CHAPTER 3

MATERIALS AND METHODS

3.1 GENERAL

The IT industry has been one of the major drivers of change in economy over the last few decades and has contributed significantly to the digital revolution. New electric and electronic equipments have infiltrated all aspects of our daily life providing us with more comfort, health and security. The same technology that has made our lives better is on the downside creating more toxic problems for our society.

With the growth of IT and related industries the usage and disposal of electrical and electronic equipment is all set to increase, which in turn will increase the quantity of E-waste generated, therefore it has become imperative to study the E-waste management practices that are being adopted. Coimbatore is set to become the next important IT destination after Chennai in Tamil Nadu, with the growth of IT industry and the economic growth the use of electric and electronic products are set to increase, as the usage increases so will the quantity of E-waste generated.

E-waste is of immense interest owing to the following factors such as increase in volume of E-waste due to changes in technology, it is relatively new form of waste that has to be dealt with when compared to municipal or biomedical wastes.

The technique for safe disposal is still being evolved, the quantity of waste is enormous, and the components present in E-waste is not uniform for all kinds of wastes. The types of wastes that come under this category are varied.
There are plenty of useful materials that can be recovered and reused. Most importantly the health and environmental effects due to the toxic substances that are a result of improper handling and disposal of E-waste is a cause for major concern.

3.2 STUDY AREA

Coimbatore (Figure 3.1), is the third largest city in Tamil Nadu-India, it has more than 40,000 small, medium and large-scale industries, which serves the engineering needs of major parts of the country. The City is known for its dynamic people and excellent infrastructure.

Figure 3.1 Map of Coimbatore – The Study Area
The entrepreneurial spirit of the business community here is renowned across the Country. Besides Textiles, the city today has evolved itself into a diversified economy with Engineering, Auto Components, Pumps and Motors (Out of every two water pumps produced in the country one is from Coimbatore), Foundries (One among the six major centers in India) and the educational institutions (the highest density in the country: 84 in 75 Square Km) which produce about 40,000 graduates of various disciplines a year.

3.2.1 Sources and Generation of E-waste in Coimbatore

According to the Statistical Handbook of 2012-2013, published by the Directorate of Census Operations, Tamil Nadu, the following number of organizations are present in Coimbatore as shown in Table 3.1, one can easily imagine the volume of EEE that is being used in these organizations.

**Table 3.1 Various Organizations Functioning In Coimbatore**

<table>
<thead>
<tr>
<th>S.No</th>
<th>Organization</th>
<th>Estimated Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Universities and Colleges(including Professional, Technical, Arts and Science and Others)</td>
<td>521</td>
</tr>
<tr>
<td>2</td>
<td>Schools(Excluding Primary and Nursery Schools)</td>
<td>494</td>
</tr>
<tr>
<td>3</td>
<td>Factories (all types of Industries)</td>
<td>20478</td>
</tr>
<tr>
<td>4</td>
<td>Health Care Facilities(Hospitals, Nursing Homes, Dispensaries etc Including Government and Private facilities)</td>
<td>3684</td>
</tr>
<tr>
<td>5</td>
<td>Specialised Research Institutions</td>
<td>09</td>
</tr>
</tbody>
</table>

Coimbatore has a population of 6,093,952 according to the Census of India 2011, out of which 26,35,907 are literate and the rest are illiterate. With the
presence of such large population, combined with the industrial and the educational sectors one can imagine the dependence on EEE. E-waste includes ever growing range of obsolete electronic devices such as computers, servers, main frames, monitors, TVs & display devices, telecommunication devices such as cellular phones & pagers, calculators, audio and video devices, printers, scanners, copiers and fax machines besides refrigerators, air conditioners, washing machines, and microwave ovens, E-waste also covers recording devices such as DVDs, CDs, floppies, tapes, printing cartridges, military electronic waste, automobile catalytic converters, electronic components such as chips, processors, mother boards, printed circuit boards, industrial electronics such as sensors, alarms, sirens, security devices, automobile electronic devices (Kalana 2010).

