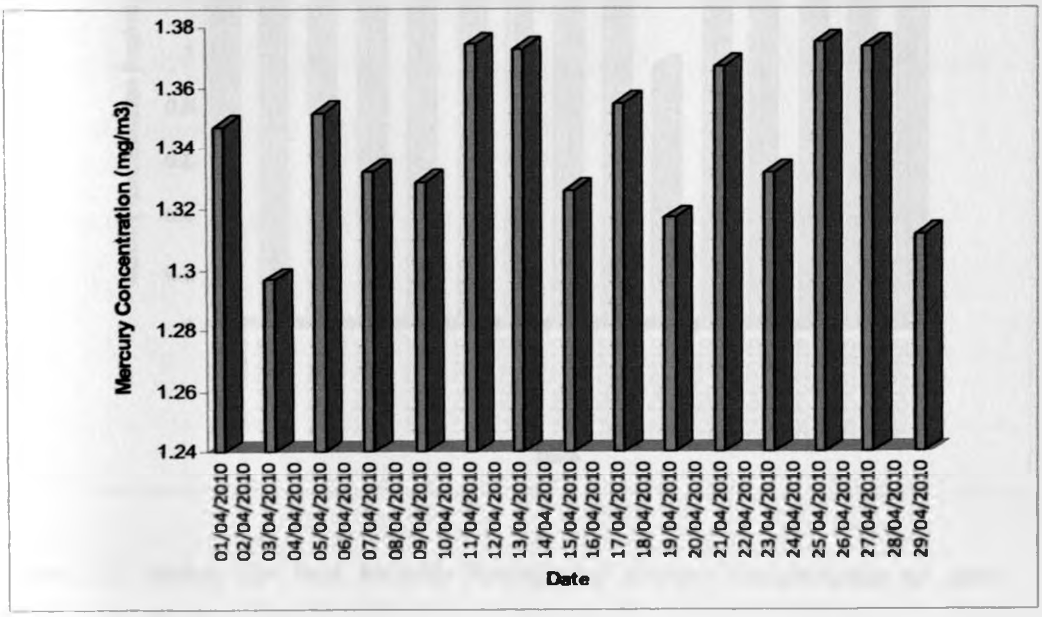


Figure 4.2: Times Tower Monthly Variation of Mercury Concentration for April 2010

4.3: Sunken Car Park Results for April 2010

On the other hand, the concentrations at the Sunken car park dump site remained high and varied between 0.95 and 1.37mg/m^3. (Annex7.6)The dumping was haphazard and uncontrolled. Sensitization could not be done under the circumstances since the garbage was dumped by a wide variety of people residing in the neighborhood of the site. Figure 4.3 depicts a rather unpredictable fluctuation pattern since garbage was not regularly ferried to Dandora dumpsite. Low mercury concentrations (0.95 mg/m^3) were evident when sampling occurred immediately after the garbage was ferried and was high (1. 37mg/m^3) when garbage stayed for long periods before ferrying. Both concentrations were above the average permissible concentrations for occupational (0.05 mg/m^3) or continuous environmental exposure (0.015mg/m^3) by World Health Organization (WHO, 1976).

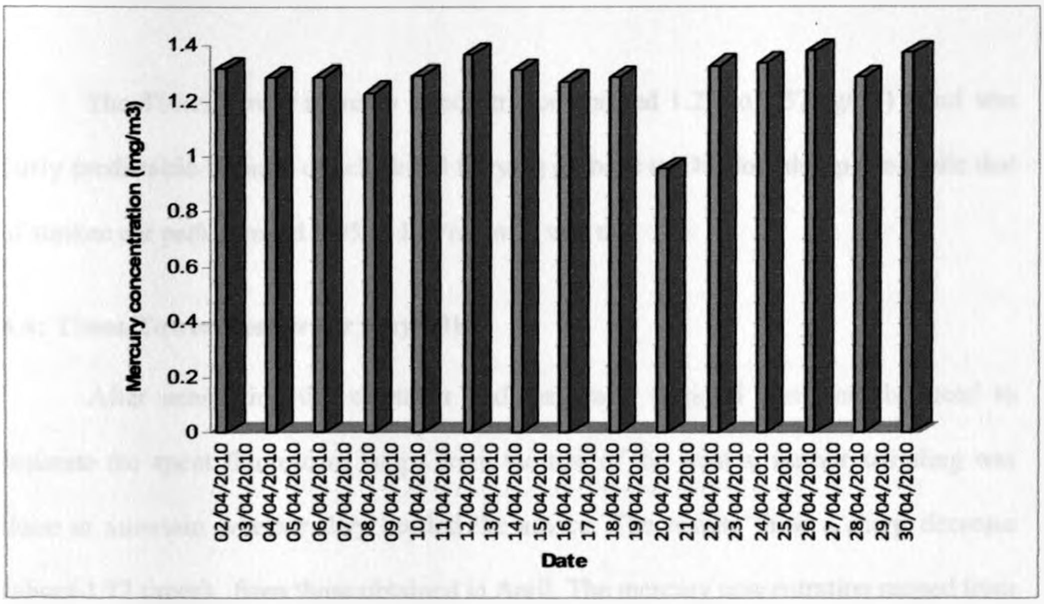


Figure 4.3: Sunken Car Park Monthly Variation of Mercury Concentration for April 2010

A comparison of the mercury concentration over the month was as illustrated in Figure 4.5 below:

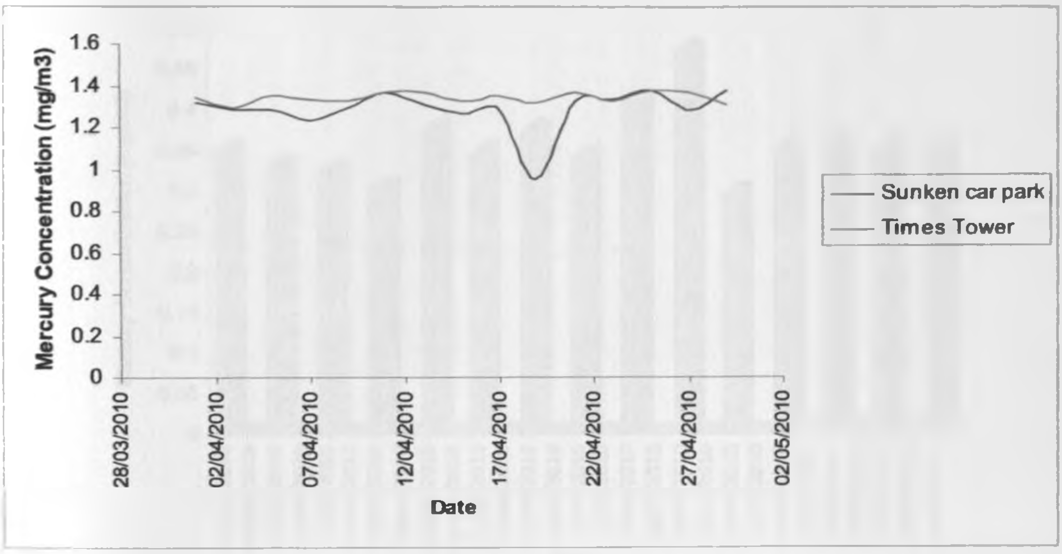


Figure 4.4: Comparison of Mercury Concentration in Both Sites for April 2010

The Times Tower mercury concentration (ranged 1.29 to 1.37mg/m^3) trend was fairly predictable because of scheduled ferrying garbage to Dandora dump site while that of sunken car park (ranged 0.95 to 1.37mg/m^3) was not.

4.4: Times Tower Results for May 2010

After sensitizing the caretaker and the waste disposal agent on the need to separate the spent fluorescent lamps from the rest of the wastes, further sampling was done to ascertain whether they heeded the advice. The results show a sharp decrease (about 3.77 times) from those obtained in April. The mercury concentration ranged from 0.29 to 0.47mg/m^3(Annex7.4).This indicated that advice was heeded although the concentrations were still above those recommended by WHO. Figure 4.5 clearly demonstrate these findings. A predictable variation trend in concentration is evident due to scheduled ferrying of garbage to Dandora.

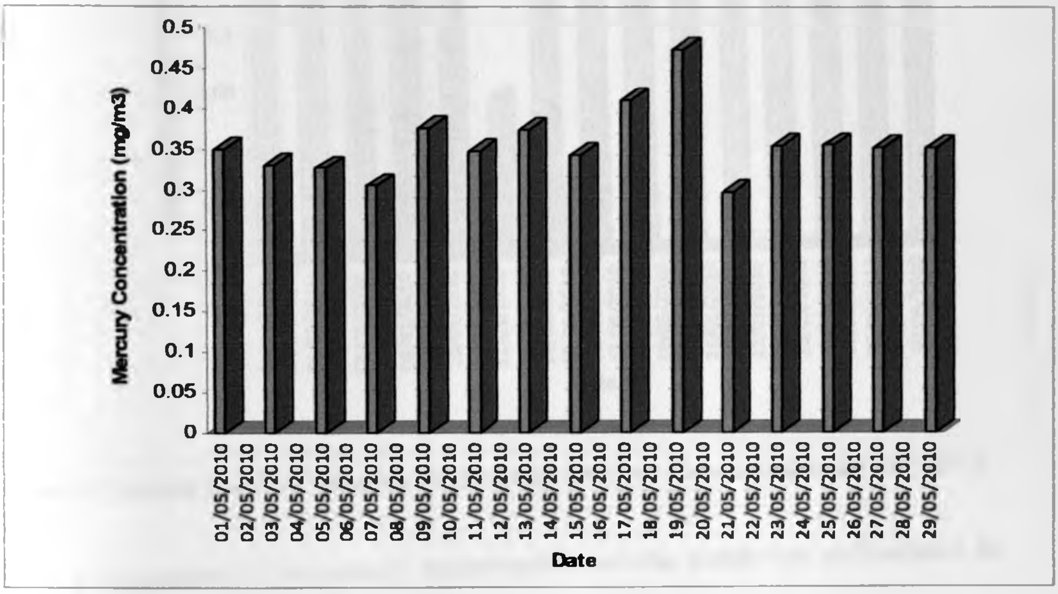


Figure 4.5: Times Tower Monthly Variation of Mercury Concentration for May 2010

4.5: Sunken car Park Results for May 2010

Results obtained indicate high mercury concentrations for the month under review. This was attributed to lack of sensitization and uncontrolled disposal of dead fluorescent lamps. Lack of scheduled ferrying of garbage to Dandora dumpsite contributed to unpredictable concentration variation trend as depicted by Figure 4.6 below. The concentrations ranged between 1.03 and 1.24 mg/m^3 (Annex7.7). The concentrations were still above those recommended by WHO.

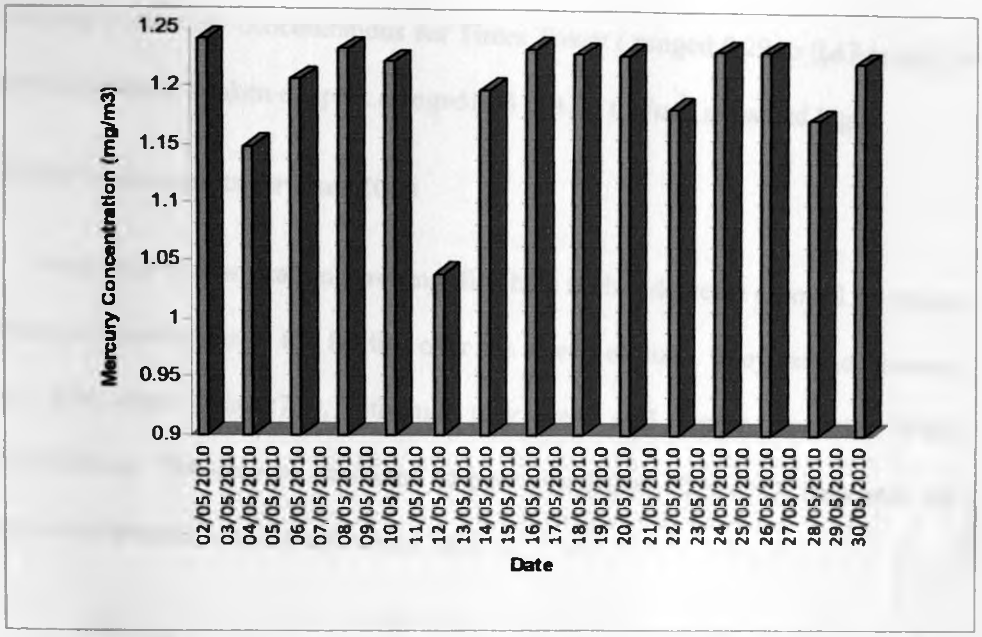


Figure 4.6: Sunken Car Park Monthly Variation of Mercury Concentration for May 2010

