A STUDY ON STATUS AND MANAGEMENT OF E-WASTE IN INDIA

By

MAHESH CHANDER

Civil Engineering Department

Submitted in fulfilment of the requirements for the award of the degree of

DOCTOR OF PHILOSOPHY
to the

DEPARTMENT OF CIVIL ENGINEERING

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A Thesis

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CERTIFICATE

Date: .10. 2017

This is to certify that the thesis titled **"A Study on status and management of E-Waste in India"** submitted by Mr. Mahesh Chander for the award of the degree of Doctor of philosophy is based on the bonafide research work carried out by him during the period from November 2010 to October 2017 under my guidance and supervision. Mr. Mahesh Chander fulfils the requirements of the regulations laid down for the Ph.D. programme of Delhi Technological University, Delhi.

To the best of my knowledge, the work presented in this thesis is an original contribution and has not been submitted, either in partial or full, to any other university or institute for the award of any degree or other similar title or recognition.

He is allowed to submit the work for award of Ph.D. in Civil Engineering at Delhi Technological University, Delhi.

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CANDIDATE'S DECLARATION

Date: .10. 2017

I hereby certify that the work, which is being presented in the thesis titled **"A Study on status and management of E-Waste in India"** submitted for the award of the degree of Doctor of philosophy in Civil Engineering, is authentic record of my own research work carried out under the supervision of Dr. S. K. Singh, Professor and Dean, in Civil Engineering Department, Delhi Technological University, Delhi.

The work presented in this thesis is an original contribution and has not been submitted, either in partial or full, to any other university or institute for the award of any degree or other similar title or recognition.

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Mahesh Chander

ABSTRACT

The discarded electronic equipment has created a new waste stream named E-waste with in solid waste. E-waste management is unfriendly in India irrespective of enormous waste. E-waste is escalating sharply as the use of short lived electronic equipment expands over large range in the country. In each sector, electronic equipment has its significant role in manufacturing and operation of equipment. Electronics evolves new equipment designs constantly; consequently enhances the demand of electronic equipment manifolds in the world. The new electronic equipment negotiates the prevailing equipment quickly and causes the accumulation of mammoth E-waste in India. The disposal of E-waste is not accomplished as it deserves in the country. Public used to dispose it of blithely and invite hazards as it is toxic characteristically. The prevailing tendency has attracted the attention of one to all because it is penetrating in the municipal waste. The treatment of unified waste is unfeasible as it encompasses biodegradable and toxic non-biodegradable substances. It creates a rift for the sustainable management in the country because it needs a separate treatment facility.

The informal recycling captures maximum E-waste in India and treats it in uncontrolled conditions. It is primarily profit driven profession keeping other aspects secondary and select only more material containing electronic equipment for it. The recyclers in developed countries treat E-waste sustainably and convert it into resources by viable technologies; but in India, such infrastructure is inadequate to deal with copious E-waste of the country. In view of that this study has taken up this issue critically and proposed that its viable disposal is essentially required to separate the

toxic metals from the E-waste so that the sustainable recovery of precious and base metals is ensured. The toxic metals should be separated from the stuff before undertaking the recuperation of other metals. In view of that the composition of metals in equipment has become significant before taking it up for metal retrieval out of it; else valuables and toxic metals will drain down in the waste and further leads to the irreparable damage to the public as well lose enormous resources and the exploitation of natural resources and pollutants loading on environment will enhance extremely.

In India, the informal recyclers carry out the recycling of electronic equipment selectively and ignore the unfamiliar and unpopular equipment in E-waste. In view of that most of such metal potent equipment destines to open dumping of waste. The discarded mobile phone is one of the electronic equipment facing similar consequences in India. It is true that the mobile phone is one of the most popular electronic equipment in the world and in Indian perspective, public has adapted it as essential equipment as conventional need. But people are oblivious about its disposal after its useful life and dispose it of as and where basis. Presently, the waste base of discarded mobile phones in India is escalating with the users. Besides other electronic equipment, the informal recyclers presumed that the resources in discarded mobile phone is null irrespective of ample precious and other metals in it and ignore its potential in India.

The composition of material in an equipment decides its sustainable disposal through infrastructure commissioned for it, because the auxiliary processes are to be planned as per material recovery needs. The mobile phone waste comprises of plastics, glass, and printed circuit board; however back up battery is detachable and can be removed easily for its separate treatment. In fact, each material can be recycled to a large extent depending upon the viable infrastructure capabilities. However, the outcome of the material varies depending upon both infrastructure efficiency as well material amalgamations, while it is manufactured. In mobile phone waste, the printed circuit board of mobile phone is the nodal component containing maximum amount of metal contents. The present study reinforces the mobile phone waste management by supplementing the requisite information about its composition of valuable material encompassing precious, base and toxic metals; plastics and glass. It explores these materials qualitatively and quantitatively in assorted mobile samples used by majority of people in India. It also facilitates to proceed for sustainable disposal of entire mobile phone waste. The hydrometallurgical processes are being employed to dissolve the metals of the samples and analysed by flame atomic absorption spectrometry methodology to conduct for metal contents assessment. The study identifies base, precious and toxic metals in the printed circuit boards in ten assorted samples.

This study is significant as it provides metal composition of precious metals: gold, silver, base metals: copper, aluminium, iron and toxic metals: lead, manganese, tin, zinc and nickel of printed circuit boards of discarded mobile phone, which encourage the material recycling from mobile phone waste; also promotes the formal recycling, yields maximum material, release pressure upon the natural resources and reduce the pollutants loading on the environment thereby improve the quality of life and safe guard the public from maximum diseases caused by them. The coexisting precious metals and other material will be made available at less cost as the local mining is less cost effective comparably. The study explores a new local mining source of valuable metals. The material recovery from local mining would reduce exploitation of natural resources for the same amount of virgin material. The health index of the public will improve in the country.

The study also introduces an innovative model to improve the E-waste management in the country. It involves all E-waste stakeholders and suitable for Indian environment. It sets a new trend for reliable and effective E-waste management in the country as management works in system and it provides an opportunity for participation to everyone. In view of this, public participation only increases the compatibility of the infrastructure, when system works. The innovative model spreads the base of sustainable E-waste management in the country.

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ABBREVIATIONS

AAS	**:**	Atomic Absorption Spectrometry
ABS	**:**	Acrylonitrile Butadiene Styrene
AD	**:**	Automatic Dispenser
ARF	**:**	Advance Recycling Fee
BAN	**:**	Basel Action Network
CE	**:**	Consumer Electronics
CFC	**:**	Chlorofluorocarbon
CPCB	**:**	Central Pollution Control Board
CRM	**:**	Certified Reference Material
CRT	**:**	Cathode Ray Tube
CV	**:**	Coefficient of Variation
DF	**:**	Dilution Factor
EE	**:**	Electrical and Electronic tools
EEE	**:**	Electrical and Electronic Equipment
EPA	**:**	Environment Protection Agency
EPA	**:**	Environmental Protection Agency
EPR	**:**	Extended Producer Responsibility
ESM	**:**	Environmentally Sound Management
EU	**:**	European Union
FAAS	**:**	Flame Atomic Absorption Spectrometry
GDP	**:**	Gross Domestic Product
IC	**:**	Ion Chromatography
ICP AES	**:**	Inductively Coupled Plasma Atomic Emission Spectrometry
ICP- MS	**:**	Inductively Coupled Plasma Mass Spectrometry
ICT	**:**	Information and Communications Technology
IT	**:**	Information Technology
LCD	**:**	Liquid Crystal Display

LE	**:**	Lighting Equipment
LHA	**:**	Large Household Appliances
Li-ion	**:**	Lithium-ion
LOD	**:**	Limit of Detection
M&C	**:**	Monitoring and Control
MD	**:**	Medical Devices
NGOs	**:**	Non-Government Organisations
NiMH	**:**	Nickel-metal-hydride
OECD	**:**	Organisation for Economic Cooperation Development
OSHA	**:**	Occupational Safety and Health Administration
PC	**:**	Poly-carbonate
PCB	**:**	Printed Circuit Board
PCBs	**:**	Printed Circuit Boards
PCs	**:**	Personal Computers
RoHS	**:**	Restrictions on Hazardous Substances
SD	**:**	Standard Deviation
SHA	**:**	Small Household Appliances
SPCBs	**:**	State Pollution Control Boards
StEP	**:**	Solution for Environment Protection
TV	**:**	Television
UNEP	**:**	United Nations Environment Programme
UNU	**:**	United Nations University
USA	**:**	United States America
WEEE	**:**	Waste Electrical and Electronic Equipment
WHO	**:**	World Health Organisation
WSSD	**:**	World Summit on Sustainable Development
XRF	**:**	X-ray Fluorescence

CHAPTER 1
INTRODUCTION

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INTRODUCTION

E-waste management is a global issue and the developing Nations are much affected due to its chaotic state. The awareness as well compatible infrastructure is deficit in these countries. The informal recyclers are handling much of E-waste and cause health risks to personals employed in this profession; also loose ample valuables of E-waste. India, is one the country facing aforesaid consequences these days as neither users nor manufacturers of the electronic equipment are disposing it of sustainably and cause chronic and acute diseases to human in the country. To for see the E-waste management situation, it is mandatory to observe its status in the country.

1.1. STATUS OF E-WASTE IN INDIA

The E-waste management in India is not as good it deserves. The stakeholders are not accustomed to it as it is a new waste for them. The public participation in its management is judiciously not much as it demands in the country. People are not conceptually equipped for its management, as they are least aware about its prospectives and consequences. In view of that the copious E-waste in the country has no solitary distinctiveness for its disposal infrastructure a like bio-degradable municipal waste. However, in developed countries, it is treated under the ambit of environmental laws. The endeavour for E-waste management in India is rolling gradually in regard to the annual E-waste turn out. Presently, it is in evolving phase. However, the political willpower strives to reinforce it and enacted E-waste rule 2015, lately. In the preceding also, E-waste management guidelines, 2008 and E-waste rule 2011were released to improve the E-waste management in the country. But, still most of people are taking on as and when, where outlook for the disposal of discarded electronic equipment after their intended use. The rag pickers are adding up these equipment in their routine collection and profit from informal recyclers. This informal cult of disposal has provided a wide space to the informal recyclers to take over discarded equipment recycling. The informal recyclers bid to redeem monetary gains out of discarded electronic equipment by employing primitive and rudimentary low cost recycling ways in uncontrolled conditions by putting back the environmental considerations. The hazardous process gains extremely small amount of material but harm utmost to the environment consequently looses valuable material and allows the escape of pollutants in the environment. The metal yield from these processes needs more refining processes for its further usage.

The backyard E-waste recycling is continuing at large scale in metropolitan cities in the country. It endangers the health of the personals engaged in this occupation for livelihood because they are innocent about its ill effects. They are not using any implements for carrying out the E-waste recycling in the backyard. It fortifies that the E-waste is treated widely in an unorganised manner in the country.

Presently, 40-70 million tons, E-waste is being produced world over. In India alone, more than 1.2 million tonne E-waste is being produced annually and its 90% amount is being treated informally by hazardous processes for the recovery of few visible materials in the equipment. However, Ministry of environment, forests and climate change is discouraging informal recycling continuously and registered 138 dismantlers and recyclers to carrying out the sustainable recycling for 0.349 million tonnes E-waste annually, in 12 states in the country **(MoEF 2014).** It is fact that the E-waste recycling quotient is very less in proportion to the E-waste produced in the country. The E-waste recycling is also low in developed countries besides the extant of all kinds of resources and infrastructure because the E-waste collection from the users is still not improved in these countries. However, public participation is more in these countries. The developed countries are dispatching the discarded equipment to developing countries instead to recyclers because the E-waste treatment cost is excessive under the ambit of stringent environment laws.

In India, according to the E-waste availability, the registered recyclers are entrusted and awarded a pay load of E-waste on annual basis. In its continuation, Karnataka has 52 registered dismantlers and recyclers in the state, which is maximum in the country **(MoEF 2014)**. Despite maximum E-waste producing state Maharashtra has only 22 registered recyclers and Delhi state has none. It is clear that there is a wide gap in the actual E-waste produced and its legible recycling in the respective states. Due to the rationale, a wide gap in the E-waste produce and its respective treatment in the same state because people are dealing it desperately in the country. In view of that the informal recycling thrives in the country.

The informal recyclers select the more lucrative electronic equipment for recycling and leave the remaining material and equipment intact, which destine to the dumping. The informal recyclers presume that that big-sized electronic equipment are worth and set high priority for them among all equipment in the E-waste irrespective of translucent information about the composition of the material in it. Besides, the equipment opted for recycling; the untreated remnant is also in huge amount for which landfills are always in demand in the metropolitan cities in India, because for urbanisation, the land is always in demand.

The E-waste is toxic inherently as the discarded electronic equipment are being manufactured by both toxic and non-toxic material. Due to informal E-waste recycling the toxins find access in human food chain and harm irreparably. The most of E-waste toxins are life threatening and cause acute diseases like cancer. However, the precious metals are also coexists in E-waste condensed with toxic metals as metalloids in the equipment. The various blended metals in varied composition operate various functions in the equipment. The metals in equipment are not available elementally but consumed in layers in the form metalloids.

The material composition of electronic equipment is decisive for its sustainable disposal. However, the equipment manufacturers have not made it public and kept as trade secret. In view of this, it is challenging to plan the equipment disposal as per environmental norms because hazardous and non-hazardous material is available in the equipment. The recycling of material from electronic equipment is always in demand formally as well as informally. The informal recyclers are more interested in monetary benefits out of electronic equipment rather than its disposal. But, due to non-availability of fractional composition, they are in fix about it and keen to know this information in concrete before proceed further. The majority of E-waste in India is being treated informally by default, which focuses upon the monetary outcome of the E-waste and set other considerations in low key while carrying out recycling. They are much professional in informal recycling and recover metalloids of poor quality from the E-waste, as they are not update with sustainable technologies. In view of this informal recycling is expanding massively and cause to loose ample quantity of recoverable plastics, glass, precious, and base metals present intact in E-waste. Further, the toxic metals drain in waste and cause health hazards severely to the public engaged in this profession; however the residents near the recycling sites as well public at far reaching places are also affected due the toxic metals, as they are persistent organic pollutants remain years together in the environment and damage it continuously.

The informal recyclers ignore majority of electronic equipment of E-waste for further recycling. By and large, computers peripherals and televisions are always in the list of informal recyclers for metals and components recycling. This equipment are popularly known as birth of electronics in the country and majority of them are being received back in the E-waste after completion of intended use and life. The other equipment like discarded mobile phone is seldom in E-waste as people are either keep it in possession or leave at service centres; however some mobile phone manufacturers offer take back schemes by receding through drop boxes in the metropolitan cities in the country. The discarded mobile phones find very low priority of disposal in India irrespective of coexisting ample precious, base, and toxic metals in prorate with regard to other electronic equipment.

The mobile phone is very popular and handy telecommunication device and more than 75% public is enjoying this electronics in India. It has become significant electronic equipment for everybody in the country. The innovations in the electronics have decreased its life drastically to less than 2 years. The mobile phone waste is escalating with new users adding continuously in the country. In view of that mobile phone waste is still unattended because even the informal recyclers ignore it; presuming that it is a very small equipment and null for material recovery purpose. It is grey area for the recyclers as neither formal nor informal recyclers are aware about the presence of particular metals in a mobile phone. All components hold some metal contents of various attributes. The printed circuit board (**PCB**) is a nodal component, contains ample recoverable metals in its composition. This study has taken up this challenge and determines the plastic, glass, precious metals, base metals, and toxic metals in mobile phone composition in assorted samples. As all metals are being condensed and metals as a whole are in metalloids, such situation are vulnerable for metal recovery because it aggravates the problem due to toxic metals as precious metals cannot be separated elementally. The metalloids are possibly treated hydrmetallurgically, so that the metals may be extracted elementally. In this study, the metals in metalloids are being dissolved in acids and further assessed by flame atomic absorption spectrometry (**FAAS**). The formal recycling of metals from aqueous solution is proficient to extract maximum metals from the digested solution. In E-waste, the discarded mobile phones are being evaluated. The results encourage the formal recycling of mobile phone waste in India and overall reduce the volume of the E-waste in the country. The study confirms that mobile phone waste recycling is a promising event for the recyclers in India, provided it is undertaken sustainably in support of E-waste management in the country.

The E-waste rule defines the responsibilities of each stakeholders contributing in E-waste management in India. The extended producer responsibility (EPR) for E-waste management is in place but still in the whole network, some activities are irresponsive and inefficient. However, whole network works with the same efficiency as to the individual activity efficiency. The collection of E-waste from all sources is still lagging behind and need to be optimised so that maximum amount of E-waste is to destined straight to the registered recycler. To strengthen whole E-waste management network, an innovative model is being introduced to bring about all activities at a level platform and the prevailing situation of E-waste management in the country can be improvised.

1.2. STUDY MOTIVATION

The informal recycling of E-waste in the backyards and scattered electronic equipment in the ambiance attracted the attention of one to all, as E-waste is toxic in nature and people are forced to expose to the toxins. In India, adequate E-waste treating facilities are not in place in the state as like municipal waste. The informal recyclers are showing more interest in metal recovery than to the health of innocent public engaged to earn their livelihood through E-waste recycling. The various toxins emanating from recycling sites are causing various chronic and acute diseases in the environment and enhancing the threat to all resources. Hence it is inevitable to organise the E-waste management in the country so that the public may be prevented from all risks and the pressure on resources may be released. It is only plausible when E-waste management is organised according to sustainable disposal for electronic equipment in E-waste. In the recycling of electronic equipment, its composition is pivotal. The material composition of specific equipment like personal computer, television is known and formal as well as informal recyclers are recovering material from these equipment. But, there is some electronic equipment like mobile phones are not spotted for recycling by both formal as well as informal recyclers. In view of that this study is aimed to explore the composition of assorted mobile phones; so that mobile waste is highlighted for its valuables and further exploited for material recovery by sustainable methodologies in India because a mammoth E-waste is available and due to lethargic attention, a large amount of recoverable metals of mobile phone waste drain in waste along with toxic metals.