E-waste recycling involves the disassembly and destruction of the equipment to recover new materials (Cui and Zhang, 2008). Recycling can recover 95 per cent of the useful materials from a computer and 45 per cent of materials from cathode ray tube monitors (Ladou and Lovegrove 2008). Mechanical separation of components is the first step in E-waste recycling.

Components may be separated for reuse or metallurgical processing (He et al 2006). This process can be automated or carried out by hand. In poor countries, there is a risk that children may be employed to separate E-waste components (Ladou & Lovegrove 2008). An open flame is often used to free components (Manomaivibool 2009), which may result in exposure to volatilized contaminants. In the light of the hazards caused by unscientific and improper disposal of E-waste a survey was undertaken in Coimbatore city to study the current E-waste management practices as it is becoming a fast developing information technology center in Tamil Nadu.
3.3 METHODOLOGY

This study has been undertaken with the objective of understanding the ground reality of E-waste management in Coimbatore. This study has been divided into three parts, as shown in the Flow Chart 3.2,

- The first part is to carry out a survey, to have a good understanding of the E-waste handling and disposal mechanism that is in existence, and also have an insight into the involvement of various stakeholders.
- The second part of the study deals with the study of all the process involved after the E-waste is collected; the purpose is to understand the factors that promote the E-waste collection and recycling activities. Also this is done to determine the fate of the fraction of E-waste that is of no use to the handlers.
- The third part of the study deals with the study to understand the potential hazards of the E-waste that is being disposed, by means of carrying out a toxicity characterization of the selected components.
Study of E-waste Management practices in Coimbatore

Understanding the existing system and determine the process in common practice

Survey to have an in-depth knowledge

Quantity of E-waste generated

Collection system

Stakeholders those are involved

Post collection process

Existing handling mechanism

Commonly practiced treatment and End of life option for obsolete waste

Process involved

Quantity of waste

Quantity of waste resold after repair

Technology adopted for handling

Components segregation

Selection of a specific component (Plastic housing units from SWEEE)

Sample collection

Sample

Toxicity characterization by means of heavy metals analysis

Standardization of procedure

Analysis of heavy metals

Statistical analysis of results obtained

Comparison with existing standards

Components of least significance or commonly discarded

Quantity of waste

Components of value

Components of no value

Fate of these components

Figure 3.2 Flow Chart of describing the various activities involved in the present investigation
3.3.1 Survey

As described above, a survey was carried in order to understand the actual situation with respect to E-waste in Coimbatore. The survey has been designed in a manner that information regarding the types of E-waste, involvement of stakeholders, collection mechanism could be understood. The survey questionnaire has been furnished as Appendix 1 at the end of the thesis.

The increase in consumption of electronic and electric equipment is mainly due to the increase in economic status and the undeniable fact that everyday life has been simplified and the increased convenience has increased the usage, which directly explains the increase in the generation of E-waste.

The management of E-waste has become an environmental concern in many developing countries as economic development and urbanization continues to take place. Hence, this study was conducted in Coimbatore City, which is next to Chennai in terms of economic development.

A questionnaire was developed in Tamil and English and distributed by hand to the E-waste handlers identified in and around Coimbatore. The Survey was conducted during the period January 2007 to January 2009. To ensure a higher response rate, face-to-face interviews were employed for data collection, as the interview survey method would give better results than mail surveys, as the E-waste handlers have very limited educational qualification.

3.3.2 E-waste Recycling Process and Recycling Oriented Characterization of E-waste

There is a universal trend in E-waste generation, which is quite alarming as the quantity of waste generated is steadily on the rise. Coimbatore
is no exception to this situation. This component of the investigation deals with providing the kind of transformation E-waste undergoes after it has been collected. Current WEEE arising across the European Union (EU-27) amounts 8.3–9.1 million tons per year, which corresponds to around 17 kg per capita and year (Huisman et al 2007). Although the per-capita production rate in populous developing countries such as China and India is still relatively low and estimated to be less than 1 kg WEEE per capita per year, the absolute volume of end-of-life appliances generated in these countries is already huge (Widmer et al 2005).