A comparison of the mercury concentration over the month was as illustrated in Figure 4.7 below:

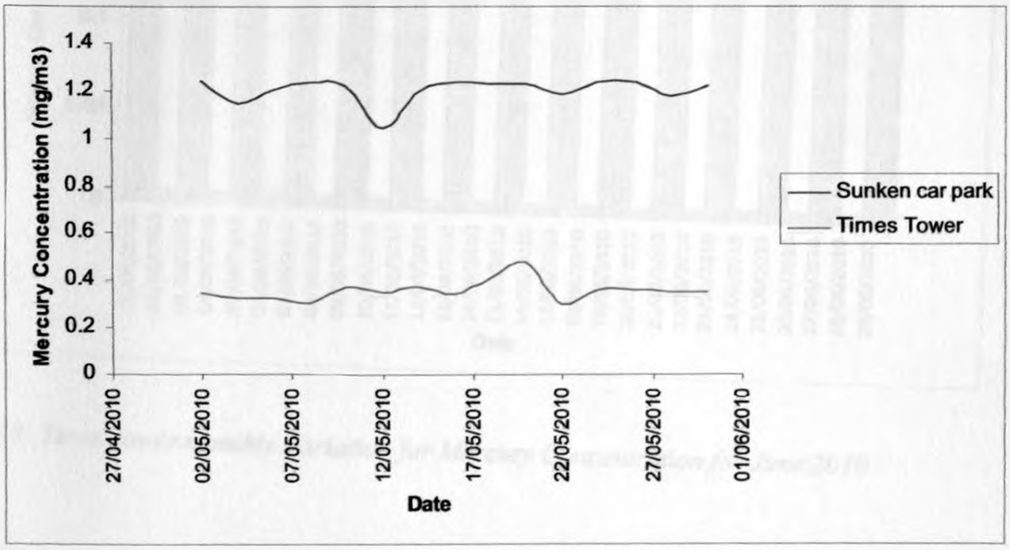


Figure 4.7: Comparison of Mercury Concentration In Both Sites for May 2010

The decrease in mercury concentrations for Times Tower (ranged 0.29 to 0.47mg/m^3) is evident while that of Sunken car park (ranged1.03 to 1.24 mg/m^3) remained high.

4.6: Times Tower results for June 2010

The impact of sensitization was amplified by a further decrease (about 1.95 times) in mercury concentrations at the facility over the month of June. They ranged between 0.12 to 0.24 mg/m^3(Annex7.5), although they were still higher than the WHO recommendations. This may be attributed to poor ventilation. Figure 4.8 illustrates the mercury concentrations variations for June 2010.

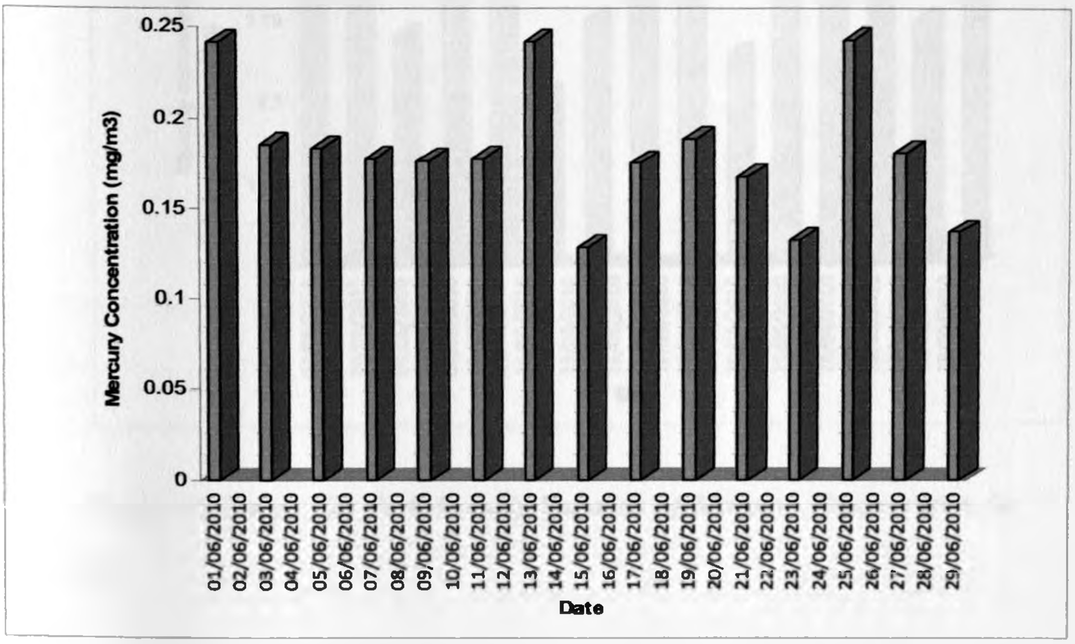


Figure 4.8: Times tower monthly Variation for Mercury Concentration for June 2010

The predictable variation in concentration due to strict adherence to scheduled garbage ferrying was evident.

4.7: Sunken Car Park Results for June 2010

Figure 4.9 depicted a high mercury concentration that ranged from 1.15 to 1.23 mg/m^3(Annex7.8). This was attributed to lack of awareness and uncontrolled dumping from the surrounding buildings. The ferrying frequency of garbage appeared to have improved as depicted by noticeable fluctuations in mercury concentrations over the month, although they are higher than the WHO recommended levels.

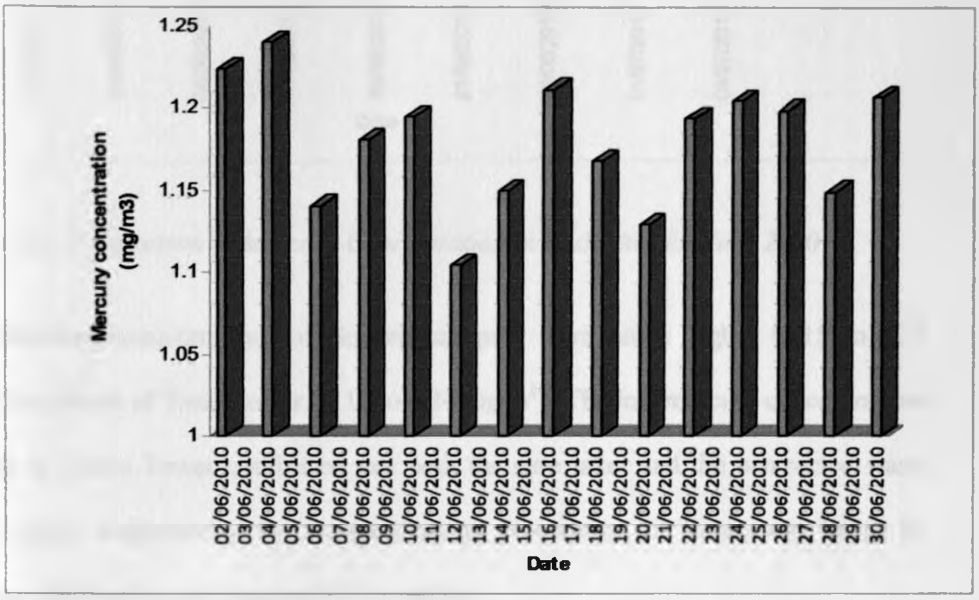


Figure 4.9:Sunken Car Park Monthly Variation of Mercury Concentration for June 2010

A comparison of the concentration levels in the two sites was illustrated by figure 4.10.