1.3. HYPOTHESIS

The electronic equipment is being manufacture by consuming various materials. The materials are intended to support the specific and multiple needs of the electronic equipment design. For instance gold and silver are used for connecting pins in the electronic equipment; plastics are used to shape the equipment and to support the other component placements. The prevailing global technologies ensure the recovery of more than 80% material out of electronic equipment. In India, E-waste sector is developed partially as the data base about the material consumed by each component is not available. The equipment may have ample precious, base and toxic metals in its construction in varied proportion. The E-waste recycling is a profit driven profession in India. It will only survive when material in the equipment is revealed. The composition of material will facilitate recyclers to go for recycling of the equipment. In view of this, it has become significant because the recyclers take up the equipment for recycling on monetary merit basis. Hence, most of equipment may have precious, base and toxic metals, but its proportion varies equipment to equipment. In this study, the composition of material in assorted mobile phone is taken up and expected that it may have precious, base and toxic metals in ample amount in the mobile phone waste. The mobile phone is sensitive equipment and may have more metals in prorate rather than other electronic equipment.

1.4. RESEARCH PROBLEM

The E-waste management is fragile in India besides enormous E-waste production. The formal E-waste treatment facilities are inadequate to deal with entire E-waste in the country. In view of that the informal recyclers capture 90% of the E-waste produced in the country. The informal recycling implies the hazardous processes to reclaim the material out of E-waste. The particular material gain from the E-waste is very low as processes of recuperation are primitive and rudimentary. The awareness about the composition of particular material to be reclaimed in equipment is partial among all.

The informal recycling encourages the big-sized equipment and considers others as null for material gains. However, the other electronic equipment are equally important for the material exploitation as recoverable material coexists in the hidden layers.

The mobile phone is one of the electronic equipment in E-waste, kept in least priority for material recovery in the country. In contrary it has lot of potential for the recovery of precious, base, toxic metals and other recoverable material; but still people are unaware about these facts. The need of precious metals in equipment varies with the sensitivity and reliability. Mobile phone is one of telecommunication equipment having such attributes. The printed circuit board of the mobile phone is a nodal source of metals and may be exploited for various metals. The present trend of recycling allows huge wastage of all kinds of material and promotes health sickness in the country. If the composition of particular mobile phone is known, then only metallurgical processes are able to exploit its material easily. Hence, the composition of material of equipment is significant. The informal recyclers are taking up recycling for few metals in few equipment and ignore the remnants equipment for recovery. The mobile phone waste being copious, facing such ignorance from all sides. But, it is very resourceful, because it contains enormous precious, base and toxic metals in prorate in its composition. Hence the composition of material of mobile phone is beneficial to all in terms of material exploitation as well as in the reduction of pollutants loading on the environment. This study preferred the composition of material of assorted brands and models of mobile phones as research problem and highlights the issue of unconsidered mobile phone waste in the country. The composition of material in mobile phone will provide an impetus to the mobile phone waste disposal in the country in years ahead.

1.5. OBJECTIVES OF THE STUDY

The E-waste encompasses computer, television, radios, mobile phone waste and so on. The informal recycling dominates over formal recycling for the electronic equipment material recuperation in the country. The informal recycling selects the equipment as per their choice and leaves others untouched. The mobile phone waste is still unrecognised in the country. The informal recyclers are not taking up its recycling. However, E-waste is mammoth and escalating rapidly in the country and nobody is sensitive about its sustainable management. The mobile phones of assorted brands and models are in use in India. After the completion of useful life, they are discarded from the intended usage. The defined disposal process of mobile phone is not practical to the users and people are not comfortable while disposing it of blithely in the locality and find as and where options to get rid of discarded phone. This impractical approach leads to unorganised disposal of mobile phone waste, as user is not aware about the components, composition of material, and the harmful effects of unorganised disposal. In view of that individual always eager to know about these gaps, this may be filled to establish sustainable E-waste management in the country.

The study converges to unveil the requisites about the mobile phone waste so that it may get same attention like other electronic equipment for further recycling. To establish a formal E-waste recycling facility, a notable output is essential to run it continuously. The prediction of toxic material hazards is also imperative to safeguard the environment; so that the remedial measures for toxic metals may be planned to neutralize their effects. The mobile phone waste is a focal area of the study as it is deprived by both formal as well as informal recyclers because they are unknown about its composition in the ray of other electronic equipment material output. Mobile phone is one of the electronic equipment contributing in E-waste as per its quantum in the country. This study is proposed to meet the following objectives:

1. To determine the material composition of discarded mobile phones of assorted brands and models by qualitative and quantitative analysis.

2. To determine the precious, base and toxic metals composition of the printed circuit board of mobile phone samples by qualitative and quantitative analysis supported by flame atomic absorption spectrometry.

3. To provide material data of mobile phones for the installation of separate formal recycling infrastructure for mobile phone waste in the country.

4. To introduce an innovative E-waste management model suitable for Indian conditions for the sustainable disposal of E-waste.

The objectives are set adhering to the hypothesis.

1.6. SCOPE OF THE STUDY

This study bears some limitations also. A sample length of ten mobile phones: Nokia 2700, Nokia 1650, Nokia 1108, Meni Max D-5027, Siemens A-50, Motorola-C1-68, Movil-MCI-CDMA, Samsung-D 500 and Nokia- 72 and Motorola W-220 are picked up randomly. The study determines plastics, glass gold, silver, copper, aluminium, iron, manganese, tin, zinc, lead and nickel in all samples. It is assumed that the selected samples array covers the maximum population of the country. The accuracy in observations as well in measurements is maintained up to five decimal points. The precious, base and toxic metals evaluated in the study are directly linked to the study. The selection of state of art is a major breakthrough for reliable, accurate, and real world results as every instrument has its strengths and weaknesses. Among all equipment, the flame atomic absorption spectrometry (**FAAS)** is used for the assessment of metal contents of digested solutions. The study addresses mobile phone waste problem and evaluates the composition of the precious, base and toxic metals. The main emphasis of the study is to know the composition of the metals in the printed circuit board of the assorted mobile phones along with other material. However, other material is also equally important in recycling of mobile phone waste because they may be put across for further manufacturing of electronic equipment.

1.7. SIGNIFICANCE OF THE STUDY

The study confirms the availability of ample amount of recoverable in the discarded mobile phones. It also identifies a new perennial source of metals in E-waste. It acts as an eye opener for the recyclers as well as mobile phone users. A new dimension is set for the sustainable disposal of mobile phone waste. The data is invaluable as it may be used for creating an infrastructure for recycling of discarded mobile phones. The yield of the material from mobile phone is tabulated for reference so that net output is to be assessed in advance commercially. The sustainable disposal of mobile phone waste is a demanding task of day as it will check the wastage of precious and other metals and mitigate pollution simultaneously. It will bring down the mobile phone waste in manageable size. The recycling profession will provide more opportunities to the jobseekers. The output of material from discarded mobile phone will compensate the demand of the virgin metals at low cost for equipment manufacturing and reduce exploitation of natural resources as used for natural mining. Further, it promotes the local mining of the E-waste in the country.

The E-waste management is not organised, as it needs. A mammoth E-waste is being produced in India; but hardly fractional E-waste destine to recycling. In view of that most of the waste remains under with the informal recycling as collection of E-waste from all sources; is lagging behind. The collection of E-waste is the backbone of recycling as it provides the opportunity to the recyclers to treat maximum waste sustainably. But in India it is far behind the target. There is a wide gap in the produced E-waste and treated E-waste in the country. To fill a gap an innovative E-waste management model is introduced suitable for Indian conditions. It will enhance collection efficiency of E-waste and support the sustainable disposal of E-waste in the country.

1.8. ORGANISATION OF THESIS

The thesis has been organised within the scope of the study in the light of objectives. It comprises of literature review, materials and methods, results and discussion, conclusions recommendations, future scope of the study and references. The brief of each chapter is described in the subsequent paragraphs.

Chapter 2 Literature Review

It gives the background of the E-waste as various definitions from various agencies, sources of E-waste, equipment and material composition in E-waste, electronic equipment categories, statistics of E-waste generation, E-waste management guidelines, rule and laws, present E-waste disposal practices, the standard E-waste disposal practices, E-waste hazards and essence of E-waste treatment in Indian scenario is presented. Area of the study selected and its significance, the contribution made by authors in the past for the sample selected for the metals composition, is presented in terms of statistics of the samples in use and their futuristic expansion.

Chapter 3 Material and Methods

In this section, the significance of the material selected in spite of other material is presented. The detail of the equipment of various methods used for the assessment of metals in extracted solution is discussed in this section. The option for the selected method is being described. The standard operating system of the equipment used is also explained. The role of dilution factor (DF) and certified reference material (CRM) in the method selected for the study. The detail pertaining to the flame atomic absorption spectroscopy (FAAS) are being described. The acid digestion by concentrated HCl followed by aqua-regia is presented. The flow diagram of the methodology used for the study, is also presented.

Chapter 4 Results and Discussion

In this section, various results starting from dismantling of the sample and further roasting analysis, acid digestion, residue analysis after HCl digestion, aqua-regia treatment to each sample is presented. In addition, the results of each metal from each sample are presented. The economic aspect of base and precious metals and hazard aspect of toxic metals are presented. The detail about each AAS reading and volume of digested solution and its calculation is also described accordingly. The recoverable percentage of metals present in the sample is drawn graphically for each metal. The total metal outcome of all kinds in consideration is tabulated.

Chapter 5 Conclusions, Recommendations and Future scope of the study

The general statement about the study is being described. The present scenario of the E-waste management and its further improvement is suggested. The future plan for such study is also mentioned.

CHAPTER 2
LITERATURE REVIEW

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LITERATURE REVIEW

The eminent researchers have carried out study on mobile phone PCB hitherto and concluded the presence of various metals in unspecified mobile phones. Globally, the mobile phone technology is changing abruptly and the composition of the material in it is also varies accordingly. It has become mandatory to determine the actual composition of the material used up in mobile phones in India, so that its waste may be disposed of sustainably and the available recoverable material in it may be utilized as resource. In India, the mobile phone waste is absolutely ignored, besides mammoth magnitude in E-waste because the cognizance about the E-waste, its equipment composition, material composition and ill affects, if treated in uncontrolled conditions is very shallow in the entire country.

2.1. E-WASTE

E-waste is a European Union (**EU**) led initiative incepted in 1992 as Basel convention, however its proceedings started in 1980 (**UNEP 2006**). The Basel convention highlighted the E-waste issue in global perspective and 170 nations ratified it for further compliance. India is one of them (**UNEP 2006**). In India, it is a computer aged waste; produced by electrical and electronic equipment. In early days, its quantity was meagre in the country and the electronic equipment usage was also limited. But now, the situation is distinct as the electronic equipment is in the reach of one to all and its usage has increased manifolds due to digitalisation in the country. The life of the equipment has decreased drastically due to innovation in equipment design and globalization. In view of that obsolescence of electronic equipment has increased massively and caused a surge in E-waste production in the country.

E-waste encompasses a wide range of electronic equipment.The absolute definition of E-waste is yet to be validated and accepted internationally. The various agencies have defined it as per their understanding about E-waste. The outlook about E-waste differs by equipment, available in E-waste in their countries. But; in all, it includes PCB in focus while defining it. PCB is designated a fundamental part of each electronic equipment regulates all functions and features of the equipment. The first definition for E-waste has been issued in 2001 by OECD and in 2002 it is further elaborated under directive EU 2002a, includes end of life electronic equipment as well as their assemblies (**Hussmann 2007)**. However, the researchers and professionals have defined it as per their considerations. The various definitions of E-waste are tabulated in **Table 1**. These definitions provide an over view about E-waste; separate it from other waste as a whole.

Table 1: Definitions of E-waste (Widmer 2005)

Reference	Definitions
OECD (2001)	"Any appliance using an electric power supply that has reached its end of life."
EU WEEE Directive (EU, 2002a)	"Electrical or electronic equipment which is waste . . . including all components, sub-assemblies and consumables, which are part of the product at the time of discarding." Directive 75/442/EEC, Article 1(a) defines 'waste' as "any substance or object which the holder disposes of or is required to dispose of pursuant to the provisions of national law in force."
Basel Action Network (Puckett and Smith, 2002)	"E-waste encompasses a broad and growing range of electronic devices ranging from large household devices such as refrigerators, air conditioners, cell phones, personal stereos, and consumer electronics to computers which have been discarded by their users."
SINHA (2004)	"An electrically powered appliance that no longer satisfies the current owner for its original purpose."
StEP(2005)	E-waste refers to ". . .the reverse supply chain which collects products no longer desired by a given consumer and refurbishes for other consumers, recycles, or otherwise processes wastes."
CPCB (2008)	E-waste comprises of wastes generated from used electronic devices and house hold appliances which are not fit for their original intended use and are destined for recovery, recycling or disposal.

In some countries WEEE (Waste from Electrical and Electronic Equipment) acronym is being used in place of E-waste, as both are same.

2.2. E-WASTE COMPOSITION

In India, E-waste comprises of discarded computer, cathode ray tube televisions, radios, stereos, speakers, video cassette recorders and its peripherals, mobile phones, laptops, remote controls, compact discs, headphones, batteries, air conditioners, refrigerators, washing machines, ovens, compact florescent tube and other PCB based household appliances in its composition. The management of mingled E-waste is difficult because shape, size, weight and usage of each equipment is distinct. Also, the need of infrastructure is different to each kind of electronic equipment and knowledge about the E-waste equipment is also minimal. In view of that E-waste is managed marginally in the country because E-waste treatment infrastructure is inadequate and public participation in E-waste management is very low. The collection of E-waste has become a pivotal aspect as it put forward wide range of challenges in front of waste managing agencies in India. However, in developed countries it is handed over with advance recycling fee (**ARF)** willingly for its further treatment and waste managing agencies organise recovery of valuable material from E-waste amiably and utilizes it as a material resource for fulfilling the material demand in their countries. The EU is managing E-waste sustainably in an organised manner in their countries. In EU countries, E-waste is classified in to ten categories (WEEE 2002) as large house appliances (LHA), small house appliances (SHA), IT and ICT, consumer electronics (CE), lighting equipment (LE), electrical and electronic tools (EE), toys, leisure and sports ,Toys, medical devices (MD), monitoring and control (M&C) and automatic dispenser (AD). All equipment are placed in these categories in accordance with their size and usage respectively. However, the composition of material in equipment varies models to model and brands to brand because the electronic design is varying in expeditious electronics' in the world. The expansion of electronics is more in developed countries as to the developing countries; consequently, the consumption of electronic equipment is more in these countries; consequently generate more per capita E-waste in their countries. The generation of E-waste is more in developing countries like India as the users of electronic equipment are more than developed countries due to more population in the country. However, the usage of electronic equipment varies regions to region and countries to country in the world. Also, the illegal penetration of discarded electronic equipment dispatched from developed countries to the developing countries is significant. The composition of E-waste in India is different to other countries because the usage of particular equipment is different to the developed countries. In India, the presence of heterogeneous equipment in E-waste is critical for E-waste management. To resolve this E-waste management worldwide snag, European Union implies that all electronic equipment may be put according to the categories for carrying out its further recycling and disposal. However, the size of the equipment varies with features. The typical percentage of each category in E-waste is presented in **Figure 1**. In E-waste, the LHA is leading among all categories and contributes 49% by weight, followed by IT and telecom equipment 21%, consumer electronics 16%, small household appliances 7%, electric and electronic tools 3.5%, lighting equipment 2.4%, monitoring control equipment and automatic dispensers 0.2% and medical devices and toys and leisure 0.1% respectively **(Lundstedt 2011)**. Further, in these categories, four categories are subdivided in to sub-categories as 1A, 1B, 1C, 2A, 2B, 2C, 3A, 3B, 3C, 6A and 6B respectively **(Lundstedt 2011)**. In LHA category, cooling, freezing and smaller items are being separated out of it. Similarly in CE category, cathode ray tube (CRT) technology and flat panel televisions (TV) are sub categorised as CRT TVs; which are more in consumer electronics waste.

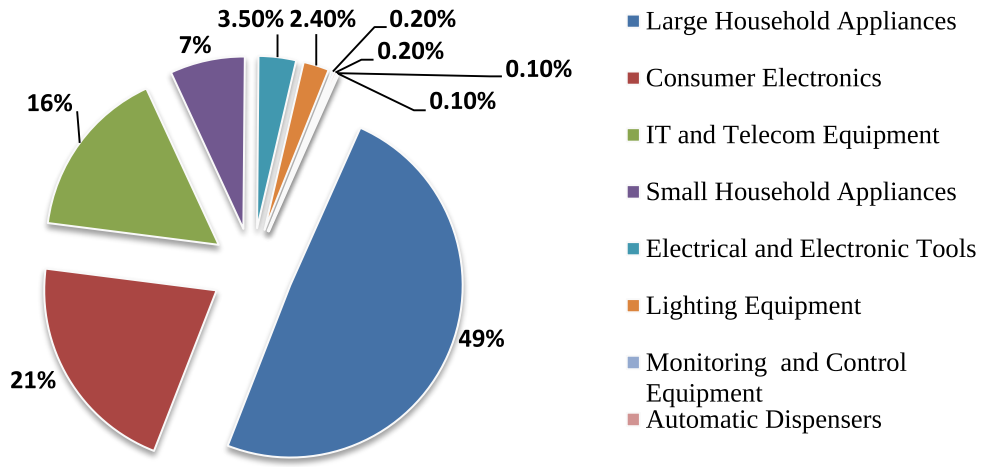


Figure 1: E-waste Categories (Lundstedt 2011)

Also, from LE categories, lamps are separated from luminaries. Four categories (1-4) account for almost 93% of the total equipment in E-waste and category LHA accounts for almost half of the total E-waste by weight. However, more electronic equipment would be added in these categories by 2018. The electronics is expanding sharply in India as like developed countries. Hence, the category wise classification of equipment is an important event for Indian perspective also as it would facilitate in E-waste management as well in establishing sustainable E-waste management in the country. The composition of electronic equipment of these sub-categories with respective to the composition of the equipment is presented in **Table 2**. In E-waste, equipment of 95 kinds are being placed in ten categories. The equipment in each category is presented in **Table 3**. The categories of information technology and telecommunication equipment lead among all categories, contains 23 equipment in its category and large household appliances category following it by 14 equipment, small household appliances by 11 equipment, medical device by 10 equipment, consumer equipment by 8 equipment, electrical and electronic tools by 7 equipment, toys, leisure and sports equipment by 6 equipment, automatic dispensers and monitoring and control instruments by 5 each equipment respectively (**UNEP 2007**). However, the equipment are much more of unique identity and their construction is also different. Earlier all equipment are categorised based upon their end use but nowadays the scenario is different so category of each equipment should be separate because in each category numerous models of varying design are being manufactured. In big sized electronic equipment, the contribution of electronic components is small and vice versa.