Since there is no well defined mechanism for collection and handling of E-waste some part of the E-waste enters the municipal waste which when carried out over a prolonged period would be hazardous. The joint disposal of WEEE with municipal solid waste (MSW) by land filling or incineration releases hazardous substances like heavy metals and brominated flame retardants (Rotter 2002, Dimitrakakis & Janz et al 2008) and causes resource losses (Hagelüken 2006).

In the market a wide range of equipment with different functions and sizes are available, each of them made of different components, materials and chemical elements, due to which each component has to be separated and treated according to its unique characteristics. Thus making handling, recycling, resource recovery and disposal highly complex, the components can be broadly characterized as Metallic fractions and Non-metallic fractions. Each of these components has to be addressed differently while considering their treatment and disposal. The Non-metallic fractions are composed of materials such as glass, fiber, plastics, epoxy resin compounds etc.

During the survey it was noticed that the recyclers in Coimbatore paid greater attention to equipments such as Large Household Appliances (Washing machines, Dryers, Refrigerators, Air-conditioners, etc.) Small
Household Appliances (Vacuum cleaners, Coffee Machines, Irons, Toasters, mobile phones, toys, calculators etc) Office, Information & Communication Equipment (PCs, Laptops, Mobiles, Telephones, Fax Machines, Copiers, Printers etc.) Entertainment & Consumer Electronics (Televisions, VCR/DVD/CD players, Hi-Fi sets, Radios, etc), as there is a well established market for the repaired and refurbished equipments as mentioned above.

The household equipments that were discarded were serviced and repaired and sold for reasonable prices. Electrical and electronic equipments that were beyond repair or those items which had little or no resale value were discarded. In most cases the SWEEE such as mobile phones (with special reference to old and outdated models), remote controls, calculators, toys, etc were discarded. This could be attributed to the poor demand, the low prices, cheaper alternatives, time consuming repair process with very marginal profit. Such SWEEE which have little or no use were discarded into existing landfills or water bodies, thus posing a major environmental contamination. Though the quantity disposed at a particular time period is small, the constant and repeated disposal will intensify the environmental problem over a period of time, due to the leachability of heavy metals and other toxic compounds into the environment. Thus it becomes imperative to address the reusability, recyclability and toxicity of SWEEE.

In general a major portion of the E-waste undergoes the following stages before being discarded,
3.4 SAMPLE COLLECTION

To understand the effect of disposal of small waste electrical and electronic equipments (SWEEE), a total of hundred and twenty five (125) obsolete SWEEE were collected through different sources. The SWEE included obsolete mobile phones (49), calculators (37), remote controls for television (21) and others (18). Some of these were collected from the recyclers, which were donated free of cost, and the rest of the samples were collected through voluntary donations from students and faculty members.

Some of the samples were intact while others were partially disassembled. The disassembled components were found to have been used for repairing and refurbishing activities by the recyclers. During sample collection it was observed that the people involved in this trade “recyclers”
collected the obsolete equipments and sorted them based on their usability, if they felt that a particular product would be of use to them then they dismantled the equipment and removed the usable parts if it was redundant then such objects were discarded.

A general hesitation was noticed while handling over the obsolete objects only upon confirmation that no harm will come to them were the recyclers ready to part with the objects. It was also observed during sampling that the people involved in the repair/refurbishing business pack together the obsolete phones, disassembled parts and other mobile phone components/accessories such as the printed wiring board (PWB), liquid crystal display (LCD) screen, battery and their working tools/materials (such as solder) in their tools bag.

The survey during sampling revealed that in some cases the recyclers had hundreds of phones and remote controls that were to be discarded. This could be an indication of the quantity of unaudited E-waste present in Coimbatore. An effort was made to collect the samples which was intact or with minor parts missing. The details of most of the samples such as make, model, age, year of manufacturing etc could not be ascertained as they were beyond ascertainment. The samples were transported to the laboratory, dismantled and classified for further work.