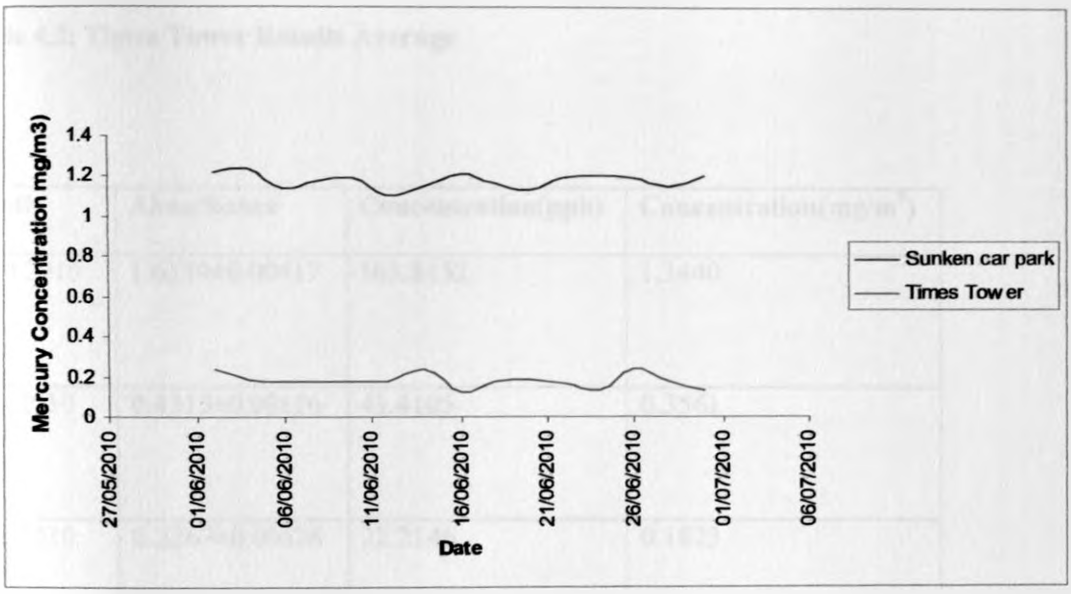


Figure 4.10: Comparison of Mercury Concentration in Both Sites for June 2010

Mercury concentrations of Sunken car park were much higher (1.15 to 1.23 mg/m^3) than those of Times tower (0.12 to 0.24 mg/m^3). The low mercury concentrations observed at Times Tower confirmed that both the care taker and the contracted waste disposal agent implemented the proper disposal procedures for fluorescent lamps by separating the dead lamps from rest of the wastes.

4.8: Averaged Monthly Results

The averaged monthly mercury concentrations for the two sites were calculated and their variance and standard deviations calculated using MS Excel. The standard deviations ranged between 0.0247 - 0.0413 and 0.1046 - 0.576 for Times Tower and Sunken car park respectively. In both cases, the dispersion of data about the mean was narrow hence high confidence level.

Table 4.2: Times Tower Results Average

Month	Absorbance	Concentration(ppb)	Concentration(mg/m^3)
April 2010	1.6359±0.00417	163.8152	1.3440
May 2010	0.4315±0.00116	43.4105	0.3561
June 2010	0.2267±0.00626	22.2146	0.1823

Table 4.3: Sunken car park Results Average

Month	Absorbance	Concentration (ppb)	Concentration (mg/m^3)
April 2010	1.5679±0.01063	157.1160	1.2890
May 2010	1.5679±0.01679	157.1160	1.2890
June 2010	1.4369±0.00558	143.8030	1.1798