Table 2: E-waste Sub-Categories (Lundstedt 2011)

Sr. No.	Category	%age of total E-waste	Sub-categories	%age of total E-waste
1.	Large household appliances Washing machines, dryers, refrigerators, air-conditioners etc.	**49**	**1A**. Large household appliances Excluding 1B and 1C	**27.7**
			1B. Cooling and freezing	**17.7**
			1C. Smaller items	**3.6**
2.	Consumer electronics Televisions, VCR/DVD/CD Players, Hi-If sets, Radios, etc.	**21**	**2A** Consumers electronics excluding. 2Band 2C	**7.8**
			2B. CRT TV's	**13.1**
			2C. Flat Panel TV's	**0.1**
3.	IT and telecom. equipment PCs, Laptops, cell phones, telephones, fax machines, copiers, printers, etc	**16**	**3A**. IT and telecom. Equipment excluding 3B and 3C.	**8.0**
			3B. CRT monitors	**8.3**
			3C. LCD monitors	**0.0**
4.	Small household appliances Vacuum cleaners, coffee machines, irons, toasters, etc.	**7.0**	-	**7.0**
5.	Electrical and electronic tools Drills, Electric saws, sewing Machines, lawn mower etc. (Except: large stationary tools/machines)	**3.5**	-	**3.5**
6.	Lighting equipment Fluorescent tubes, sodium lamps etc. (Except: bulbs and halogen bulbs)	**2.4**	**6A.** Luminaries	**0.7**
			6B. Lamps	**1.7**
7.	Monitoring and control equipment	**0.2**	-	**0.2**
8.	Automatic dispensers	**0.2**	-	**0.2**
9.	Toys, leisure and sports equipment Electric train sets, coin slot machines treadmills, etc.	**0.1**	-	**0.1**
10.	Medical devices	**0.1**	-	**0.1**

Table 3: Equipment in each Category (UNEP 2007)

Sr.no.	Category	Equipment in category
1.	Large household appliances (LHA)-14	Large cooling appliances
		Refrigerators
		Freezers
		Other large appliances used for refrigeration, conservation and storage of food
		Washing machines
		Clothes dryers
		Dish washing machines
		Cooking
		Electric hot plates
		Microwaves
		Other large appliances used for cooking and other processing of food
		Electric heating appliances
		Electric radiators
		Other fanning, exhaust ventilation and conditioning equipment
2.	Small household appliances(SHA)-11	Vacuum cleaners
		Carpet sweepers
		Other appliances for cleaning
		Appliances used for sewing, knitting, weaving and other processing for textiles
		Iron and other appliances for ironing, mangling and other care of clothing
		Toasters
		Fryers
		Grinders, coffee machines and equipment for opening or sealing containers or packages
		Electric knives
		Appliances for hair-cutting, hair drying, tooth brushing, shaving, massage and other body care appliances
		Clocks, watches and equipment for the purpose of measuring indicating or registering time Scales.
3.	IT and Telecommunications equipment(IT&TE)-23	Centralised data processing
		Mainframes
		Minicomputers
		Printer units
		Personal computing:
		Personal computers (CPU, mouse, screen and keyboard included)
		Laptop computer (CPU, mouse, screen and keyboard included)
		Notebook computers
		Notepad computers
		Printers
		Copying equipment
		Electrical and electronic typewriters
		Pocket and desk calculators
		And other products and equipment for the collection, storage, processing, presentation or communication of information by electronic means
		User terminals and systems
		Facsimile
		Telex
		Telephones
		Pay telephones
		Cordless telephones
		Cellular telephones
		Answering systems
		And other products or equipment of transmitting sound, images or other information by telecommunications

4.	Consumer electronics (CE)-8	Radio sets Television sets Video cameras Video recorders Hi-fi recorders Audio amplifiers Musical instruments And other products or equipment for the purpose of recording or reproducing sound or image, including signals or other technologies for the distribution of sound and image than by telecommunications
5.	Lighting Equipment(LE)-6	Luminaries for fluorescent lamps with the exception of luminaries in households Straight fluorescent lamps Compact fluorescent lamps High intensity discharge lamps, including pressure sodium lamps and metal lamps Low pressure sodium lamps Other lighting or equipment for the purpose of spreading or controlling light with the exception of filament bulbs
6.	Electrical and electronic tools(E&ET)-7	Drills Saws Sewing machines Equipment for turning, milling, sanding, grinding, sawing, cutting, shearing, drilling, making, holes, punching, folding, bending or similar processing of wood, metal and other materials Tools for riveting, nailing or screwing or removing rivets, nails, screws or similar uses Tools for welding, soldering or similar use Equipment for spraying, spreading, dispersing or other treatment of liquid or gaseous substances by other means Tools for mowing or other gardening activities
7.	Toys, leisure and sports equipment(T,L&SE)-6	Electric trains or car racing sets Hand-held video game consoles Video games Computers for biking, diving, running, rowing, etc. Sports equipment with electric or electronic components Coin slot machines
8.	Medical devices(MD)-10	Radiotherapy equipment Cardiology Dialysis Pulmonary ventilators Nuclear medicine Laboratory equipment for in-vitro diagnosis Analysers Freezers Fertilization tests Other appliances for detecting, preventing, monitoring, treating, alleviating illness, injury or disability
9.	Monitoring and control instruments(M&CI)-5	Smoke detector Heating regulators Thermostats Measuring, weighing or adjusting appliances for household or as laboratory equipment Other monitoring and control instruments used in industrial installations (e.g. in control panels)
10.	Automatic dispensers(AD)-5	Automatic dispensers for hot drinks Automatic dispensers for hot or cold bottles or cans Automatic dispensers for solid products Automatic dispensers for money All appliances which deliver automatically all kind of products

So IT and telecommunication equipment category is very significant because all equipment fitted with printed circuit boards (PCBs) as a pivotal component of the equipment and its size is bigger than other components. Also, the monetary outcome from the bigger PCB is ever more to others. The life of the IT & TE is extremely less but equipment are being used more in the country, **Figure 2.**

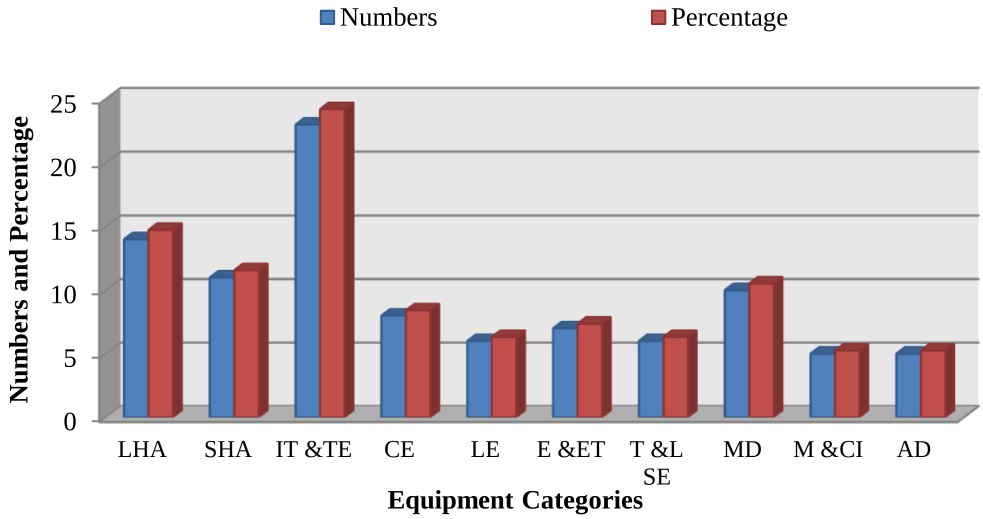


Figure 2: Equipment in Categories (Widmer2005)

The innovations have transformed the world with less energy consuming, low cost, more and updated featured IT equipment. The present E-waste would make up partially the modified composition of electronic equipment; which are to be destined in E-waste in years to come. The discarded mobile phones are less in E-waste composition as people are keeping most of them in their possession or dispose it of blithely in the municipal waste.

2.3. MATERIAL COMPOSITION OF ELECTRONIC EQUIPMENT

The electronic equipment is being manufactured by the use of more than 1000materials.In the equipment construction, the material contributes significantly, as plastics provide shape to the equipment, metals provide hardware of the equipment, and fire retardants provide safety to the conductors against heat and fire in the instrument. The materials of same physical properties are blended with other homogenous material to support the parts and components of the instrument. For instance a plastic is a versatile material encompassing various types of plastics. Similarly, metals are of different attributes as precious, base and toxic are being used as metalloids in the instrument hardware as elemental material alone does not fulfil design needs because either it would be uneconomical somewhere or loose the parametric functions as and when it is required. The material composition in each equipment is different. Also, the design of the equipment of same intended usage is different but the components supporting the features of the equipment are similar besides, the material composition of the components are different to each other. The electronic and electrical equipment are composed of metals and non-metals.

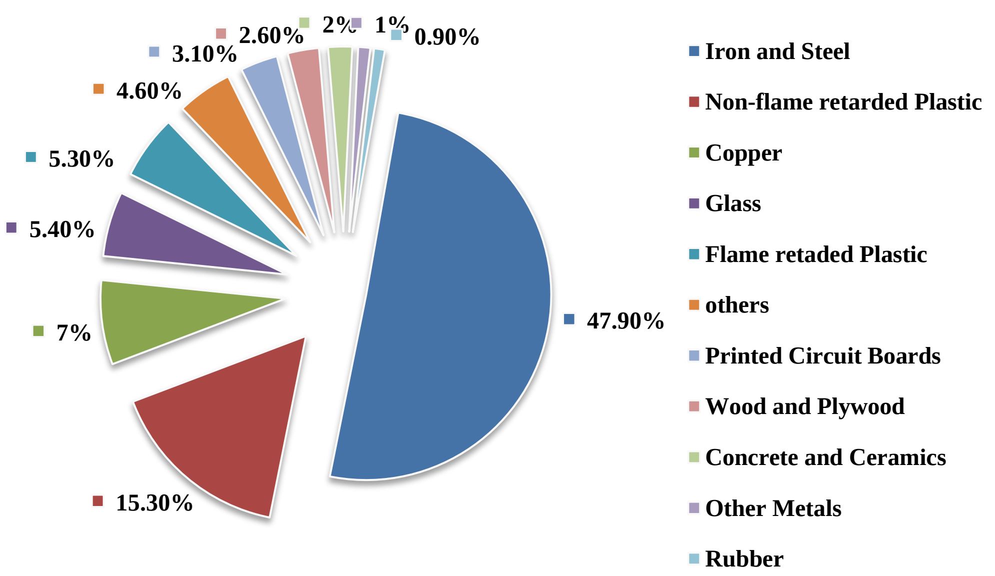


Figure 3: Weighted percentage of material in E-waste (Widmer 2005)

In electronic equipment composition, steel constitutes 50%, copper, aluminium and other non-magnetic metals 13% and plastics 21% by weight **(ETC/SCP 2009).** The recoverable precious metals play a pivotal role in the metal economics as it provides

95% financial support to the recycling infrastructure; however other metals and materials like lead, nickel and various plastics may be of worth after recovery from E-waste **(He 2006, Cui and Zhang 2008).** The weighted percentage of material in E-waste is presented in **Figure 3.**

In an electronic equipment, Iron and steel share 47.90%, copper 7%, aluminium 4.7%, other metals 1%, non-flame retarded plastic 15.3%, flame retarded plastic 5.3%, printed circuit boards 3.10%, glass 5.4%, wood and plywood 2.6%, concrete and ceramics 2%, rubber 0.90% and others 4.6% (**Widmer 2005**). Similarly, another study concludes that an equipment contains 60.2% metals, 15.2% plastics, 5% metal-plastic mixture, 2% cables, 11.9% CRT and LCD screens 1.7%printed circuit boards, 1.40% others, and 2.7% pollutants, **Figure 4** (**EMPA 2006**). However, the material in cables includes fire retardants, plastics and conducting material. The plastics is also put in layers based upon the design at the locations, some where it is used to resist plastic weathering and sometimes it is used to resist conductance to check the flow of electricity. The encapsulated material cannot be separated elementally as it is used in condensed form in the components. The principal component of each equipment is printed circuit board, which is a rich source of metals.

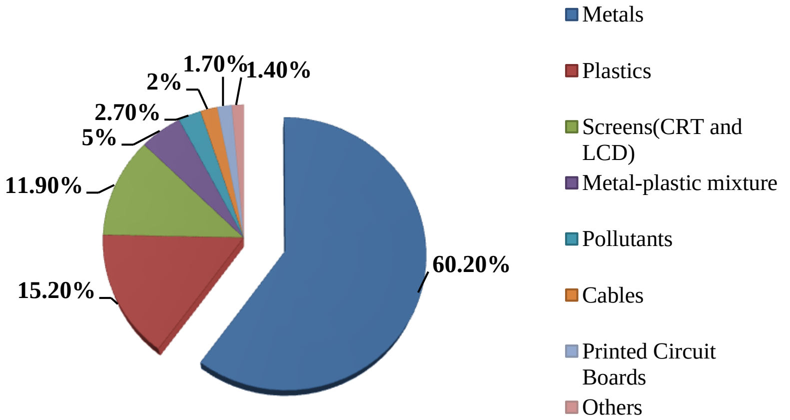


Figure 4: Weighted percentage of material in E-waste equipment (Widmer 2005)

In the category of toxic metals, it is unsafe to consume them beyond permissible limits. The permissible limit to ingest them by weight of the body is mentioned in **Table 4**. The toxic material alike lead, cadmium, mercury, polychlorinated bi-phenyls (PCBs), etched chemicals, brominated flame retardants with non-toxic material are put in a nutshell in electronic component of the equipment. The toxicity of material up to certain concentration is meagre but beyond threshold values they are hazardous. The threshold values of safe and unsafe limits of few metals are also presented in the **Table 4**. The toxic material and their by-products are persistent organic pollutants and remain in atmosphere years together. The pollutants released while E-waste processing, recycling or disposal in uncontrolled conditions and pose risk on human health (**UNEP 2005**).

Table 4: Safe and unsafe concentration of material in equipment (MoEF 2008)

Sr. No.	Material	Safe Permissible concentration in mg/Kg	Unsafe threshold concentration in mg/Kg.
1.	Antimony	<50	=>50
2.	Beryllium	<50	=>50
3.	Cadmium	<50	=>50
4.	Chromium (VI)	<50	=>50
5.	Mercury	<50	=>50
6.	Polychlorinated biphenyls, Polychloroteriphenyls	<50	=>50
7.	Halogenated aromatic compounds	<50	=>50
8.	Cobalt	<5000	=>5000
9.	Copper	<5000	=>5000
10.	Lead	<5000	=>5000
11.	Nickel compounds	<5000	=>5000
12.	Inorganic tin compounds	<5000	=>5000
13.	Vanadium compounds	<5000	=>5000
14.	Tungsten compounds	<5000	=>5000
15.	Silver compounds	<5000	=>5000
16.	Halogenated aliphatic compounds	<5000	=>5000

Sr. No.	Material	Safe Permissible concentration in mg/Kg	Unsafe threshold concentration in mg/Kg.
17.	Phenol and phenolic compounds	<5000	=>5000
18.	Chlorine	<5000	=>5000
19.	Bromine	<5000	=>5000
20.	Halogen-containing compounds	<5000	=>5000
21.	Tin	2 mg per person per day	>2 mg per person per day
22.	Mercury	0.001 to 0.0003 mg per kg BW per day	>0.001 to 0.0003 mg per kg BW per day
23.	Manganese	0.02 mg per cubic meter	>0.02 mg per cubic meter
24.	Zinc	0.17-0.25 mg per kg BW per day	>0.17-0.25 mg per kg BW per day

The Toxic material in equipment is 2.7% to its weight **(Widmer 2005)**. The presence of these constituents in E-waste made it a complex hazardous waste. In view of that it is very difficult to separate them from the discarded equipment elementally.

2.4. E-WASTE INVENTORY

The inventory of electrical and electronic equipment is increasing with the emerging technology in electronics; consequently an ordinate increase in E-waste is registered in India due to the reducing life of the equipment; as it is caused by innovations in electronics. The globalisation is offering an opportunity to the public to use more and more equipment at reasonable price in the world. The accessibility to the electronic equipment enhances the reliability on electrical and electronics equipment in India as the usage and users are increasing sharply in India. The public is replacing the prevailing electronic equipment in the name of novel technology, energy efficiency, cost effectiveness, green technology. Besides these attributes, the durability and age of the electronic equipment has reduced drastically. For instance, the life of the mobile is reduced to less than two years in developed countries and less than three years in India. Now, in India people are fond of acquiring update technology in electronics as it meets both present and futuristic demand of the users, however technology is shifting quickly in the country and sooner or later people have to adopt it for their routine work.

The various electronic equipment are being used at large scale in India, but the inventory of these items is not maintained for public domain. Also the life of the equipment is not prescribed along with date of manufacturing. In view of that, the actual E-waste produced per annum in the country is not known to the public; only it is estimated for its management because the inventory of used up electronic equipment is neither available legibly nor informally. The CPCB is striving to prepare the E-waste inventory for the years to come. The preparation of inventory for E-waste produce per annum is underway and in the coming years it would be made public.