Figure 3.4 Sample of Small Waste Electrical and Electronic Equipments
While attempting to classify and characterize E-waste one has to understand that for the characterization of WEEE, no standards exist so far (Chancerel & Rotter 2009). Even the technical standard VDI 2343 part 3 “Recycling of electrical and electronic equipment – disassembly and processing” of the Association of German Engineers (VDI 2002) provides technical specification for disassembly and processing of WEEE and also deriving marketable material fractions which was used to identify goal-oriented parameters for a classification of assemblies and materials. The details of each sample could not be recorded in detail due to the poor condition of the sample. Thus, in the first step appropriate attributes to be measured had to be identified. Table 3.2 shows the investigated attributes and the applied analytical methods.
Table 3.2 Removal strategy for components of E-waste

<table>
<thead>
<tr>
<th>S. No</th>
<th>Removal strategy</th>
<th>Materials and components that need a selective treatment according to Annex II of WEEE Directive</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Easily manually removable components</td>
<td>- Batteries</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- External electric cables</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Toner cartridges, liquid and pasty, as well as colour toner</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Gas discharge lamps</td>
</tr>
<tr>
<td>2.</td>
<td>Components and substances that cannot be removed without dismantling the equipment or special treatment</td>
<td>- Printed circuit boards of mobile phones generally, and of other devices if the surface of the printed circuit board is greater than 10 square centimetres</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Liquid crystal displays (together with their casing where appropriate) of a surface greater than 100 square centimetres</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Cathode ray tubes Chlorofluorocarbons (CFC), hydro chlorofluorocarbons (HCFC) or hydro fluorocarbons (HFC), hydrocarbons (HC)</td>
</tr>
<tr>
<td>3.</td>
<td>Components and substances that are difficult to identify and that cannot be removed without deep dismantling of the equipment</td>
<td>- Plastic containing brominated flame retardants</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Polychlorinated biphenyls (PCB) containing capacitors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Electrolyte capacitors containing substances of concern (height &gt; 25 mm, diameter &gt; 25 mm or proportionately similar volume)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Mercury containing components, such as switches or backlighting lamps</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Asbestos waste and components which contain asbestos</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Components containing refractory ceramic fibres</td>
</tr>
</tbody>
</table>
Table 3.4 Characterization of E-waste based on their attributes and the method of Determination

<table>
<thead>
<tr>
<th>S. No</th>
<th>Characteristic class</th>
<th>Attribute</th>
<th>Method of Determination</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>General data on the equipment</td>
<td>Classification of the appliances (determination of the equipment type)</td>
<td>Inspection of producer information on the equipment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Identification of producer and model type</td>
<td>Year of production Inspection of producer information in the equipment if available. If not, estimation after visual inspection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Year of production</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inspection of producer information in the equipment if available, If not, estimation after visual inspection</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Physical and Mechanical Properties</td>
<td>Weight of the equipment and its assemblies</td>
<td>Weighting Measurement of dimensions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Size of the equipment and its assemblies</td>
<td>Visual inspection to identify the materials, identification of ferrous metals with magnet, weighting with laboratory scale</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Material fractions</td>
<td>Visual inspection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Colour</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Chemical Composition</td>
<td>Identification of polymers</td>
<td>Inspection of producer information on the equipment if available, near-infrared</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Elemental composition</td>
<td>spectroscopy, infrared spectroscopy, sliding-spark-spectroscopy</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>X-ray fluorescence spectroscopy, atomic-absorption spectroscopy, ion chromatography</td>
</tr>
</tbody>
</table>

3.4.2 Sample Preparation

In order to quantify the volume of metallic and non-metallic fractions the samples were disassembled and segregated into material fractions and assemblies. Each unit of the sample was dismantled and
separated into its parts (assemblies) and material fractions. The disassembled parts were categorised as plastics, rubber and glass, ferrous materials, non-ferrous materials and composite materials (those materials which are not mechanically separable in homogeneous material fractions like ‘motors’, ‘batteries and other parts containing interconnected materials) to determine the volume of each category. From which the specific volume of waste being reused or dumped could be determined, based on the contribution of each component to the entire volume of waste.