Figure 4.11: Mercury Concentration Trend over the study period

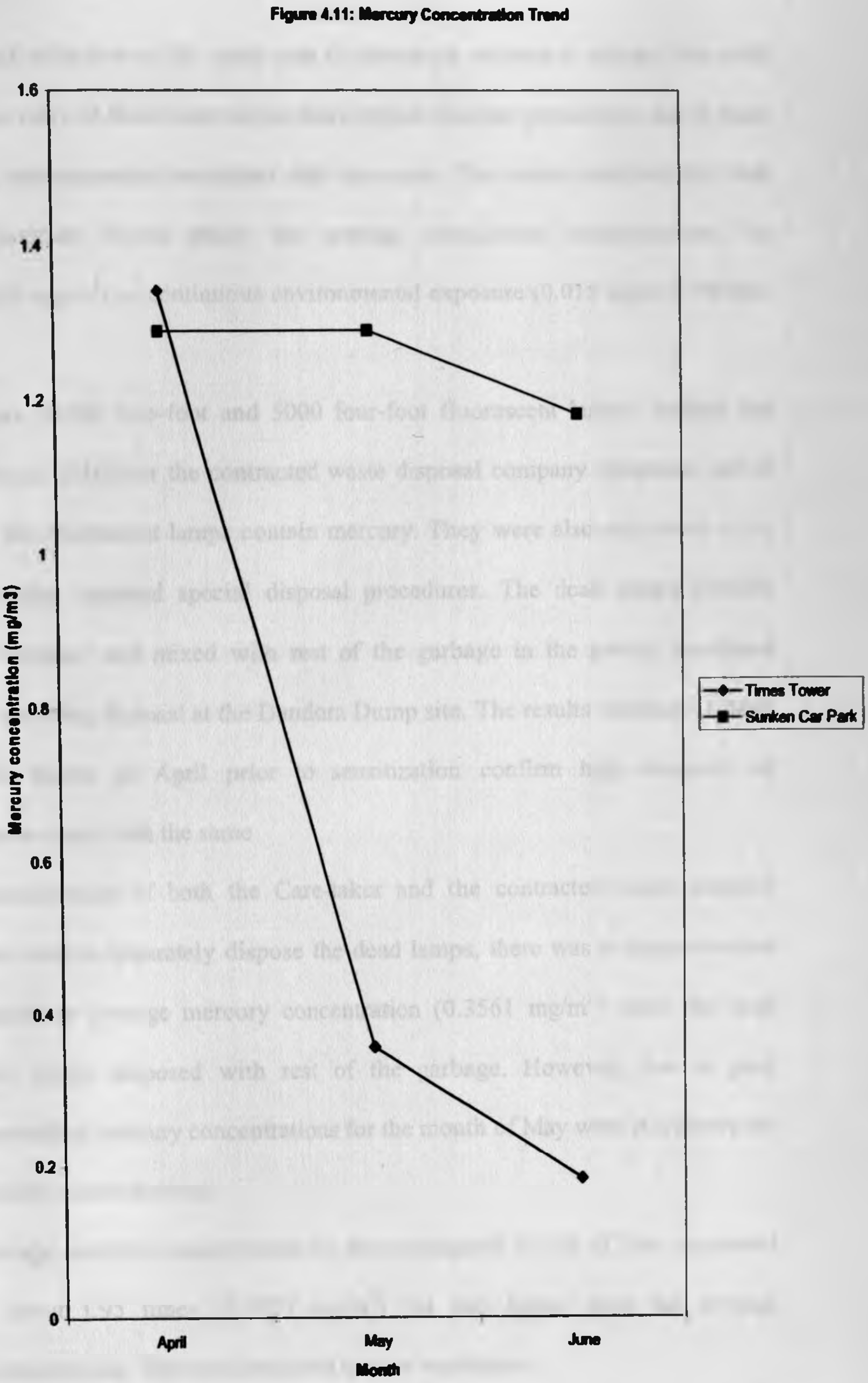


Figure 4.11: Mercury Concentration Trend over the study period

The overall objective of the study was to determine whether a selected site with high consumption rates of fluorescent lamps have proper disposal procedures and if there is high mercury contamination associated with the same. The results obtained for both sites indicate mercury levels above the average permissible concentrations for occupational (0.05 mg/m^3) or continuous environmental exposure (0.015 mg/m^3) (WHO, 1976).

Times Tower has 50,000 two-foot and 5000 four-foot fluorescent lamps. Neither the Care-taker (Obingo, 2010) nor the contracted waste disposal company (Mureithi, 2010) was aware that the fluorescent lamps contain mercury. They were also not aware of its dangers or that they required special disposal procedures. The dead lamps (20,000 annually) were crashed and mixed with rest of the garbage in the poorly ventilated holding facility awaiting disposal at the Dandora Dump site. The results obtained (1.3440 mg/m^3) for the month of April prior to sensitization confirm high mercury air contamination associated with the same

After sensitization of both the Care-taker and the contracted waste disposal company on the need to separately dispose the dead lamps, there was a sharp decrease (about 3.77 times) in average mercury concentration (0.3561 mg/m^3) since the dead lamps were no longer disposed with rest of the garbage. However, due to poor ventilation, the residual mercury concentrations for the month of May were still above the average permissible concentrations.

The average mercury concentration for the subsequent month of June decreased even further, about 1.95 times (0.1823 mg/m^3) but still higher than the average permissible concentrations. This was attributed to poor ventilation.

For reference, sampling from an open dump site (Sunken Car Park) where control measures did not exist and the surrounding buildings were high fluorescent lamps

›nsumers and temporarily dump haphazardly their wastes at the site. The Nairobi City ouncil then ferried the garbage to the Dandora Dump site.

The mercury concentration for the month of April averaged 1.2890 mg/m^3. This as lower than that of Times Tower since it is an open holding site hence continuous air ixing. However, the mercury concentrations were higher than the average permissible ›ncentrations. There was no decrease in the average concentration for May (1.2890 g/m^3).

The average mercury concentration for the month of June was 1.1798 mg/m^3, a ight decrease (1.09 times) from those previously obtained, attributable to air mixing. lthough there was a decreasing trend in the concentrations over the study period in the unken Car Park the mercury concentrations were significantly higher than those bserved in the Times Tower since no sensitization was carried out, proper disposal rocedures and scheduled ferrying of wastes was lacking. The decrease could be ttributed to air mixing.

The overall decrease was 5.72 times for Times Tower while that of Sunken car ark was 1.09 times.

CHAPTER 5

5.0: CONCLUSION AND RECOMMENDATIONS

5.1: Conclusion

The overall objective of the study was to determine whether selected sites with high consumption rates of fluorescent lamps have proper disposal procedures and if there is high mercury contamination associated with the same. The results clearly indicate that both the care-taker and waste disposal agent in the selected sites were not aware that the fluorescent lamps contain mercury. They were also not aware of its dangers or that they required special disposal procedures. Initially, high concentrations were obtained before sensitization at Times Tower. The impact of sensitization was evidenced by the sharp drops in the subsequent months of study (5.72 times overally). This shows that mercury pollution can be controlled through awareness and proper disposal procedures.

On the other hand, mercury concentrations at Sunken Car Park dump site remained high throughout the study period (decreased 1.09 times overally). This is attributed to uncontrolled dumping, lack of awareness of fluorescent lamp disposal requirements and knowledge that the lamps contain mercury, a powerful neurotoxin. Non-implementation of scheduled ferrying of wastes to Dandora dumpsite aggravated the already bad situation.

With the increased use of energy-efficient fluorescent bulbs, the disposal of such items posed a potentially serious source of mercury contamination. Although the amount of mercury used in each bulb is small, the cumulative impact of the disposal of millions of such bulbs in the future needs to be addressed by national and municipal governments. People who live near these waste sites can be exposed to elevated levels of mercury due to releases to the soil, air, and water.

The study confirmed that it was possible to reduce ambient air mercury pollution through proper regulation and implementation of best environmental practices of creating awareness on the importance of separating dead fluorescent lamps from the rest of the wastes. It is imperative that all stakeholders be involved in setting up collection points for disposal and recycling. These findings point to the urgent need for environmental and human health risk assessments to guide interventions by the relevant authorities. They also imply the need for policy intervention regulating the production, consumption and disposal of such goods, hence a challenge to key policy stakeholders including manufacturers/ distributors, National Environment Management Authority, Nairobi City Council, Ministries of Environment and Natural Resources; Local Authorities and Energy; and Kenya Bureau of Standards to take leadership towards containing further risk to human and the environment.