The inventory of E-waste is decisive in its recycling because the material recovery is directly proportional to the E-waste produced. E-waste is being produced by definite as well as indistinct sources in the country. It includes offices, commercial sectors, institutional sectors, R&D organizations, manufacturing sectors, industrial sectors, household, local collectors and stockists (**Vats and Singh 2014**). By and large, E-waste is being produced by the institutions of Government, public and private sectors, which accounts 70%, household 15% and remaining 15% with the manufacturing sectors of the total E-waste produced in the country (**Research Unit 2011)**.

Presently, it is anticipated that 50-70 million tons of E-waste is being produced annually in the world **(Vats and Singh 2015**). In India, more than 1.2 million tonnes E-waste is being produced annually, which is about 2.5% of the global produce. The produced E-waste at global scale is 5% of the total municipal waste in the world (**UNEP 2006),** while in India it is 1.76% as India is producing 1.7 million tons per annum **(PIB 2016)**. Globally, E-waste is increasing in pro-rata with the population by 4 to 5% per annum. The developed countries produce more per E-waste as to the developing countries. However, solid waste production magnitude is high in developing countries as to the developed countries. In 2010, the United Nations anticipated that by 2020, the computer waste would rise to 400% in China and 500% in India and mobile phone waste would rise seven times higher in China and 18% higher in India with respect to the 2007 level **(Tom Young 2010).** Nowadays the equipment are being discarded in India to make a way for the new technology in the country. Also, the comptroller of auditor general **(CAG**) in 2010, reveals that 48 million tons of municipal waste is being produced along with 7.2 million tons hazardous waste, 0.4 million tons E-waste, 1.5 million plastics waste, 1.7 million tons medical waste annually in the country **(Agarwal 2010).**

E-waste generation profile in India is fascinating as 10 states generate 70 % E-waste of the country; also within country, 65 cities generate more than 60 % E-waste in the country (**Rajya Sabha 2009)**. The Indian states are presented in the order of most E-waste producing states as Maharashtra, Tamil Nadu, Andhra Pradesh, Uttar Pradesh, West Bengal, Delhi, Karnataka, Gujarat, Madhya Pradesh and Punjab and the metropolitan cities are Mumbai Delhi, Bengaluru, Chennai, Kolkata, Ahmedabad, Hyderabad, Pune, Surat and Nagpur **(Research Unit 2011)**

The E-waste generating profile depicts the expansion of the electronic goods usage and the modified lifestyle of the people in these regions. The gross domestic product (**GDP**) and the population of the region are pivotal in the E-waste production as more economically sound people encourage the use of more electronic products in their day to day needs. Presently, the per capita E-waste generation in India is 1 kg/Inh **(Vats and Singh 2014).** However, the per capita E-waste generation in Europe is 15.6Kg/Inh (**Balde 2015**).It expresses the more usage as well as electronics expansion in developed countries than developing countries.

The magnitude of the individual electronic equipment waste is increasing quickly and its multitude alone is sufficient to feed as pay load for the E-waste management infrastructure. In view of that equipment needs its own management starting from its collection to its disposal. Hence, the retrieval of material is based upon the material yield from each equipment has become critical to decide the economic viability because the material in the equipment decides the recuperation options. In a nutshell, the sustainable disposal of equipment is possible only when the inventory of the equipment is prepared accordingly for material reclamation. Hence, E-waste inventory is a key success for its management in India.

The E-waste generation in the country has good kith and kin to its population and GDP. However, both are increasing at varied rate. The consumption of new electronic goods is an index of societal development and decides the country technological rank in the world. Also, the demographic, geographical, socio-economic perimeters of the country decide the fate of the E-waste production in the country (**Beiglet 2008**). In India, urban habitants generate more E-waste as they are using more electrical and electronic equipment due to their accessibility to goods, markets, production units, institutions and other amenities in urban areas. In India, 31% population of the country lives in urban areas (**Census 2011)**.

The developed and developing countries alike USA, Australia, Germany, United Kingdom, Japan, France, Brazil, South Africa and China are producing more than 1 kg E-waste per capita per annum, **Figure 5**.

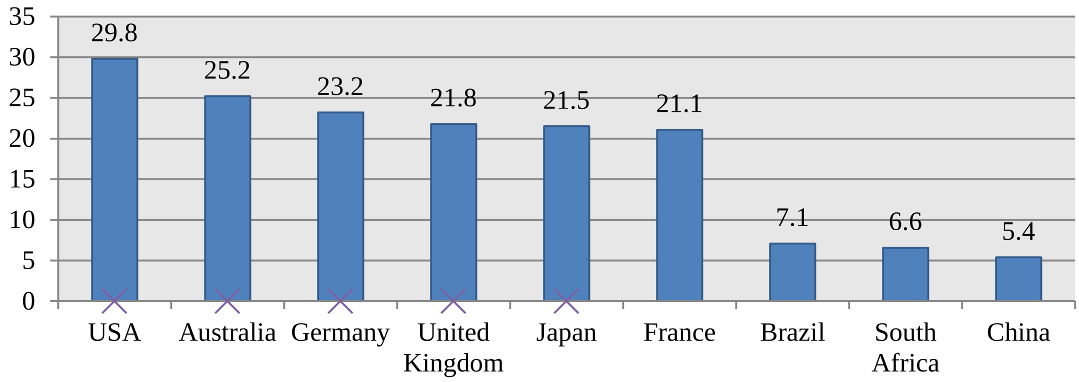


Figure 5: E-waste generation per capita in Kg (StEP 2012)

Additionally, the present population of India is 1.32 billion and it is expected that in year to come 1.32 million tonnes of E-waste would be produced by the country which is merely 3.3% equipment as per their country GDP and discard the obsolete equipment to the proportion of adaptability. The population of users in the country is also an important factor in E-waste accumulation all over the world because the population of users is more in India than most of the developed countries.

In E-waste statistics 2012, the developing and developed countries are presented with their respective probable E-waste in **Figure 6**. The countries namely Mexico, Brazil, Russia, Japan, India, China, USA, EU, Germany, Russia, United Kingdom, France, Australia, South Africa are being incorporated for the statistics. In E-waste production in million tons per annum, EU is leading by 10.93, followed by USA 9.4 and then China 7.3, India 3.03, Japan 2.7, Germany 1.9, Russia 15.56, United King and Brazil 1.4, France 1.3,Mexico 1.138, Australia 0.6, and South Africa 0.3 respectively. In view of that in developing countries like China and India has more overall E-waste production per annum than Russia, UK, France, Australia, Germany, Japan and Brazil. E-waste has become fastest growing waste in waste stream in the world (**Research Unit 2011**). However, in the past 1990s, in India the use of EEE was limited and life span of the electronic equipment was also more. But, after globalization, the innovations in EEEs products enhanced the production as well utilization of these equipment manifolds. The life span of the equipment has also reduced drastically because technology of the equipment changing quickly. In view of that the inventory of discarded and obsolete electronic equipment has grown up quickly. In India, 0.4 million tonnes of e-waste was produced in 2010 **(Agarwal 2010**). However, in 2010, the technology expansion was low comparably to the prevailing era.

In 2013, E-waste production surged to 0.8 million tonnes per annum (**Basu 2010**). The current E-waste generation data is not available. However, the predictions show an alarming E-waste production in the country. In contrary, the compatible E-waste treating infrastructure is expanding steadily in the country. A glimpse of e-waste production in 2009 by top ten states and metropolitan cities is presented in **Table 5**.

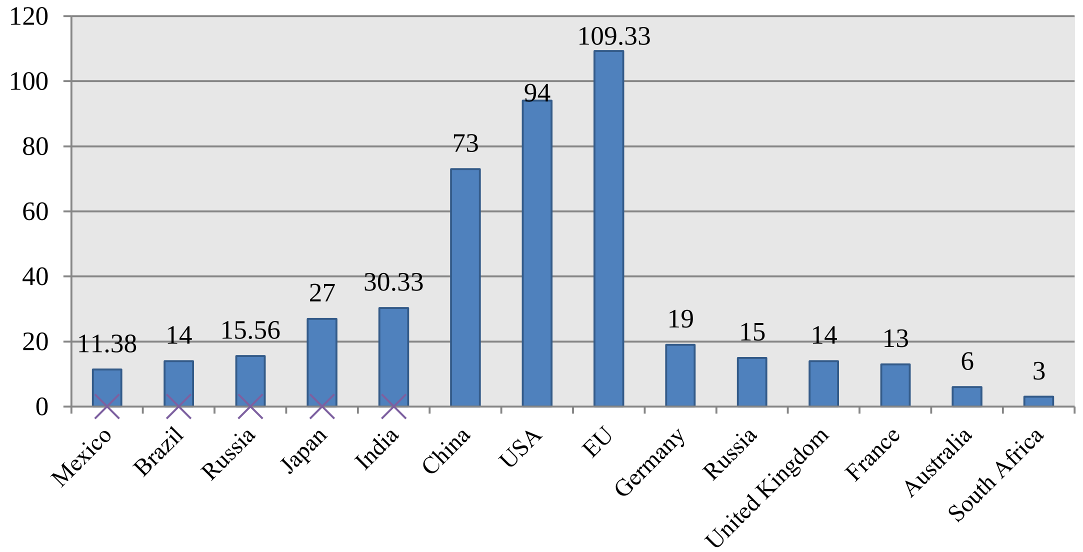


Figure 6: E-Waste Generation per Annum in x 10^5 tonnes in 2012 (StEP 2012).

In consumer electronics, the use of mobile phones has increased by 80%, PCs's 20% and TV 18% respectively (**CII 2006). **However, the E-waste generation data in the table is the data is provided by CPCB

Table 5: E-waste generation in States and Metropolitan cities of India (Research unit 2011).

Sr. No.	States	E-waste Generated in MTA	Metropolitan Cities and others	E-waste Generated in MTA
1.	Maharashtra	20270.59	Mumbai	11017.1
2.	Tamil Nadu	13486.24	Delhi	9729.15
3.	Andhra Pradesh	12780.33	Bengaluru	4648.4
4.	Uttar Pradesh	10381.11	Chennai	4132.2
5.	West Bengal	10059.36	Kolkata	4025.3
6.	Delhi	9729.15	Ahmadabad	3287.5
7.	Karnataka	9118.74	Hyderabad	2833.5
8.	Gujarat	8994.33	Pune	2584.2
9.	Madhya Pradesh	7800.62	Surat	1836.5
10.	Punjab	6958.46	Nagpur	1768.9
MTA : Metric Tonnes per Annum				

In India, trans-boundary movement of waste also effects significantly. Annually, 0.05 million tons E-waste is being received from importation, it is 13% of the indigenous E-waste generated **(Khatter 2007).** The E-waste dispatched from developed countries may be more in the country as the authentic data of illegally received E-waste is not in place for the accounting. In the total imported E-waste, 80% is from USA and rest from EU countries **(Pratap 2009)**. In the indigenous E-waste, only 1,44,143 tonnes of E-waste has been documented from 3,82,979 tonnes, and remaining 62.36% either wasted or treated informally **(Khatter2007).** However, only 19000 tonnes (13%) of E-waste has been recycled out of 1, 44,143 tonnes **(Khatter2007).** A new E-waste inventory is prepared to for the E-waste production in the country based upon 1 kg per capita per annum. The new inventory of ten states and ten metropolitan cities is presented in **Table 6.** For the reported E-waste, the viable E-waste treatment facilities have been commissioned by registered recyclers as per CPCB norms in nine states of the country, other states are supposed to divert their E-waste towards the nearest installed facility as per their convenience. Based upon the new prediction, ten states generate 60.5% E-waste and ten metropolitan cities. The present Population of India is 1320 million.

Table 6: E-waste Inventory in India 2016

Sr. No.	States	E-waste Generated in MTA*	Metropolitan Cities and others	E-waste Generated in MTA*
1.	Maharashtra	112372	Mumbai	22000
2.	Tamil Nadu	72138	Visakhapatnam	4290
3.	Andhra Pradesh	84665	Bengaluru	11556
4.	Uttar Pradesh	199581	Chennai	9814
5.	West Bengal	91347	Kolkata	5017
6.	Delhi	16753	Ahmadabad	7571
7.	Karnataka	61130	Hyderabad	11723
8.	Gujarat	60383	Pune	5926
9.	Madhya Pradesh	72597	Surat	6043
10.	Punjab	27704	Nagpur	2705
MTA : Metric Tonnes per Annum, * Based on May 2014 population				

2.5. E-WASTE LAWS IN INDIA

The E-waste laws are governing the movement of E-waste in India; but its implementation is not uniform in the country. It is not as promising to the developed nations. The informal recycling of E-waste is still surviving under the ambit of these laws. However, the efforts are on to curb the informal E-waste recycling so that streamlined E-waste management is maintained under the laws. The E-waste treating infrastructure is increasing steadily in the country.

The state pollution control board **(SPCB**) is responsible for E-waste management in states. The environmental laws are pivotal to establish E-waste management infrastructure in the country. However, the ministry of environment forests and climate change always strive to reinforce the E-waste laws according to the need of the day.

E-waste was put initially under the hazardous waste management and handling rule 1989, because it contains toxic material in its composition. However, this rule was further amended in 2000, 2003 and 2008 accordingly. Further, the ministry of environment, forests and climate change issued guidelines for E-waste management and handling to cope the enormous E-waste produce in the country and further E-waste rule 2011 and E-waste rule 2015 are also being enacted to resolve the E-waste problem in the country. These laws are beyond to radioactive material management in the country. The E-waste rule 2015 is applicable on producers, marketing agencies, refurbishing centres, collection centres, dismantler and recyclers of EEEs and its components mentioned in schedule1. In this rule, the responsibilities of each stakeholders i.e. Producer, Collection centre, Consumer or bulk consumer, dismantler, other stakeholders have been defined in support of E-waste management. According to these rules, the SPCBs compliance report regarding implementation of these rules need to be furnished to CPCB latest by 30th September every year. The E-waste storage duration is permitted for 180 days and beyond it would be offensive until unless it is permitted by SPCB concerned for unavoidable circumstances.

India has signed multilateral environmental treaties as Montreal Protocols, Rotterdam convention, Stockholm convention, Basel convention, United Nations environmental programmes governing council (UNEPGC), global mercury treaty for the environmental safety in the interest of environmental safety, also. But still to ratify the Basel BAN (Basel Action Network) amendment (II/XII, COP II) is in transition because the licences to import the E-waste from USA and UK are being issued, which directly violates the provisions in article 11 in Basel convention (**Toxics Link 2009**). Further, India participated in all environment concerned conferences like Rio summit in 1992, world summit on sustainable development (**WSSD**) in 2002.

The environmental laws are being flexibly followed by all stakeholders in the country as these are not mandatory for them. For instance, the user is free to dispose it off as and when and where basis; but in developed countries every user is supposed to hand over E-waste with advance recycling fee, only to the registered recyclers as per law. In contrary, in India, the user is expecting some monetary benefit out of it instead to pay and sell it willingly to the street corner waste collectors. In India, the E-waste rules are in place but their compliance is not as fruitful for E-waste management as it needs.

The environment is defined based upon three prevailing national policies: forest policy 1988, policy for abatement of pollution 1992 and policy on environment and development 1992 in India. It encompasses water, air, land, human beings, other living creatures, plants, microorganisms and property. For the protection of all mentioned above, the environmental laws are being enacted. The E-waste management lies in the domain of environmental laws. It has become a challenging task for the law enforcing agencies because the production of E-waste is escalating in India; but most of it gets shifted in unsafe hands, besides environmental laws. The E-waste rule, handling and disposal guidelines are in place to deal with E-waste; but still, the expected results for the disposal of E-waste are awaited as it deserves. The E-waste rule are crucial because it regulates all activities for the E-waste management for the entire waste. The recyclers are being registered for sustainable E-waste treatment. However, a huge investment is required for the E-waste treating infrastructure to start with. The integration of various stakeholders for E-waste management is only possible when environmental laws are implementing uniformly in the country. It is a fundamental right of every citizen to live in pollution free environment. The Indian constitution article 48 states that 'States shall endeavour to protect and improve the environment and to safeguard the forests and wild life of the country'. However, article 21 provides the right to life and states that the degradation of environment violates the right of life. In view of that sustainable E-waste management is in great demand in the country, so that its adverse effects may be reduced to a large extent.

Besides E-waste laws, the other rules and acts are in place for human health and environment safety also; namely Wildlife Protection Act came inexistence in 1972, Wildlife (Transactions and Taxidermy) rules in 1973, Wildlife (Stock Declaration) Central Rules in 1973, Water (Prevention and Control of Pollution) Act in 1974, Water (Prevention and Control of Pollution) Rules in 1975, Water (Prevention and Control of Pollution) Cess Actin 1977, Water (Prevention and Control of Pollution) Cess Rules in 1978, Forest (Conservation) Act in 1980, Forest (Conservation) Rules in 1981, Air (Prevention and Control of Pollution) Act in 1981, Air (Prevention and Control of Pollution) Rules in 1982, Wildlife (Protection) Licensing (Additional Matters for Consideration) Rules in 1983, Environment (Protection) Act in 1986, Environment (Protection) Rules in 1986, Hazardous Wastes (Management and Handling) Rules in 1989, Manufacture, Storage and Import of Hazardous Chemical Rules in 1989,Public Liability Insurance Act in 1991, Public Liability Insurance Rules in 1991, Wildlife (Protection) Rules in 1995, Wildlife (Specified Plants - Conditions for Possession by Licen) Rules in 1995, National Environment Tribunal Act in 1995, National Environment Appellate Authority Act in 1997. It is better to understand about act, rule and law. Act is an official terminology for the proposal of the public in form of bill put up to both houses. After approval of both houses it becomes law. For the implementation of the law, certain official procedures are defined in concurrence with regulations so that approved proposal may be implemented as per need in the public domain.

For E-waste management, Basel convention is a fundamental inspiration and initiative in the world. It is introduced to check the movement of hazardous waste and its disposal across the borders. It is a United Nations treaty. It was signed on 22nd March 1989 at Basel and came in force on 5th of May 1992. Presently 185 countries ratify it. India agreed upon Basel convention on 15th of March 1990 and ratifies it on 24th of June 1992 and in India, it came in force on 22nd of September 1992.