3.4.3 Components Separation

The samples (125) SWEE were initially disassembled using simple tools such as stainless steel screw-drivers and pliers etc., Care was taken to avoid excessive force so as to cause minimum damage during dismantling, and then separated into the major components like PWB, LCD and plastic housing. Materials were divided into various categories based on visual identification and to a certain extent using permanent magnets to categorise the parts as ferrous and non-ferrous materials. Once the basic segregation was done the plastic samples were first covered with a clean cloth (for each sample) for protection and to avoid cross-contamination and then crushed/weakened by the use of a standard hammer before size reduction by cutting using a stainless steel scissors.

The samples were analyzed “as is” without washing or any form of pre treatment before weighing and processing for further work. Each of the components were measured separately using a laboratory scale weighing balance. After all the components were weighed and recorded, they were labelled and packed in to poly bags and for storage and avoidance of contamination. This step was mainly undertaken to quantify the contribution of different components to the waste stream.
Determining the major contributors would give an idea about the volume of waste being produced and discarded by the recyclers in Coimbatore, and also determine how much of recycling potential each component has, so that the recyclable components could be segregated and the unwanted portions could be further processed or discarded in an environmentally sound manner. As the SWEEE are not being considered for recycling they are mostly discarded, when the volume of this stream increase it will be a threat to the environment owing to their toxic components.

![Pie Chart](image)

**Figure 3.6 Percentage by weight of various components present in SWEEE**

### 3.5 HEAVY METALS ANALYSIS OF PLASTIC HOUSING UNITS

From the above studies it was determined that plastics, either in loose or moulded form contributes to about 30% of the total volume of E-waste, making it a significant component of the E-waste issue. Hence it has become imperative to study the fate of the PHU that are summarily discarded in most cases. Plastics are considered to be low cost raw materials, whose recycling is complex when compared to the easy availability of virgin materials.
Also the nature and characteristic of each from of plastic has its own unique features. Hence plastics from E-waste has not been considered as a source of plastics suitable for recycling.

Concerns regarding toxic metals contents of plastic materials have led to studies at finding rapid, sensitive and reliable methods and instruments for such analysis (Piorek 2004). Several testing methods have been adopted in assessing the toxicity of electronic wastes (and other solid waste materials) and in regulating their disposal or EoL management. These include the toxicity characteristics leaching procedure (TCLP), the synthetic precipitation leaching procedure (SPLP), the waste extraction test (WET) and the Total’s test (results compared with the total threshold limit concentrations, TTLC threshold values). The TCLP and the SPLP are the leaching tests most commonly used by the US EPA in waste management decision-making.

The WET and Total’s test were established by the California Department of Toxic Substances Control (DTSC). The TCLP and WET procedures are designed to simulate landfill conditions while the SPLP is an acid rainfall test. The Totals test is an acid digestion procedure that aims at providing information on the elemental composition of solid waste materials.

### 3.5.1 Optimization Studies on Heavy Metals in Plastic Housing Units

This study was carried out to examine the heavy metals, such as (Pb, Cd, Hg, Cr, Ni, Cu, Zn and Br) in waste plastic housing of SWEEE. The objective of this study was to determine the heavy metal levels of a selected component (plastic) of discarded/obsolete SWEE as “discarded” electronic waste items and not necessarily the inherent metal levels of the plastic materials. This became necessary considering the large quantities of plastic housing units generated and the various low-end management practices for these and other waste materials from the information
communications and technology sector in Coimbatore. Such waste materials are most commonly burned openly, disposed into surface waters or with municipal solid waste (Osibanjo & Nnorom 2007).

Figure 3.7 Flow Chart of the activities involved in the Investigation on heavy metals analysis of plastic Housing Units (PHU’s) from SWEEE
3.5.2 Sample Preparation for further Analysis

The plastic housing units were collected from the 125 obsolete SWEEE, were taken for further analysis. Once the optimization studies were carried out, the plastic housing units were treated under the optimised conditions and then they were used for further analysis.

The plastic housing units were cut into small pieces and this was divided into ten equal parts by weight (about 95 gm each) and labelled as Samples S1 to S10, to enable easy identification during the analysis. Since, the objective of the study is to determine the concentration of certain heavy metals in the plastic housing units the samples were not categorised based on the location, model, category and so on. The results obtained were compared with the TTLC limits (Appendix II) for selected methods.