5.2: Recommendations

These findings shall be communicated to all stakeholders so as to chart the way forward. Having been sensitized, the stakeholders shall develop a CFL management policy based on life-cycle approach. Implementation strategies may involve joint plans of actions with ministries, municipalities, manufactures, distributors, advocacy groups and institutions working on waste management. Agreed remedial measures may be implemented at grass root, national or regional levels and may be short-term, mid-term or long-term coupled with appropriate monitoring and evaluations,

A strong political will and mass momentum are crucial for efficient mercury management (Mohapatra. 2007). The public should be sensitized on advantages and disadvantages of fluorescent lamps, clean up procedure in case of accidental breakage and where to dispose when the lamps die. The existing Waste Management regulations (Legal Notice No. 121) Fourth Schedule *(Regulation 16)* relating to disposal of

Hazardous wastes should be reviewed /revised to include The Fluorescent Lamp Disposal procedures.

The Fluorescent Lamp Disposal procedures should be strictly enforced to reward/ punish compliance / offences and all stake holders including manufactures/ distributors, National Environment Management Authority, Nairobi City Council, Ministries of Environment and Mineral Resources; Local Authorities and Energy; and Kenya Bureau of Standards to take leadership towards containing further risk to human and the environment.

Uncontrolled disposal of mercury-containing products or wastes may be reduced by introducing and enforcing deterrent regulation and improving access to suitable waste facilities such as identified collection points and setting up a local mercury waste disposal facility, hence a life cycle approach. When considering possible options, factors such as the overall environmental impact, total cost, technical viability, and safety concerns should be part of the evaluation process. Any assessments should be based in science, using the best available data. The technical ability to manage and process a spent electrical products into useable and beneficial materials should be an underlying principle in the decision making process. If collection and recycling are deemed to be the best option at end of life, then the responsibility for implementation and execution should be shared among all the stakeholders along the product value chain. (NEMA, 2009) (Annex 7.9)

Substitution with non-mercury products and processes may also help. A case in point may be halogen-incandescent lamps which have, an inner capsule filled with halogen gas around a filament to make the bulb about 25% more efficient than a traditional incandescent. They're also the cheapest alternative (Bounds, 2011).

The National Energy Plan should have phase out plans for incandescent and fluorescent lamps so as to have a smoothly coordinated transition to better lighting technology. Most people were accustomed to buying bulbs based on watts, which referred to energy usage rather than on actual brightness, which is measured in lumens. Manufacturers have figured out a way to produce the same amount of light with fewer watts. For instance, a typical halogen-incandescent model today needs only 43 watts to create 800 lumens--the same brightness as a 60-watt incandescent bulb (Bounds, 2011). This will ensure human and environmental safety.

The public should be encouraged to use safer, alternative lamps such as Light Emitting Diode (LED). LED lamp is an ultra-compact light source using a semiconductor chip that is up to 85% more efficient than incandescent and lasts 25 times longer (Bounds, 2011).

More research on less toxic lighting components should be enhanced. In response to safety concerns, ClearLite recently introduced its ArmorLite™ bulbs, A Safer CFL™, which contain no liquid mercury and instead use amalgam, an alloy of mercury with other metals in a solid form. To further enhance the safety of the bulbs, ClearLite's ArmorLite also contains a safety-coating, which helps provide an added barrier between users and the toxins inside if broken, by helping to capture both the broken glass and the mercury (Boca, 2010).

Source reduction programs should be identified, model legislation developed and implemented at local, bilateral and regional levels.

Better analytical techniques should be availed locally to encourage research on mercury and mercury containing wastes. Technology (Zeeman Atomic Absorption Spectrophotometer; RA-915+ Mercury Analyzer) that enables real-time mercury concentrations determinations at sampling sites for different matrices would greatly simplify analysis thus enhanced mercury related research.

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7.0 ANNEXES

7.1 WASTE DISPOSAL AGENTS QUESTIONNAIRE

AGENCY

NAME...

INTERVIEWEE'S

NAME..

RANK...

...

Do you separate the waste into categories at the collection points? Yes/No

Are you aware that fluorescent bulbs contain mercury? Yes/No

Are you aware that mercury is highly poisonous? Yes/No

Do you have protective clothing for staff? Yes/No

Where do you dispose the waste?

How often do you ferry the waste to Dandora dumpsite?

7.2: MERCURY STANDARDS STATISTICAL ANALYSIS

Standard concentration	**Absorbance 1**	**Absorbance 2**	**Mean absorbance**	**Standard deviation**	**Error**
0	0	0	0		
10	0.0991	0.0987	0.0989	0.0002	±0.0001
20	0.2001	0.2081	0.2041	0.0040	±0.0028
40	0.3986	0.3966	0.3976	0.0010	±0.0007
60	0.5872	0.6002	0.5937	0.0065	±0.0046
80	0.7966	0.7938	0.7952	0.0014	±0.0010
100	1.0019	1.0023	1.0021	0.0002	±0.0001
120	1.2003	1.2001	1.2002	0.0001	±0.0001
140	1.3997	1.3981	1.3989	0.0008	±0.0006
160	1.5955	1.6001	1.5978	0.0023	±0.0016
180	1.8007	1.7995	1.8001	0.0006	±0.0004

7.2: MERCURY STANDARDS STATISTICAL ANALYSIS

Standard concentration	Absorbance 1	Absorbance 2	Mean absorbance	Standard deviation	Error
0	0	0	0		
10	0.0991	0.0987	0.0989	0.0002	±0.0001
20	0.2001	0.2081	0.2041	0.0040	±0.0028
40	0.3986	0.3966	0.3976	0.0010	±0.0007
60	0.5872	0.6002	0.5937	0.0065	±0.0046
80	0.7966	0.7938	0.7952	0.0014	±0.0010
100	1.0019	1.0023	1.0021	0.0002	±0.0001
120	1.2003	1.2001	1.2002	0.0001	±0.0001
140	1.3997	1.3981	1.3989	0.0008	±0.0006
160	1.5955	1.6001	1.5978	0.0023	±0.0016
180	1.8007	1.7995	1.8001	0.0006	±0.0004