For the effective E-waste management in the country, EPR is in place but its effectiveness is still low and hope so it will be worked out comprehensively very soon. It entails the responsibility of electronics producer till its disposal. The CPCB has worked upon a lot in bridging the informal to formal recycling by inviting all kinds of professionals on common platform and organized various seminars and conferences with the objective to disseminate the information among all stakeholders. However, the participation of non-governmental organizations is also increasing because they have conducted various consolidated studies on E-waste. With the introduction of EPR the responsibilities have shifted from municipality to original Equipment Manufacturer (**Yu and Hills 2006**). The additional initiatives of OEMs in support of EPR are also progressing. Recently Nokia, Wipro and Dell have started it in the country. Take back is inclusive of the EPR. The improvement in fundamental design of the equipment is also advancing globally and the producers are asked to comply RoHS (Restriction of Hazardous Substances) and produce green product design in the forth coming manufacturing.

In other countries like China, Japan, United States America **(USA),** Switzerland, UK, Ghana, Australia, Austria have also addressed the E-waste problem as per environmental laws provisions in their countries. But their main objective is similar to all to safeguard the environment, human health and resource exploitation. The mammoth E-waste produce has enhanced the accountability of rules and regulations for the effective and reliable management in India.

2.6. E-WASTE DISPOSAL

E-waste is being disposed of by both formal as well as informal recycling in India. The formal ways of disposal expanding steadily and lagging behind to the swiftness of E-waste produce in the country. However, the SPCBs are registering more and more recyclers to deal with escalating E-waste in the country. But, the condition of E-waste management is improving gradually. The prevailing formal recycling infrastructure is insufficient to treat the entire E-waste in the country. In view of that ample amount of E-waste remains abandoned. The informal recyclers undertake this unprivileged E-waste informally; because a sustainable E-waste management is not widened as it needs in the country. The formal disposal recycling practices are defined as per E-waste rules but in contrary, there is no defined procedure for informal recycling in the country. The informal recyclers carry out as and where E-waste treatment in uncontrolled conditions by primitive, rudimentary and least cost effective hazardous processes. The informal recyclers aim to recover particular metals and material from the selective electronic equipment and recycle them with their own ways of treatments. The hazardous processes allow the escape of toxins in the atmosphere and recover few metals in diminutive magnitude of poor quality. The outcome of the hazardous processes containing toxic metals mixes up in the air and get in the body through inhalation and dermal routes. The toxic metals are poisonous metabolically and harm the population with acute and chronic diseases. The diseases potential of toxic metals varies metals to metal and presence of its concentration at receiving end. The metals obtained after recuperation needs more refining processes for its further usage because the metals are present in a chunk of metalloids. In view of this, the disposal of E-waste is an important aspect in the E-waste management in India. The 60% of indigenous E-waste does not destine for any kind of recycling and remains either in landfills or in municipal waste. In view of that the informal and formal recycling treats 40% indigenous E-waste in the proportion of 95 to 5% in the country **(Khatter 2007 and Raghupathy 2009).** In recycling process 95% E-waste is being used for the refurbishment and only 5% undergoes disposal process (**Khatter 2007**). The informal E-waste recycling promotes the recovery of few materials only, while formal recycling recovers majority of materials from E-waste. The informal processes of reclamation of material from E-waste are in trend in the backyards asopen burning for base metals, acid leaching for precious metals and open melting for plastics. The sustainable methodologies for the recovery and recycling of material out of it are well defined for formal processes. By and large the formal recycling promotes the local mining of the material out of E-waste because it saves enormous energy to be consumed for the recovery of virgin material. The quantity of E-waste with the demand of local mining material is increasing in the country simultaneously because it is cheap and meaningful in all respect. The energy saving profile of few materials is presented in **Figure** 7. It shows the energy saving when these are mined locally. It will lessen the exploitation of resources, reduce the human resources application and check the spreading of pollutants in the ambiance.

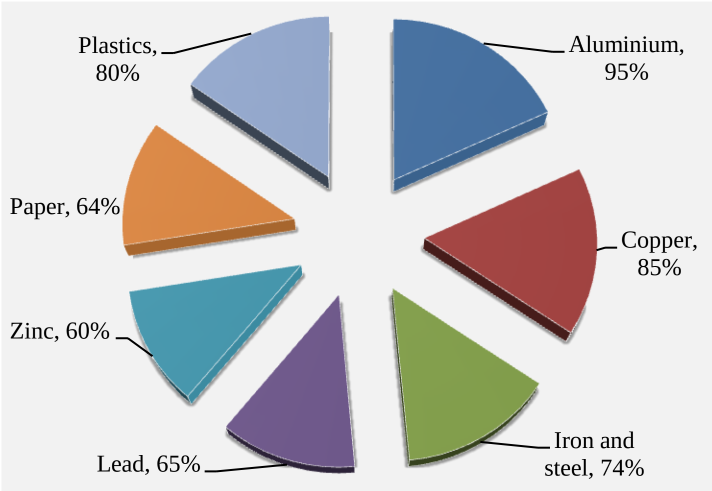


Figure 7: Energy saving percentage by recycled material (Cui 2003, ISRI 2003)

The local mining of material saves energy as 95% for aluminium, 85% for copper, 74% for iron and steel, 65% for lead, 60% for zinc and 80% for plastics (**Cui 2003, ISRI 2003**) respectively.

The informal recyclers get the E-waste from local waste collectors at very least price and recover the targeted metals like copper, aluminium, iron and steel with rudimentary and primitive methodologies and produce a huge amount of pollutants. The evolution of pollutants per ton of the metal recovery is a great concerned as it enhances the pollutants loading on the environment. The CO_2 emission for primary production of metals is presented in **Figure 8**. They are using open burning, acid leaching for the recovery of metals, which are non-environment friendly methods.

The recovery of materials is set to be a lucrative business and acts as feedstock for the manufacturing of the new equipment, which is going to meet the user equipment demand at very cheap rate (**Research Unit 2011).** The state of the art is available to recover maximum metals from the e-waste equipment easily. Umicore in Belgium, Boliden in Sweden and Attero in India are the appropriate examples recovering gold up to 99% **(MoEF 2008)** out of E-waste**.**

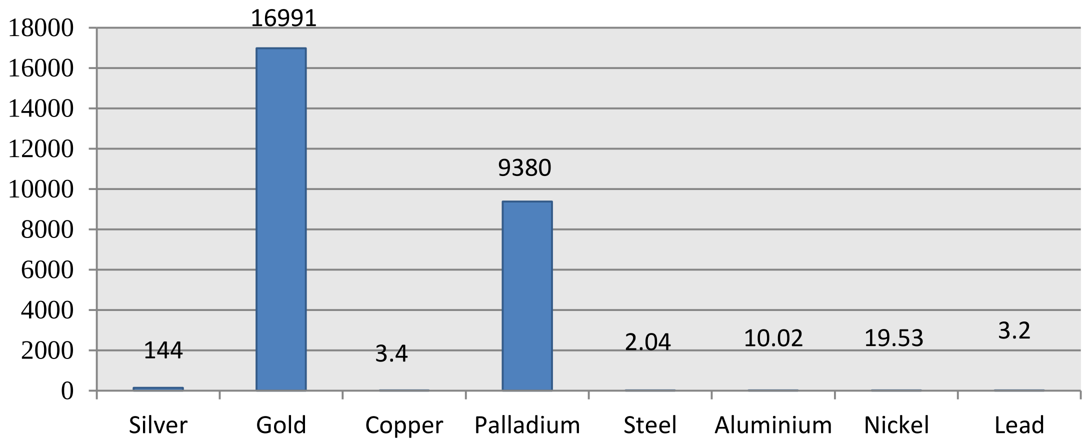


Figure 8: CO_2 Emission for primary production per ton of metals (**Frederik 2011**)

The formal recycling in the country is in the transition and CPCB is registering recyclers every year and presently registered 138 E-waste dismantlers and recyclers for the treatment of 3,49,154.6 MTAE-waste produced in the country (**MoEF 2016**). The registered recyclers have to comply with the E-waste management guidelines and adhere to rule 2012 while treating E-waste. A fixed quantity of e-waste is being allotted to them, **Table 7**; however, they are not getting it easily and always strive to get it from import channels so that the state of the art facility may be run at absolute load.

The informal recovery system is low environment efficient comparably to the formal in terms of the state of the art technology. For example: for the recovery of 1g gold and 6g of silver, the informal recyclers are using more than 50 litres water, 3 and 21 Kg Chemicals and explode 1.3g and 3g of mercury in the environment due to uncontrolled treatment (**Keller 2006**).However, the metal yield by using chemical processes10 to 20% more if it is carried out formally **(Keller 2006)** but they are not carrying out it in the ambit of environment sound management. The e-waste inventory for discarded equipment is not managed properly and only focal equipment are considered for further treatment processes. The inadequate record keeping by all E-waste stakeholders made it tedious task. It is unsafe to plan infrastructure based upon the tentative data of E-waste inflow as huge investment and management is required to run the facility.

Table7: Registered Recyclers and permissible E-waste quantity (CPCB 2014)

Sr. No.	States	Recyclers (Nos.)	E-waste Allotted in MTA*
1.	Rajasthan	09	67470
2.	Karnataka	52	50318.5
3.	Haryana	13	47225
4.	Uttar Pradesh	11	43150
5.	Tamil Nadu	14	38927
6.	Maharashtra	22	32180
7.	Uttrakhand	04	28150
8.	Gujarat	07	20849.12
9.	Madhya Pradesh	02	6585
10.	Andhra Pradesh	02	11800
11.	Chhattisgarh	01	900
12.	West Bengal	01	600

***MTA (Million Ton per Annum)**

People should look forward to hand over the E-waste to the registered recyclers rather than treat it themselves otherwise they would be victimized by the toxic and hazardous substances in the e-waste. However, for the informal recyclers, research scholar are striving to get environment friendly, low cost, effective, handy e-waste processing and treating techniques (**Sepulveda 2010**). New techniques may bridge the informal and formal processing methods and environmentally sound e-waste management may be established easily.

2.6.1. Formal E-waste Disposal Practices

The E-waste rule 2015 has specified that each stakeholder will comply with the guidelines mentioned for handling and management of E-waste 2008. A road map has been prepared for the registered recycler while carrying E-waste recycling in the country. The guidelines have separate provisos for individual electronic equipment as well as mixed E-waste.

In CPCB guidelines 2008, the environmentally sound management has been suggested by SPCB to deal with the E-waste in the country. It treats in phase manner and divided in to various activities. For each activity and material the treatment is different. The objective of the strategy is to dispose of the E-waste in sustainable and environmental friendly manner through viable infrastructure exhibits controlled conditions and adhering to the occupational health norms suggested by Occupational Safety and Health Administration **(OSHA**). The treatment of e-waste is well monitored by the SPCB time to time and adequacy report of the installed infrastructure is being scrutinized on regular basis by the SPCB. For comprehensive treatment, the e-waste undergoes various stages of treatments i.e. 1^{st} Level, 2^{nd} Level and 3^{rd} Level treatments to E-waste equipment.

***1^{st} Level Treatment* (MoEF 2008)**

In 1^{st} level treatment the e-waste is being decontaminated, dismantled and segregated. The decontamination process involves making all items non-hazardous by withdrawing all liquids and gases from the equipment and storing them separately at safe place in isolatable form. In dismantling, the components are being removed safely by manually or mechanised arrangements. The segregation process separates the hazardous and non-hazardous items of E-waste so that these are put to next processes, **Figure 9**. The first level treatment is significant because it converts the E-waste into manageable form as it is received in various shapes and sizes from various sources in dilapidated condition. The Large sized equipment are easy to segregate from mingled waste. While carrying out the dismantling of the equipment, the safety precautions should be taken into account so that any health hazard may be obviated easily. In each activity, the outcome is also important because is mandatory to the recyclers to accommodate remedial measures for them also. In decontamination as such only hazardous items breakages is handled and from intact equipment foreign material is removed to make safe the equipment, so output of decontamination is non-hazardous equipment and components. In dismantling, the toxins laden air emissions, noise, contaminated soil caused by spillage of toxins and hazardous E-waste fractions are the output of this activity.

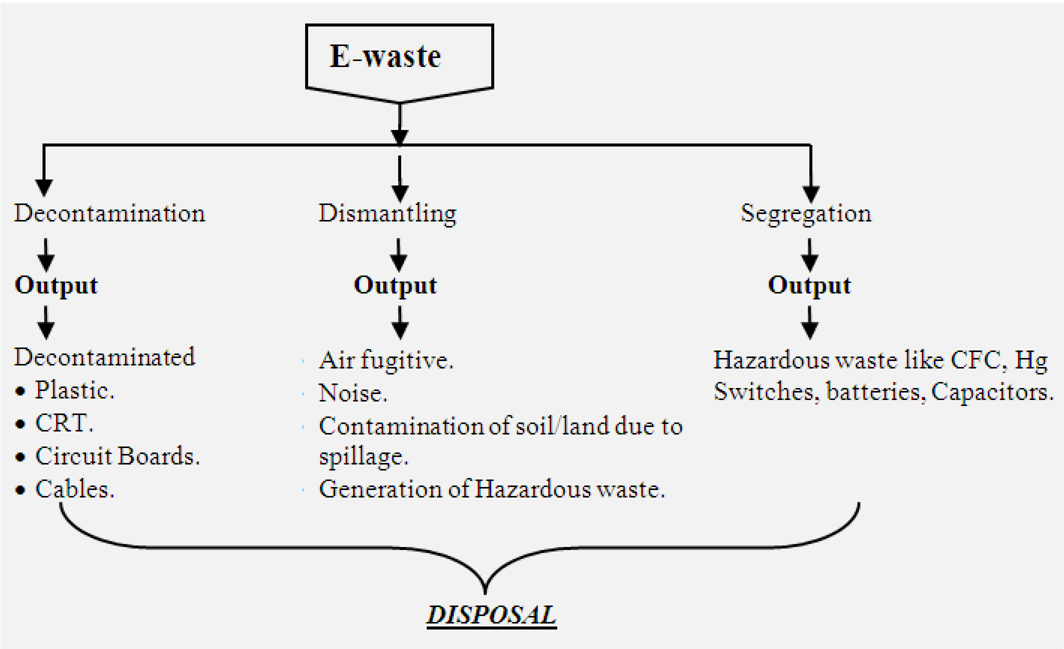


Figure 9: 1st levels E-waste treatment (MoEF 2008)

Similarly, in segregation, hazardous components and non-hazardous components are the outcome of this activity. The hazardous waste handling is troublesome because it is encapsulated in the components and damages the human health. In view of that third process named segregation; isolate the items from the dismantled material is essentially required. It mitigates the spreading of the toxic material in the environment, **Figure 9**. The output disposal of 1st treatment becomes the input of 2nd

level treatment in the form of intact and staggered equipment and components and residue of mixed hazardous E-waste. For the execution of 2nd level treatment, the activities in 1st level treatment are essentially required because it aligns the E-waste according to the suitability of 2nd level treatment.

2nd Level Treatment

It is carried out with the aim to put up the material in different arrays for its further recovery from equipment. It includes hammering, shredding and specific treatment processes. The hammering process reduces the size of the equipment as per need to feed into the infrastructure and make all manageable. The shredding process reduces the size of the equipment by shredding the equipment into small pieces instead of compressing it. However, the sizes of the pieces vary with the equipment size because after shredding somehow it is compressed for the reduction the size of the equipment. Also, the specific treatment processes are involved like CRT treatment, electromagnetic separation, eddy current separation and density separation using water with the aim to separate various material of the equipment, fig 10. All processes are concurrently applied to the waste containing CRT in E-waste depending upon the necessity for further processes.

CRT Treatment

In CRT, the open treatment is not feasible because the phosphor used in the interior coating is harmful and spreads in the environment as it is maintained in vacuum in the CRT. CRT is a fundamental part of TV and PC, **Figure 11**; however CRT is upgraded to LCD in TV and PC. In CRT, lead, phosphors, antimony and mercury are hazards prone material. In view of that its disposal is of much concerned for the E-waste management.

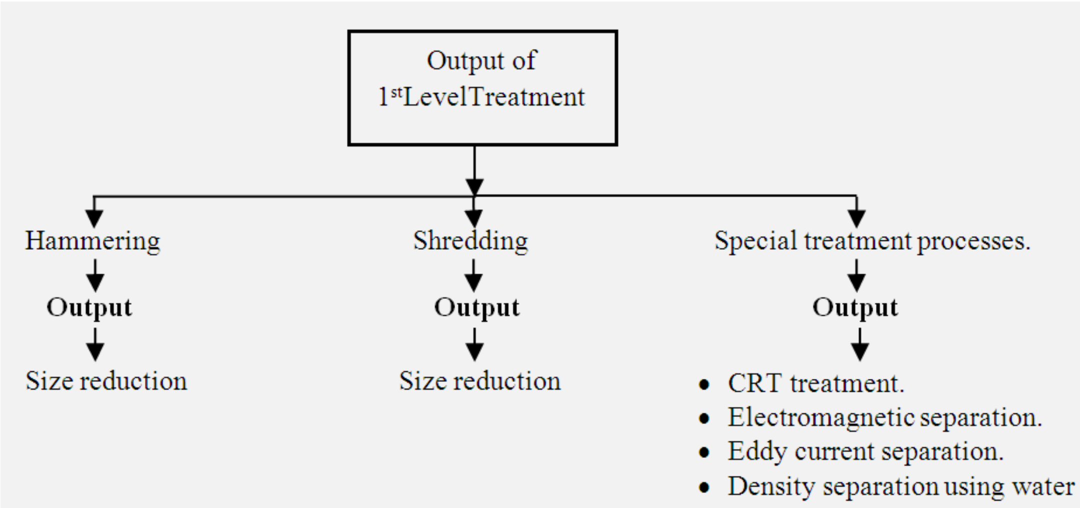


Figure 10: 2nd levels E-waste treatment (MoEF 2008)

The treatment of CRT starts from removal of funnel, screen glass, plastic casing of wooden casing. The CRT splitting technology namely NiCrome hot wire cutting, thermal sock, laser cutting, diamond wire method, diamond saw separation and water jet separation are being used depending upon its feasibility.

Figure 11: Discarded CRT of TV and PC Monitor

The glass cullet is obtained after CRT recycling unit operations. The CRT manufacturers in India retrieve material from the discarded CRT as panel glass. The various activities performed are being presented in the flow diagram of this technology in **Figure 12**. In the recycling of other material like plastics, precious, base and toxic metals other mode of operations are employed for the preparation of feed for the hydrometallurgical processes of assessment and recovery. Hence all toxic based material needs isolation first and then respective treatment. The CRT is cut and cleaned with HNO_3 and separate it from effluent and then cut by any of process such as thermal shock, Nicrome, hotwire cutting, laser, laser jet or diamond saw cutting and separated funnel and panel. The panel is further treated with Acid and separated from effluent and finally get panel glass. For funnel, an acid cleaning is carried out and got the funnel glass.

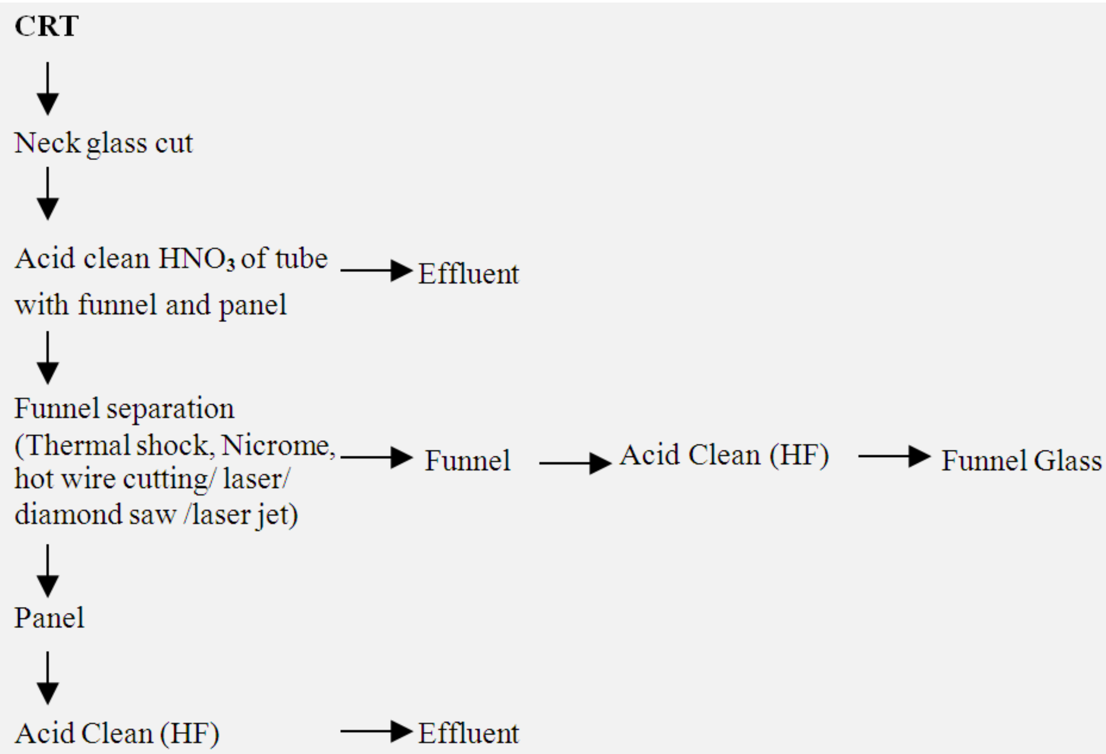


Figure 12: CRT treating operations

Magnetic Separation

It separates the magnetic contents from the mingled waste stuff. The mixed material is powdered and put on the moving belt moving over the magnetic roller. The magnetic material gets collected in magnetic bin and rest in the non-magnetic bin, **Figure 13**.

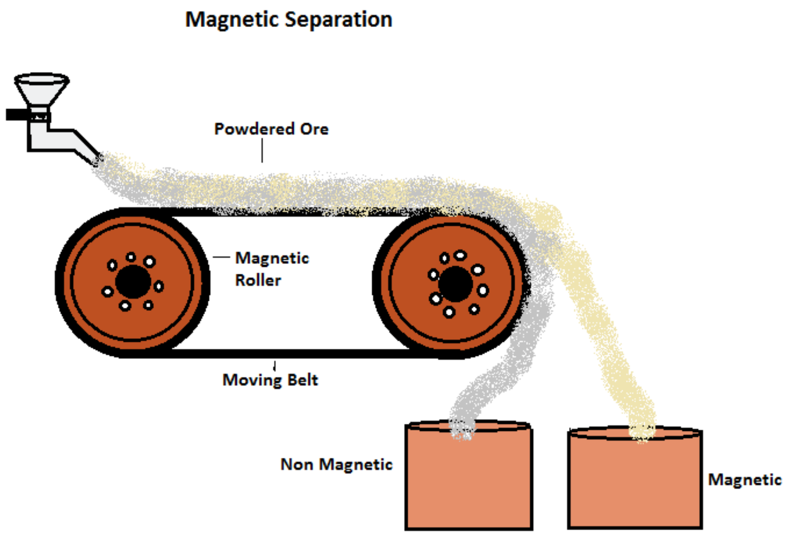


Figure 13: Magnetic separation process

Eddy Current Separating Process

The eddy current separates the non-ferrous metals namely copper, aluminium, zinc and other metals, whose grain size is more than 1 mm. The magnetic rotor maintains the frequency 12000-30000 Hz and designed speed.

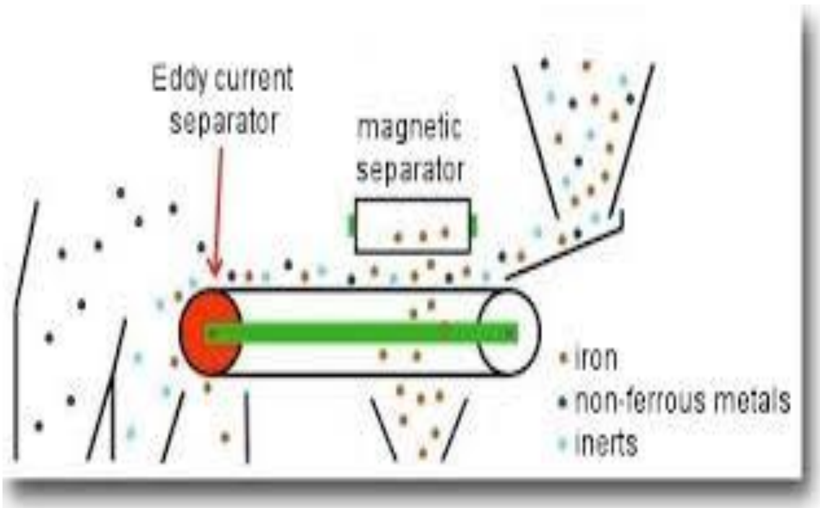


Figure 14: Eddy current separating process

The magnetic conveyor belt carrying heterogeneous waste push forward the non-magnetic material by eddy current and separates it from the magnetic material, **Figure 14**.

Density Separating Process

From the mingled E-waste powder the material is separated by density separation using water as a flux because each mineral has its own density and grain size.

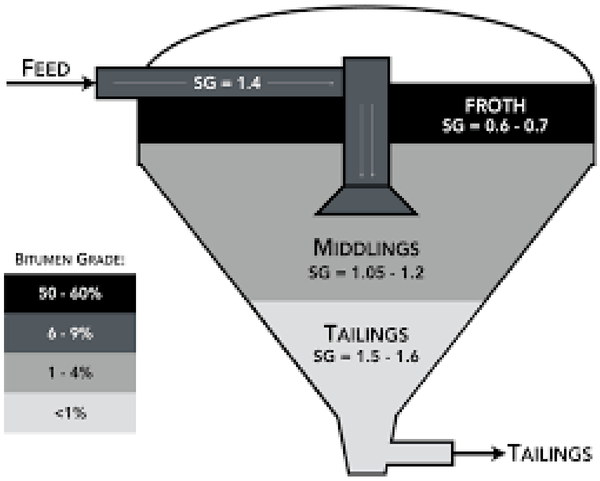


Figure 15: Density separating process using water

The range of the densities may be divided in three zones as upper, middle and lower. The densities of the material in the stuff will facilitate in settling the concerned material at that level. If the mineral has density and grain size to the liquid used as flux then the mineral will float on the liquid and vice-versa, **Figure 15**.

The provisions discussed above are capable to deal with E-waste comprehensively to deal with E-waste containing CRT a predominant material including others.

3rd Level Treatment

In the continuation of the E-waste treatment processes, the Non-CRT material also presents in the waste and need processes for further treatment. The processes discussed in the 2nd level treatment are universally applied wherever required because it isolates the material easily from the mixed grounded material. The material encompasses metals and non-metals both except CRT. The E-waste is pre-pulverised for rough liberation out of it. The traditional methods such as magnetic separation and eddy current separation are being applied to separate the ferrous and non-ferrous metals on intimately grounded mixed E-waste and separated copper, iron, aluminium, silver, gold and other precious metals. Since, the E-waste is mixed containing plastics also in addition to the metals.

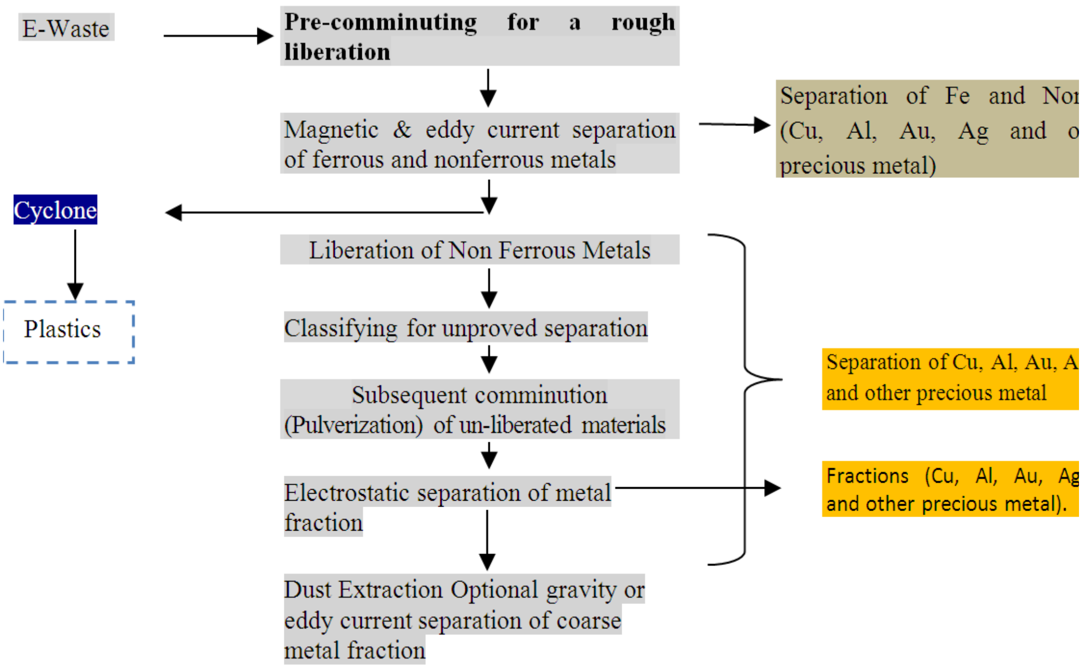


Figure 16: Process flow of non-CRT based E-waste treatment (MoEF 2008)

The plastics contents cannot be separated by as usual methodology as used for metals. In view of that the residual material containing plastics is put in the cyclone and separated the plastics from the mixed material of E-waste. The ferrous and non-ferrous metals are not available in the elemental form and available in metalloid. The liberated non-ferrous metals are further classified, pulverised and comminute subsequently and separated by hydrometallurgical processes including from dust and coarse metals collected from eddy current separation. The mix is treated by electrostatic separation for the precious metals recovery, **Figure 16.**

The non-CRT material has also material recovery potential and need to be treated accordingly. Apart from eddy current separation, magnetic separation etc. the e-waste feedstock is treated with incineration; refining, smelting and distillation to get heat energy and concentrated metals. The techniques are available with developed Nations to recover recyclable material like plastics, ferrous metals, non-ferrous metals and their efficiencies are high and but varies material to material. For example magnetic separation achieves a material separation target of ferrous metal up to 95% and eddy current separation method separates 90% non-ferrous metals from E-waste **(MoEF 2008).**

2.6.2. E-Waste Informal Disposal Practices

The informal recycling has large space countrywide in E-waste management. The backyard recycling treats maximum E-waste in the country. The informal E-waste recycling over rules the standard guidelines and laws for the E-waste treatment. The ground conditions are pathetic, spreading nuisance in the ambiance. The informal recyclers use their own methodologies to recover metals from the E-waste. These methods are of least cost effective and hazards prone to all. It includes open burning and acid leaching. The informal recyclers promote the recovery of few metals from selective equipment and least bothered about the other metals, equipment and environment. These informal E-waste disposal practices of E-waste are unsafe and unregulated causing environment sickness. The informal recycling intensifies the presence of persistent organic pollutants around the treating sites as well as on far off places because toxins migrate according to their specific gravity.

The lawless E-waste management in India has attracted the attention of one to all. The informal recycling is held responsible for this act of hazardous activities; but the involvement of public in its promotion cannot be ignored because public is disposing off the discarded electronic equipment blithely in the locality and provides an access to it. Hence, the informal recycling thrives on the public attitude. However, the lack of defined system to collect the E-waste is also time demand because there is no demarcated place for the E-waste in the locality and further, no arrangement to lift it off for succeeding course of action also. In view of this, the users either keep the discarded equipment in their possession or handover it to the corner side street-side collectors. In India, a huge quantity of uncared E-waste is available and only 40% of it is reported and 13% is being recycled by the informal agencies at its own arrangements.

In the informal recycling, the copper metal is always on focal because recyclers are allegedly greedy for it. After the recycling of intended metals and other material, the remnants let burn in open with abandoned waste. The intact components of the electronic equipment are being used in refurbishing.

Recycling

Recovery

Reuse

Dismantling

Segregation

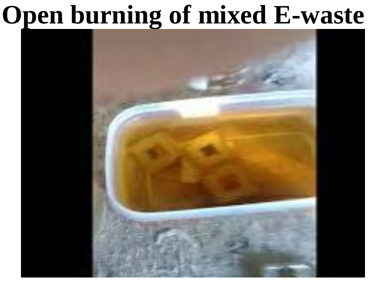
Refurbishment

Figure 17: Options prior to incineration

The refurbished electronic equipment market has potential to provide equipment at low price. The recycling and recovery of materials from E-waste have become essential as it provides not only functional components but metals in ample quantity also. However, the quality of metals is inferior as to the virgin. The material if not so happened to be recovered impacts on the environment in terms of water resources contamination, air pollution, soil degradation and always fears of inclusion in food chains. The recycled components make functional the equipment at least cost and fulfil the rising demand of same components in the market.

It supplements in the overall life the equipment and releases the burden on natural resource to be consumed in the manufacturing of new components of same specifications. The informal recycling exploits the all resources of the discarded electronic equipment. The processes are involved in this gamut are recycling the refurbishment, **Figure 17.**

Open burning of mixed E-waste **Open burning of E-waste cables**



Acid Leaching

Figure 18: Hazardous methods of E-waste disposal

The informal recyclers are using primitive and rudimentary disposal methods for E-waste like open burning for the recovery of metals: copper, aluminium, steel and put rest of the material like plastics, PCBs, ceramics, asbestos, which are of hazards prone attributes in nature and during incineration/ open dump burning, the toxins explode in the atmosphere. Some of the hazardous ways to deal with E-waste are shown in **Figure 18**.

2.6.3. Metals Recovery Opportunities

In E-waste, enormous metals are available. These metals are recoverable to a large extent. The viable technology can recover them to a maximum. It is giant source of precious, base and toxic metals. The local mining of these metals from E-waste is professionally lucrative. The toxins in E-waste are in concealed along with precious and base metals. Hence, the toxins containing items are to be segregated and isolated from the E-waste manually and put forth for recovery; it includes batteries, CRT-Glass, LCDs, encapsulated metals and plastics **(Cui and Forsberg 2003 and UNEP 2009).**The toxins in the equipment component are treated as per their characteristics separately by their methods of treatments. For example mercury containing components are normally treated in specialized mercury recovery facilities or authorized hazardous waste incinerators having modern flue gas cleaning systems **(OECD 2003)**. However, E-waste undergoes through other mechanical processes like shredding, grinding, magnetic and eddy current separation, which are the primary requirement of recovery of material from equipment as shown in **Figure 19.**The recovery of metals from E-waste is demanding these days as various technologies are available in abroad, successfully recovering metals in abundance.