7.3: Times Tower Results for April 2010

Sample date	**ABSORBANCE**			**Mean**	**Standard deviation**	**Error**	**ppb**	**Mg/m^3**
1/4/2010	1.6399	1.6403	1.6404	1.6402	0.00021602	±0.00012	164.2458	1.3474
3/4/2010	1.5867	1.5708	1.5705	1.5784	0.00756709	±0.00437	158.0573	1.2967
5/4/2010	1.5984	1.6685	1.6693	1.6454	0.03323562	±0.01919	164.7666	1.3518
7/4/2010	1.6208	1.6224	1.6222	1.6218	0.00071181	±0.00041	162.4033	1.3324
9/4/2010	1.6109	1.6209	1.6210	1.6176	0.00473779	±0.00274	161.9827	1.3289
11/4/2010	1.6689	1.6743	1.6746	1.6726	0.00261916	±0.00151	167.4903	1.3741
13/4/2010	1.6598	1.6761	1.6762	1.6707	0.00770757	±0.00445	167.3000	1.3726
15/4/2010	1.5978	1.6215	1.6227	1.6140	0.0114656	±0.00662	161.6220	1.3260
17/4/2010	1.6377	1.6542	1.6554	1.6491	0.00807589	±0.00466	165.1371	1.3548
19/4/2010	1.5879	1.6089	1.6122	1.6030	0.01076197	±0.00621	160.5207	1.3169
21/4/2010	1.6597	1.6651	1.6663	1.6637	0.00287054	±0.00166	166.5991	1.3668
23/4/2010	1.6189	1.6212	1.6220	1.6207	0.00131403	±0.00076	162.2932	1.3315
25/4/2010	1.6687	1.6754	1.6758	1.6733	0.00325679	±0.00188	167.5604	1.3747
27/4/2010	1.6586	1.6797	1.6765	1.6716	0.00928475	±0.00536	167.3902	1.3733
29/4/2010	1.5896	1.5985	1.6002	1.5961	0.0046483	±0.00263	159.8298	1.3113
Average				**1.6359**		**±0.00418**	**163.8152**	**1.3440**

Variance $= \frac{0.00911764}{15} = 6.0784 \times 10^{-4}$

7.5: Times Tower Results for June 2010

Sample date	A B S O R B ANCE			Mean	Standard deviation	Error	ppb	Mg/m^3
1/6/2010	0.3217	0.3016	0.2779	0.3004	0.0179014	±0.01034	29.4366	0.2415
3/6/2010	0.2286	0.2303	0.2329	0.2306	0.00176824	±0.00102	22.5968	0.1854
5/6/2010	0.2258	0.2301	0.2263	0.2274	0.00192007	±0.00111	22.2832	0.1828
7/6/2010	0.2169	0.2254	0.2183	0.2202	0.00372111	±0.00215	21.5875	0.1771
9/6/2010	0.2214	0.1899	0.2481	0.2198	0.02372111	±0.01373	21.5385	0.1767
11/6/2010	0.2157	0.2189	0.2257	0.2201	0.00416973	±0.00241	21.5679	0.1769
13/6/2010	0.3254	0.2915	0.2867	0.3012	0.01722382	±0.00994	21.5149	0.2421
15/6/2010	0.1578	0.2006	0.1216	0.1600	0.03228911	±0.01864	15.6786	0.1286
17/6/2010	0.1989	0.2213	0.2320	0.2174	0.01379054	±0.00796	21.3033	0.1748
19/6/2010	0.2421	0.2101	0.2501	0.2341	0.01728198	±0.00998	22.9397	0.1882
21/6/2010	0.2143	0.1992	0.2132	0.2089	0.00687362	±0.00397	20.4704	0.1679
23/6/2010	0.1597	0.1635	0.1706	0.1646	0.00451737	±0.00261	16.1293	0.1323
25/6/2010	0.3009	0.3124	0.2912	0.3015	0.00866526	±0.00500	29.5443	0.2424
27/6/2010	0.2334	0.2223	0.2169	0.2242	0.00686877	±0.00397	21.9696	0.1802
29/6/2010	0.1679	0.1695	0.1729	0.1701	0.00208487	±0.00120	16.6683	0.1367
Average				**0.2267**		**±0.00626**	**22.2146**	**0.1823**

$$\text{Variance} = \frac{0.01855599}{15} = 0.0012$$

7.6: Sunken Car Park results for April 2010

Sample date	ABSORBANCE			Mean	Standard Deviation	Error	ppb	Mg/m^3
2/4/2010	1.6245	1.6005	1.5876	1.6042	0.01528987	±0.00883	160.6409	1.3179
4/4/2010	1.5558	1.6011	1.5444	1.5671	0.02448796	±0.01414	156.9258	1.2874
6/4/2010	1.5901	1.5431	1.5721	1.5687	0.01936251	±0.01118	157.0860	1.2888
8/4/2010	1.5001	1.4867	1.5153	1.5007	0.01168361	±0.00675	150.2766	1.2323
10/4/2010	1.6000	1.5841	1.5316	1.5719	0.02922636	±0.01687	157.4064	1.2914
12/4/2010	1.6545	1.6357	1.7060	1.6654	0.02971677	±0.01716	166.7693	1.3682
14/4/2010	1.5865	1.6021	1.6075	1.5987	0.00890393	±0.00514	160.0090	1.3127
16/4/2010	1.5435	1.5636	1.5348	1.5473	0.01206068	±0.00696	154.9430	1.2712
18/4/2010	1.5761	1.5535	1.5690	1.5662	0.00943645	±0.00545	156.8356	1.2867
20/4/2010	1.1596	1.1638	1.1662	1.1632	0.00272764	±0.00157	116.4802	0.9556
22/4/2010	1.5875	1.6080	1.6498	1.6151	0.02592463	±0.10497	161.7324	1.3269
24/4/2010	1.5798	1.6790	1.6225	1.6271	0.04062864	±0.02346	162.9340	1.3367
26/4/2010	1.6801	1.6741	1.6894	1.6812	0.00629444	±0.00363	168.3515	1.3812
28/4/2010	1.5592	1.5702	1.5689	1.5661	0.00490782	±0.00283	156.8256	1.2866
30/4/2010	1.6745	1.6321	1.7193	1.6753	0.03560375	±0.02056	167.7607	1.3763
Average				**1.5679**		**±0.01063**	**157.1160**	**1.2890**