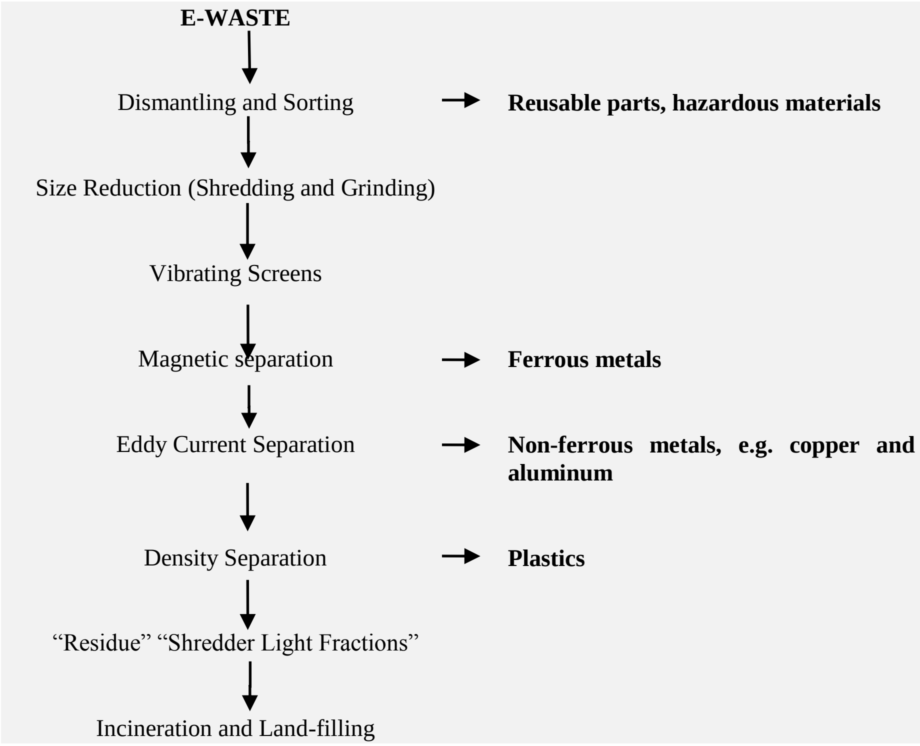


Figure 19: Schematic of the first step in a typical E-waste recycling

One of the famous facilities in abroad for the recovery of copper and precious metals is presented in **Figure 20**. In India, the use of these technologies is also progressing steadily. However, still the majority of informal recyclers carrying out E-waste recycling for developed countries and dispatching the material to abroad located/commissioned facilities for metals recovery. The E-waste cost overrun for its recycling is less comparably due to the availability of cheap human resources in India. In view of that the developed countries prefer to dispatch E-waste to India for its further treatments and the people in the country take it as an opportunity and made it a source of livelihood. The profile for dismantling and sorting varies according to the scale of the operations required as small for manual and large to the automated operations are desirable to deal with the E-waste. Ideally, for further refining of metal fractions, initially the pyro-metallurgical process is used followed by hydro-metallurgical processes. However, the hydro- metallurgical process may also be used as alternate process in place of pyro-metallurgical process since it consumes less energy and it is exact and more predictable and easy to control during operation. Both processes are in use since more than two decades and followed by electrolytic refining.

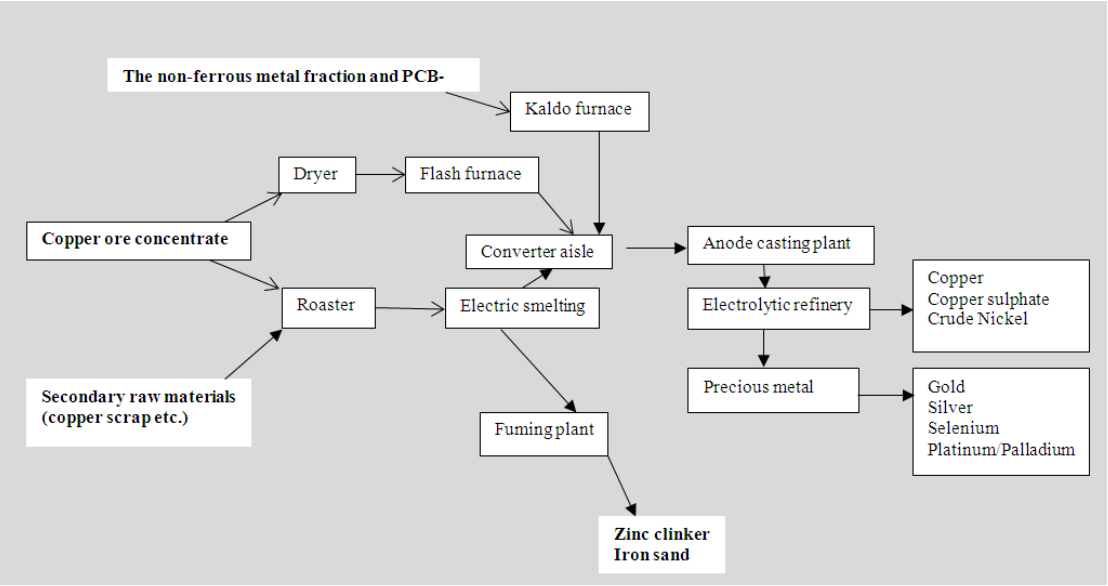


Figure 20: Schematic processes used to recover copper and precious metals from ore concentrate, copper scrap and E-waste (Boliden 2010).

For example, for the recovery of non-ferrous metals and precious metals, pyro-metallurgical processes in copper smelter is used and further refining electrolytic process is used **(Cui and Zhang 2008)**. The recovery of metals achieved by this process is 99% and the remaining 0.9% in electrolyte is treated with acidic solution to recover the metals from electrolyte. This kind of smelters are in place in Boliden in Sweden, Umicore in Belgium, Noranda in Canada, Norddeutsche Affinerie AG in Germany **(Allsopp 2006)** and Dowa Eco-System in Japan **(IGES 2009).**The flow diagram of the facility functioning is shown in the **Figure 20.**

In this facility the non-ferrous metal fractions and PCB, copper ore concentrate and secondary raw material are treated. The non-ferrous metals are feed to Kaldo furnace and its output to converter aisle and further to anode casting plant. The anode casting plant, by electrolytic refining, it yields copper, copper sulphate, crude nickel, gold, silver, selenium, platinum and palladium. Similarly the copper ore concentrate has two options of treatments. In first option, it is dried and put in the flash furnace and further to converter aisle. In second option, it is roasted and put further to electric smelting. From the electric smelting the mixed zinc and iron are being recovered as clinker through fuming plant. The remaining material obtained from electric smelting is put in converter aisle and from this pool it is shifted to anode casting plant and similar yield is obtained in the form copper, copper sulphate, crude nickel, gold, silver, selenium, platinum and palladium as most of the metals are metalloids. For the secondary raw materials, it is first roasted and put to electric smelting, and then fuming plant to get zinc clinker and iron sand. The remaining material is again routed to converter aisle and further to anode casting plant and finally get copper, copper sulphate, crude nickel, gold, silver, selenium and palladium.

These are the following main steps in hydo-metallurgical process treating the solid material with caustic or acids caused leaching of the material resulting the reduction in grain size of the material and facilitate more metal yields from the material. The leaching solvents are commonly used namely cyanide, thio-urea, thiosulfate, and sodium hydroxide and acids such as aqua-regia, sulphuric acid, nitric acid, and hydrochloric acid. After treatment, the metal of interest is isolated from the solution and concentrated by applying any of the suitable methods like the solvent extraction, precipitation, cementation, adsorption, ion exchange, filtration and distillation **(Cui and Zhang 2008, Antrekowitsch 2006).**

The plastics has potential to be recovered from E-waste as similar to metals because it has high economic potential for recycling **(Kang and Schoenung 2005)**. However, it has limited scope in India as merely 25% of plastics is being recycled because presence of numerous polymers and additives made it very complex materials **(Schlummer 2007).** The different products and quality of plastics are separated from the e-waste and subsequent separation is being made by using the following techniques like sieving, density separation (in various aqueous or non-aqueous media), electrostatic separation (e.g. tribo-electric separation) and air-separation, in combination with various size reduction steps, such as grinding, milling and granulation **(Kang and Schoenung 2005)**. The foreign material in plastics is separated by performing the following techniques magnetic separation, eddy current separation and air-separation. The plastics so obtained are used in the manufacturing of new plastic products. However, the attempts are made to transform the plastics into coke, coke oven gas and other chemicals by using pyrolysis and depolymerisation techniques as alternative recycling methods **(Kang and Schoenung 2005).** Also, the plastics is being used both for heat and energy recovery system and acts as a fuel and reducing agent in the smelter process and replaces some of the coke used for the purpose **(Kang and Schoenung 2005, Schlummer 2007).** However, it contradicts in the abatement of pollution resulting from the process as the formation of dioxin and furan in the ambience.

In the developing countries, the informal recyclers are inviting health hazards not only for engaged workers but to the environment also. During recycling they use rudimentary and primitive methods to recover the targeted metals like copper, steel, plastics, aluminium etc and leave behind the precious metals either in the waste or in ash due to lack of awareness about the recovery of precious materials by new technology and techniques. These activities are carried out in small workshops or just outdoors **(BAN and SVTC 2002).** They do not have any control over the process/ emission generated from the combustion of E-waste and causes various kinds of diseases to human body and other creatures.

2.7. E-WASTE HAZARDS

The E-waste treatment by hazards prone processes invited toxins hazards to air, water, soil, and ecology as it causes a range of acute and chronic diseases to the creatures because it supplements the persistent organic pollutants in the environment continuously. The electronic equipment contains toxic metals besides precious metals in varying magnitude. The informal recycling exposes personals to high levels of toxins namely as lead, mercury, cadmium and so on. It leads to irreparable damage to their health; causing cancers, miscarriages, neurological damage and diminished intelligence. The toxic metals oxidised as well as leached easily. The informal E-waste recycling allows both conditions while accomplishing open burning. The E-waste costs heavily in terms of both environment and budget management as the equipment obsolete in short duration and replacement happens frequently and need further revenue for its disposal also. It is part of affectionate towards consumerism in day to day life. The unmonitored backyard recycling and illicit land fill sites cause substantial damage to the environment. The unregulated informal recycling and recovery processes in the developing Nations like India, China are the vulnerable in the abatement of pollution generated by the E-waste because the presence of heavy metals alone responsible for its hazardousness. They carry out the recycling and recovery in closed small workshops cause occupational health hazards or dump the leftover after recovery of intended material. This open burning of E-waste with heavy metals penetrate in food chain, spoil our aquifers, spoil underground water reserves, decrease the fertility of soil. These are persistent organic pollutants and remain in atmosphere years together and harming the ecology continuously. Even in the controlled and perfect recycling there is speculation of heavy metals leakage. This section will describe the hazards aspects involved for the e-waste treatment and disposal.

2.7.1. E-waste Recycling Hazards

In developed Nations, the integrated facilities are in place to carry out recycling of E-waste and keep exposure level of pollutants minimal. The environmental laws are stringent and E-waste recycling is expensive in these countries. In view of that a large part of E-waste is being dispatched to the developing countries. However, the informal recyclers are part of this speculation also. , they are dumping this waste in the developing countries to get it recycled as the labour required for the recycling is much more cheap in these countries. The developing countries without any infrastructure are treating the e-waste generated indigenously as well as dumped by developed Nations and are most effected due to e-waste rudimentary and primitive treatment. However due to international effort as Basel Convention and new technical development like RoHS decreased the use of hazardous substances in E-waste but still there are some hazardous substances remained in the E-waste. Due to their presence, always there is a possibility of hazards. It encompasses hazards during collection and dismantling, mechanical shredding and separation, pyro-metallurgical processing, hydro-metallurgical processing, recycling of plastics, manual dismantling and recovery of valuable materials, acid extraction of metals, melting and extrusion of Plastics, burning of plastics and other materials, dumping of residual materials, Soil and sediment contamination, Water contamination, Air contamination, Human exposures and health effects .The informal E-waste recycling has occupational as well as environmental risks while it is carried out in controlled and uncontrolled conditions.

Table 8: Risks Associated with E-waste (SWEDISH Report 6417 2011).

End-of-life process	Occupational risks	Environmental risks
In Traditional E-waste handling		
Land-filling		Leakage of metals (e.g. Pb, Cu, Ni, Sb, Cd, Zn) and organic compounds (e.g. BFRs, plasticizers).Evaporation of Hg and MeHg.
Incineration		Emission of various metals and organic compounds via exhaust gases (e.g. dioxins, BFRs, PAHs, Cu, Pb, Sb).Leakage of various compounds from ashes (e.g. dioxins, Cu, Pb, Sn)
In Controlled recycling		
Collection and Dismantling	Dust containing various compounds during dismantling activities. Dust containing Pb and Ba-oxide from broken CRTs, Cuts from CRT glass in case of implosion. Volatile compounds (e.g. Hg) from broken components.	Emissions of volatile compounds (e.g. Hg) from broken components.
Shredding	Dust containing various compounds (e.g. BFRs, TPP, phthalates, Cd, etc.).	
Pyro-metallurgical Processes	Dust and fumes of the shredded material and the melting process, containing various compounds (e.g. Pb, Cd, Hg, Be, BFRs, dioxins, TPP, phthalates).	Emissions of various metals (e.g. Pb, Cd, Hg, Be) and organic compounds from the melting process (e.g. BFRs and dioxins).
Hydrometallurgical Process	Acid fumes containing various hazardous compounds	
Plastic recycling	Dust and fumes of various chlorinated and brominated compounds (e.g. BFRs and dioxins), and some metal additives (e.g. Cd)	Emissions of various chlorinated and brominated compounds (e.g. dioxins) from the thermal processes used.
In Uncontrolled recycling		
Collection and Dismantling	Dust containing various compounds during dismantling activities, e.g. Pb and Ba-oxide from broken CRTs. Cuts from CRT glass in case of implosion. Volatile compounds (incl. Hg) from broken components.	Emission of dust and fumes containing various metals (e.g. Pb, Zn, Cu, Sn, Sb, Cd, Ni, Hg) and organic compounds (e.g. BFRs) to the local environment.
PC-board heating	Exposure to fumes of various compounds from solder and PC-board components (e.g. Pb, Sn, BFRs and dioxins)	Leakage of various compounds (e.g Cu….) from dumped PC-board residues.
Toner sweeping	Exposure to toner dust including carbon black.	Leakage of various compounds from emptied and dumped toner cartridges.
Acid extraction	Exposure to acidic fumes containing various hazardous compounds.	Leakage of various metals (e.g. Pb, Sn, Cu, Sb, Ni, Hg, Ba, Cd) and organic compounds (BFRs, phthalates, TPP, dioxins) from dumped residues of the extraction process.
Shredding	Dust and fumes of various metals and organic compounds present in the plastics (e.g. BFRs, phthalates, TPP, Cd, etc.)	Emissions of dust containing various plastics Components to the local environment.
Plastics and waste Burning	Exposure to a wide range of metals (incl. Cd, Cu, Pb, Zn, Sb) and organic compounds (incl. PBDEs, PAHs, PCBs, dioxins) via smoke.	Emissions of a wide range of metals (incl. Cd, Cu, Pb, Zn, Sb) and organic compounds (incl. PBDEs, PAHs, PCBs, dioxins) to the local, regional and global environment.
Dumping of residual materials	Exposure to dust and fumes, containing various compounds, from dumped materials. Secondary exposure via contaminated drinking water and food.	Leakage of various metals and organic compounds to the ground and water reservoirs in the surroundings

It is very risky to handle E-waste in general as it causes various diseases due to leakages of metals in the environment. In India, traditionally E-waste is either land filled or incinerated in open. In view of that the toxins escape and cause damage to the environment continuously as these are persistent organic pollutants, remain years together in the environment. In controlled conditions, E-waste undergoes through dismantling, shredding, plastic recycling, hydrometallurgical process, pyro-metallurgical processes and cause emissions of various chlorinated and brominated compounds from the thermal processes, various metals and organic compounds, volatile compounds. Similarly in uncontrolled conditions, the informal E-waste recyclers undertake the metals recovery and other non-friendly activities by acid extraction, toner sweeping, pc-board heating, shredding, dumping of residual materials, plastics and waste burning and cause environment sickness. **Table 8** shows the hazards associated with EOL process, occupational and environmental hazards created by traditional waste handling, controlled recycling and uncontrolled recycling.

The exposure to hazardous compounds takes place more while inhalation of fumes and dust. In the ambience of treatment facility, these POPs are affecting the residents continuously and it is observed in Guiyu China that children are suffering from respiratory diseases, skin infections, and stomach problem **(Leung 2006 and Sepulveda 2010).** The **Table 9** shows the individual effects of these hazardous compounds present in e-waste.

2.7.2. Hazardous Compounds Effects on Mammalians.

The hazardous processes are producing enormous pollutants while carrying recovery of material from E-waste. The personals are getting exposed to these pollutants because the informal recycling is accomplished barely by innocent people.

Table 9: Hazards associated with metal/acid/compound and their sources (Poonam 2012)

Metal , Acid, Compound	Source and Associated Hazards.
Lead	Mechanical breaking of CRTs, removal of solder from microchips. Being a neurotoxin affects the kidneys and the reproductive system, mental development in children.
Mercury	Breaking and burning of circuit boards and switches, microbial activity. It affects the central nervous system, kidneys and immune system, impairs foetus growth and harms infants through mother's milk and can enter the human food chain through aquatic.
Cadmium	Crushing and milling of plastics, CRTs and circuit boards. Being a carcinogen, causes itai-itai disease, affects the kidneys and softens bones.
Plastics	It is found in circuit boards, cabinets and cables all contain carcinogens. BFRs or brominated flame retardants emit carcinogenic brominated dioxins and furans. Dioxins can harm reproductive and immune systems.
Chromium	It is used to protect metal housings and plates in a computer from corrosion. The Chromium(VI) can damage liver and kidneys and cause bronchial maladies including asthmatic bronchitis and lung cancer.
Beryllium	It is found in switch boards and printed circuit boards. It is carcinogenic and causes lung diseases.
Acid	The sulphuric and hydrochloric acids are used to separate metals from circuit boards. Fumes contain chlorine and sulphur dioxide, which cause respiratory problems. They are corrosive to the eye and skin.
Beryllium oxide(Beryllia)	They are very toxic and may cause cancer by inhalation.
Beryllium metal.	It is very toxic, may cause cancer by inhalation. However, Beryllium component scrap is classified as non-hazardous in the OECD, Basel and EU regime.
Selenium	It exposure of high concentrations can cause selenosis.
Polychlorinated biphenyls (PCBs)	It is used as dielectric fluids, heat transfer fluids, additives in adhesives and plastics. It causes cancer in animals; also effects on the immune system, reproductive system, nervous system, endocrine system.
Dioxin and Furan	These are the by-products in the manufacture of substances like some pesticides as well as during combustion. Dioxins bio-accumulate in the body and can lead to malformations of the foetus, decreased reproduction and growth rates and cause impairment of the immune system among other things .
Brominated flame retardants (BFRs)	The flame retardants make materials, especially plastics and textiles, more flame resistant. It releases halogenated case material from printed wiring boards combustion at lower temperatures and cause severe hormonal disorders.
Arsenic	It is a poisonous metallic element and its chronic exposure can lead to various skin disease, decrease nerve conduction velocity, cause lung cancer.
Barium	It is used in sparkplugs, fluorescent lamps and getters in vacuum tubes. It is highly unstable in the pure form and forms poisonous oxides when in contact with air. Its short-term exposure can lead to brain swelling, muscle weakness, damage to the heart, liver and spleen.