Variance = $\frac{0.15321987}{14}$ = 0.0109

7.7: Sunken Car Park for May 2010

Sample date	ABSORBANCE			Mean	Standard Deviation	Error	ppb	Mg/m^3
2/5/2010	1.5007	1.4991	1.5104	1.5034	0.00499266	±0.00288	151.1588	1.2401
4/5/2010	1.4736	1.5067	1.2521	1.4108	0.11302852	±0.06526	141.1909	1.1483
6/5/2010	1.4004	1.5696	1.4094	1.4598	0.07772722	±0.04488	147.0514	1.2064
8/5/2010	1.4859	1.5121	1.5044	1.5008	0.01099485	±0.00635	150.2866	1.233
10/5/2010	1.4674	1.5005	1.4955	1.4878	0.01456869	±0.00841	148.8970	1.2216
12/5/2010	1.2513	1.310	1.2667	1.2736	0.02487904	±0.01436	126.6489	1.0390
14/5/2010	1.5003	1.4895	1.3878	1.4592	0.05067958	±0.02926	146.0347	1.1981
16/5/2010	1.4993	1.5034	1.5009	1.5012	0.00168721	±0.00097	150.2967	1.2331
18/5/2010	1.5090	1.4762	1.5067	1.4973	0.01494947	±0.00863	149.8477	1.2294
20/5/2010	1.5124	1.4935	1.4827	1.4962	0.01227436	±0.00709	149.7377	1.2285
22/5/2010	1.4172	1.4301	1.4721	1.4398	0.02343886	±0.01353	144.0932	1.1822
24/5/2010	1.5197	1.4709	1.5136	1.5014	0.02171006	±0.00253	150.2581	1.2327
26/5/2010	1.4985	1.5003	1.5030	1.5006	0.00184932	±0.00107	150.2666	1.2328
28/5/2010	1.4061	1.4963	1.3852	1.4292	0.04820795	±0.02783	143.0324	1.1735
30/5/2010	1.4735	1.4846	1.5104	1.4895	0.01545768	±0.00892	149.0671	1.2230
Average				**1.5679**		**±0.01613**	**157.1160**	**1.2890**

$$\text{Variance} = \frac{0.04639268}{14} = 0.0033$$

7.8: Sunken Car Park for June 2010

Sample date	ABSORBANCE			Mean	Standard deviation	Error	ppb	Mg/m^3
2/6/2010	1.5004	1.4872	1.4933	1.4903	0.00518684	±0.00299	149.1472	1.2236
4/6/2010	1.4997	1.5167	1.5136	1.5100	0.00739234	±0.00427	151.1187	1.2398
6/6/2010	1.4121	1.3782	1.3776	1.3893	0.0161239	±0.00931	139.0392	1.1407
8/6/2010	1.4050	1.4501	1.4604	1.4385	0.0240584	±0.01389	143.9631	1.1811
10/6/2010	1.4469	1.4579	1.4602	1.4550	0.00580402	±0.00335	145.6144	1.1946
12/6/2010	1.3503	1.3451	1.3396	1.3450	0.00436883	±0.00252	134.6057	1.1043
13/6/2010	1.3755	1.4211	1.4052	1.4006	0.01889815	±0.01091	140.1701	1.1500
14/6/2010	1.4833	1.4562	1.4870	1.4755	0.0137305	±0.00793	147.6660	1.2115
16/6/2010	1.4167	1.4215	1.4305	1.4229	0.00572014	±0.00330	142.4019	1.1683
18/6/2010	1.3802	1.3741	1.3725	1.3756	0.00331763	±0.00192	137.6882	1.1294
22/6/2010	1.4606	1.4484	1.4536	1.4542	0.00499867	±0.00289	145.5343	1.1940
24/6/2010	1.4579	1.4630	1.4813	1.4674	0.01004689	±0.00583	146.8554	1.2048
26/6/2010	1.4774	1.4483	1.4645	1.4601	0.01201926	±0.00694	146.1248	1.1988
28/6/2010	1.4131	1.3869	1.3985	1.3995	0.01071945	±0.00619	140.0600	1.1491
30/6/2010	1.4708	1.4721	1.4659	1.4696	0.00266958	±0.00154	147.0556	1.2066
Average				**1.4369**		**±0.00558**	**143.8030**	**1.1798**

$$\textbf{Variance} = \frac{\mathbf{0.02038194}}{\mathbf{15}} = \mathbf{0.0014}$$

7.9: FLOURESCENT LAMPS RECYCLING PROCESS

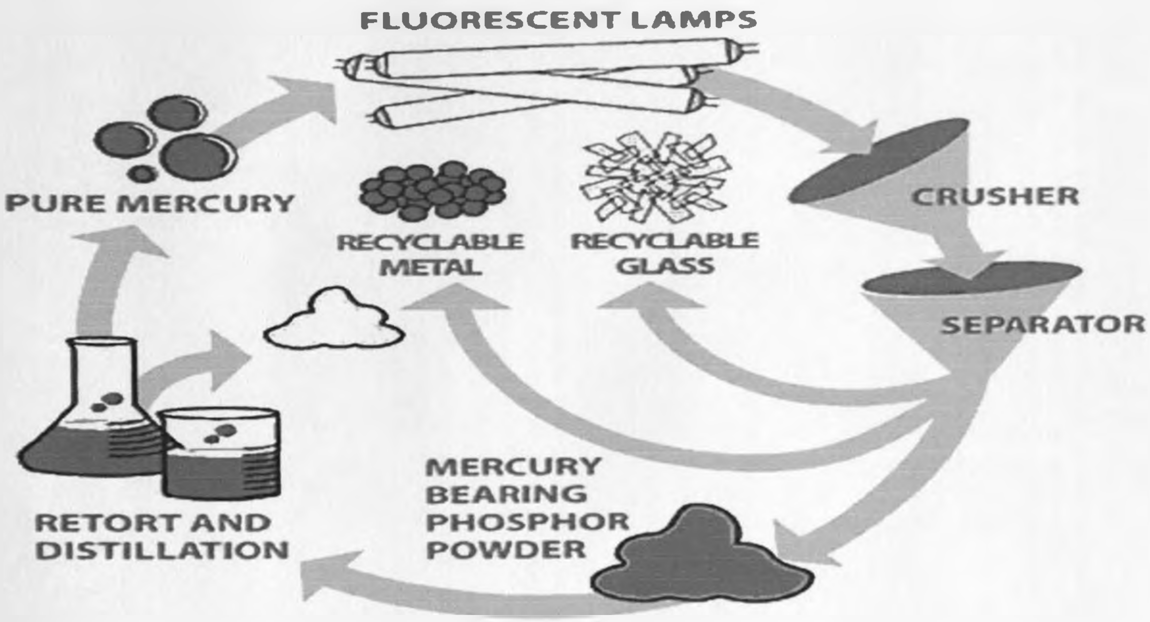

Figure 7.9: Lamp Recycling Process (Source: Total Reclaim Environmental Services)