The pollutants get into the human body through dermal contact, ingestion and inhalation pathways, **Figure 21**. In dermal contact it comes in the contact of skin and eyes. Similarly, in ingestion, the pollutants find way to gastro intestine (GI) tract and in inhalation the pollutants are inhaled and reach to the lungs directly. The pollutants with intrinsic toxicity activate metabolisms system. It interacts with other parts of the body and initiates toxic effects everywhere in the body. The physiological changes in the body takes place may be in CNS, injury to the reproductive system, interaction with nucleic acids leading to carcinogenesis. The damage or changes depends upon the concentration of pollutants. The action of toxicants may cease storage, biotransformation or excretion. Besides human body the pollutants affect the soil also. The concept soil-plant barrier was introduced in 1980, explaining how metal addition, soil chemistry and plant chemistry affect human being when the soil is full of metals (**Chaney 1980**). The plants absorbed metals via pore water. The plants have both active and passive to take up and exclude metals depending upon the internal concentration **(US EPA 2003).** The metals (e.g. copper, selenium, and zinc) are nutritionally essentially required elements at low levels but toxic at higher levels, and others (e.g. lead, arsenic, and mercury) have no known biological functions as metals are naturally occurring having organisms and accumulated in essential metals **(Fair brother 2007).** Similarly, the pollutants emitted from the E-waste treating sites, contaminate the water resources drastically, as the processes pertaining to its treatment are both wet and dry and consumes a lot of water.

For example, in China, the WEEE residue and leftover either dumped in fields or in rivers and irrigation ditches. The samples collected by BAN from the Lijiang River shows heavy contamination of cadmium (0.01–0.033 mg/L against 0.003 mg/L - **WHO guidelines**, lead (1.9 to 24 mg/L against 0.01 mg/L -**WHO guideline**.

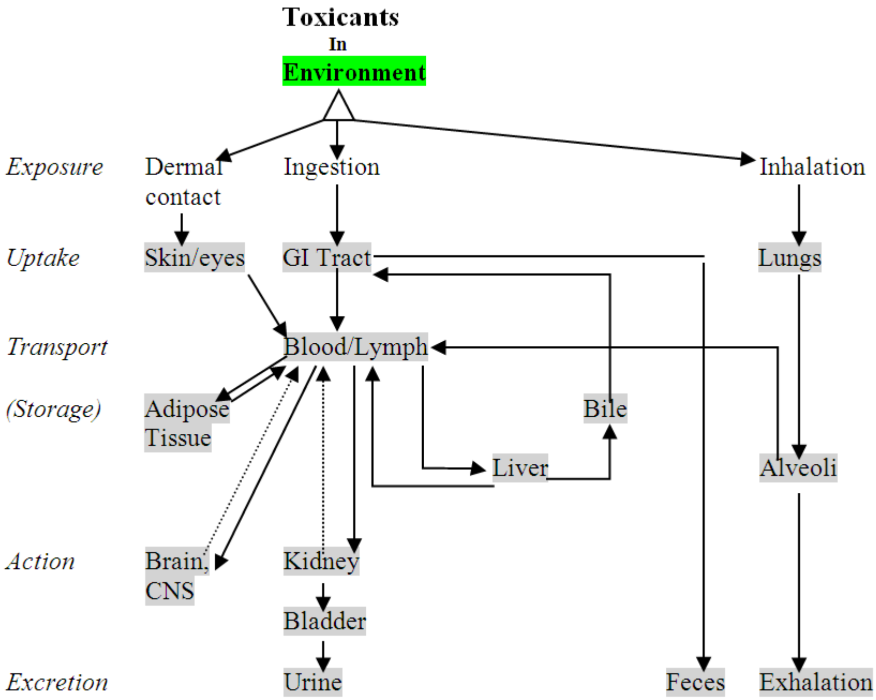


Figure 21: The poisoning process in animals and humans by Toxicants (Ming 2000)

In view of that people in Guiyu are bound to consume water from nearby town only after the one year existence of WEEE industry there **(BAN 2002).**The E-waste concerns are much more in terms of health and valuable resource. The people engaged in the recovery, recycling and other activities are need to be made about the ill and long term effects of E-waste which they are handle. The developed countries are dispatching E-waste for recycling without guidelines about precautions to be taken care before and after E-waste treatment. The identification and isolation of hazardous materials is very essential before taking up any kind of E-waste treatment.

In India, E-waste (Management & Handling) Rules, 2011 call for reduction the use of hazardous substances in electrical and electronic equipment. The threshold value for cadmium 0.01% by weight in homogeneous material and for lead, mercury, hexavalent chromium, poly-brominated- biphenyls and poly-brominated di-phenyl ether is 0.1% by weight of the equipment. This reduction will be achieved by 01 May

2014. The equipment are exempted placed six years before the commencement of these rules **(MoEF 2011**).

2.8. E-WASTE MANAGEMENT CHALLENGES IN INDIA

The informal recyclers treat largest part of E-waste with primitive and environment unfriendly E-waste disposal practices in India. Besides compliance of existing CPCB provisions for E-waste management, it has become troublesome to one to all as the formal infrastructure to deal with prevailing E-waste is average and the valuables in the E-waste drain down in the waste and simultaneously toxic material harm the environment irreparably. After recovery of target material, it is being left rather in open or put in the municipal waste; pollute the air, contaminate the water and spoil the soil fertility. The leachable heavy metals leach out from the components and lead to our natural resources through leachate. The ESM is in practice partially in India as on ground only registered recyclers are complying ESM. However, more recyclers have expressed their interest in ESM but their numbers are insufficient in the proportion to the E-waste produce in the country. As more than 90% E-waste produced destine to Local collectors and remnants to landfills. It is very true that E-waste treatment in India is a profit driven profession. The compliance from E-waste stakeholders is lagging behind, since they are not working as per ESM cohesively. The ESM implementation in India is a big challenge in front of them. In view of that, a wide gap exists between the formal and informal E-waste recycling. There are obvious factors are responsible for it. The activities contributing in it are being highlighted as they impede in the implementation of ESM in India.

- Lack of Inventory of E-waste in the country.
- Ineptness of familiarity about E-waste treatment technology.

- Inadequate infrastructure in proportion to E-waste produces.
- Apathy towards E-waste collection from sources.
- Unanimity for common E-waste disposal point in the ambiance.
- Lack of E-waste classification.
- Trend of inattention in EEEs disposal.
- Sloppy E-waste collection and refurbishment system.
- Clumsiness in recycling and recovery of the materials from E-waste.
- Ineptness of proficient incinerating facility.
- Deficit secured landfills.
- Timidity of recyclers towards allotted quantum of E-waste.
- Deprivation of financial and technical assistance for creating infrastructure.
- Deficit in formal E-waste collection and storage system.
- Lack of formal reporting of E-waste generated by major E-waste generators to CPCB on annual basis.

Besides, the defined roadmap of CPCB, the formal E-waste recycling is increasing steadily ; but need more efforts and resources to restore it at it is required in the country because E-waste is increasing drastically and need its conversion into resources. It is hour demand to exploit the E-waste comprehensively so that equilibrium may be maintained in terms of resources and pollutants production.

2.9. E-WASTE MATERIAL POTENTIAL

E-waste has enormous a variety of recoverable material in its composition. The recycled material is always in demand because it is cost effective to the virgin material. Nowadays, the developed countries are exploiting E-waste to a maximum by viable technology and it is extending to developing countries also through transfer of technology. The recycling of material from E-waste is an environment concern. The recycling and recovery of material from E-waste is under exploitation in India. In view of this, the material in E-waste drains down to waste because maximum amount of E-waste is being treated by informal recycling by primitive processes. However, the material yield from E-waste is very low of poor quality and needs further refining for its usage ahead. The informal recycling encourages the selective equipment of E-waste for material retrieval and leaves other equipment, components and material untouched because the informal recycling focuses on visible metals like copper, aluminium and iron and leave other hidden metals encapsulated in components. It is fact that the electronic equipment is being manufactured by consuming precious, base and toxic metals. The precious metals are being condensed in the interior of the components.

In India, the informal recycling encourages the revival of metals from computer mother boards, and television printed circuit boards only because it is believed that these parts are of metal potential of copper metals and other equipment like mobile phones are being ignored for it. But, it is interesting to note that mobile phone has numerous metals in its composition; but still it is not explored in India because recycling is a profit driven profession and no recyclers is interested to take any risk for its material recovery without knowing the actual outcome of metals because this information is scarce to them. It is presumed that it is a small electronic item and null for material recovery and the profession will not survive due to its output alone. The recuperation of material from mobile phone is believed to be uneconomical for the informal recyclers.

The material composition of mobile phone is comprises of plastics, metallic covering, glass, battery, printed circuit board (PCB). The precious metals are always in focus while considering the metals reclamation from the mobile phone waste. The plastics, glass, battery and magnetic metals are on least priority of the recyclers and generally remain at bottom-line. The PCB of mobile phone is a principal component and a rich source of base and precious metals, containing toxic metals also. The recovery of precious and base metals is not as easy as these metals are being used as metalloids in layers in the PCB. It is very difficult to extricate the toxic metals from other metals. The informal recyclers are desirous to recover precious metals instead of others. So, the recuperation of these metals not only demands viable infrastructure but isolation of toxic metals also; so that any hazards of any form may be obviated. It is fact that the innovations in retrieval technology are the key drivers to have ample metals sustainably. Similarly, the awareness about the presence of valuables in PCB enhances the recycling of metals of mobile phone waste.

The global demand of metals has been escalating with the dictation of electronics equipment globally. In India, the particular data pertaining to actual consumption of metals in electronics is still under preparation because the majority of electronics items are being marketed in the country after manufactured in abroad. At global scale, around 267.3MT of gold and 7275MT of silver are being consumed annually for manufacturing mobile phones, laptops and other electronic equipment **(Thomson Reuters 2014)** of which only 15% is being recuperated from the waste generated from electrical and electronic equipment; the remainder lies in the storage yards or landfills. The wastes comprise of the glass, plastics, wires, batteries, PCBs, metal casing, etc. The PCB is composed of precious metals which has immense potential of recycling and recovery.

Mobile phones contribute 1% to the e-waste generated in India exclusively (**Vats and Singh 2014**). The mobile phone among all electronics equipment is widely utilized in the world as integrated telecommunication and information equipment. It is handy and small electronic equipment. Due to innovation, all electronic equipment's are operated with printed circuit boards in the rudimentary design. The much attention was not paid towards the recoverable metals present in its PCB. The discarded PCB of all kinds of equipment contributes 3% to the total e-waste generated worldwide (**Sohaili 2012**). The Printed Circuit Board of typical mobile phone weighs 15 - 43% by weight. The PCB contains 28% metals and 70% non-metals (**UNU 2009**). In one ton mobile phone waste, 340g of gold, 3.5 kg silver, 140g palladium, 130 kg copper exist as recoverable metals (**UNU 2009**).The weight percentage of precious metals in PCB is less than 1% but its monetary value among PCB material is 80% (**Young 2009**). Henceforth, mobile phone is a potent source of recoverable metals. The major metals present in the mobile phone are reflected in **Figure 22.**

Presently, 96.9% of the population in the world is utilizing mobile phones (**US and World 2015**). In India 74% population is utilizing mobile phones (**Census 2011**), in USA more than 100%; in Finland 170% and in North Korea 8.3%.

The composition of PCB varies model to model of the each mobile phone brand. Internationally, Nokia, Samsung, BlackBerry, Philips, Sony, Ericson, Motorola are patrons in mobile phone manufacturing. The forecasting of the mobile phone subscribers has been anticipated 8.2 billion at the cessation of 2018 as presented in **Figure 23** (**Soo 2014).**However, the life of the mobile phone has reduced drastically. It ranges as less than 2 years in developed countries to 3 years to the developing countries (**Ogunniyi 2009**).

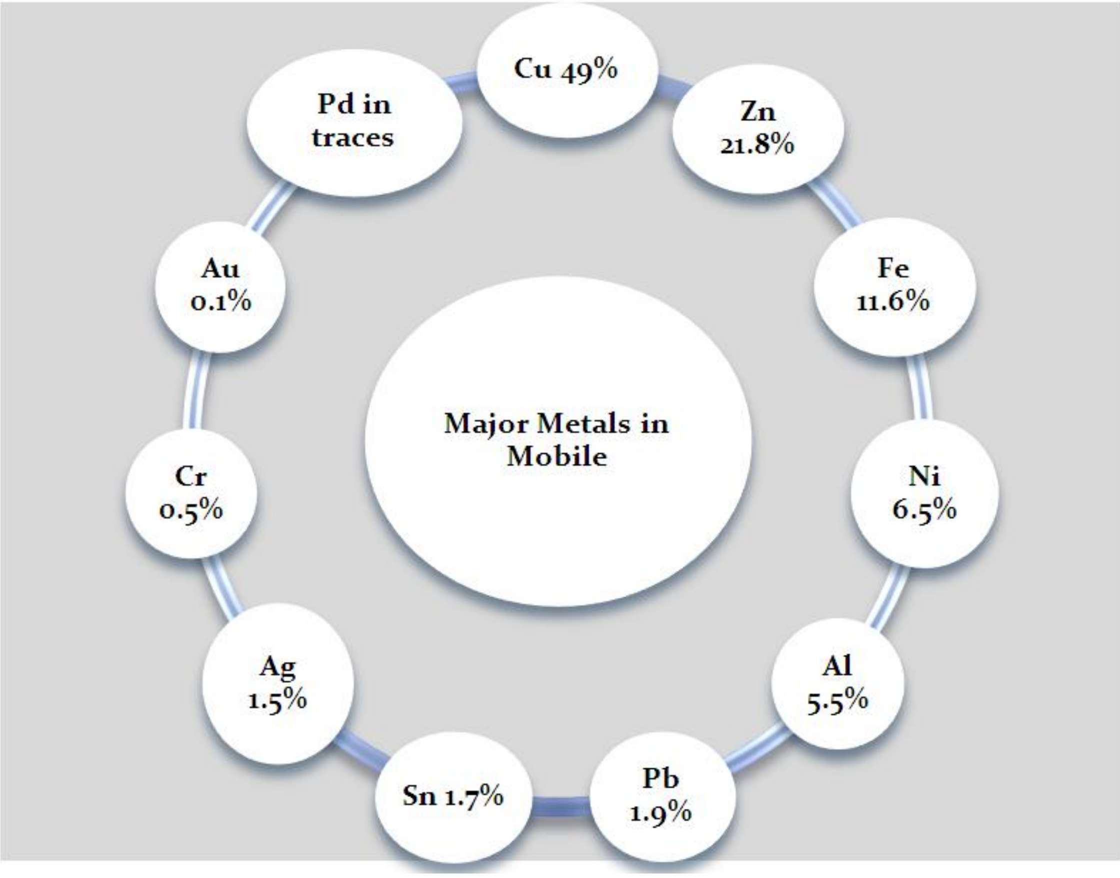
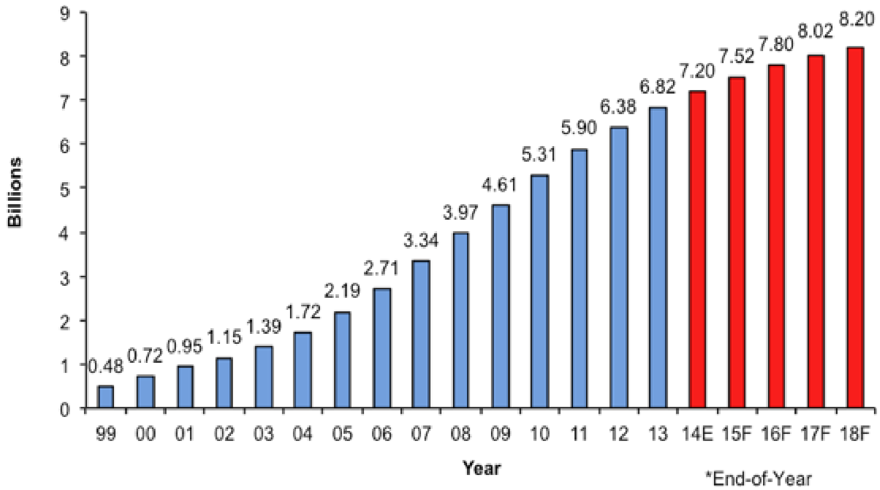


Figure 22: Major Metals in Mobile Phone

Hence, a copious mobile phone waste of more than 8.2 billion mobile phones is expected to be accumulated worldwide in the coming years.

The disposal method of discarded mobile phone is not defined in developing countries. After end of life of the mobile handset, people deem it as of nil monetarist items and decide its disposal blithely. The end of life mobile phone poses health hazards due to presence of toxins in it (**Ogunniyi 2009**). The contents of precious metals are much richer in printed circuit board than natural ores as the metals in printed circuit boards are used in very thin layers. It confirms the dire need for recovery of metals out of printed circuit boards in terms of profitable and environmental outlook **(ECTEL 1997**).



E – Estimated number of subscribers; **F** – Predicted/Forecasted number of subscribers

Figure 23: Total Worldwide Cellular Subscription from 1999 to 2018 (IC Insights)

The environmental laws for E-waste management in developing countries are lenient indeed and the informal cyclers are fortunate to carry out E-waste recycling personally than sustainably. A 30% of gold is coming from recycling of the gold scrap (**Vats and Singh 2014**). The gold was made available in 2012 by the recycling in USA (123tons), Italy (123 tons), China (120 tons), India (113 tons), UAE (73 tons, Turkey (72 tons), UK (69 tons), Mexico (63 tons), Egypt (54 tons) and Indonesia (49 tons). It amounts total 864 tons which are 37% of the total gold (1616 tons) recycled (**Thomson Reuters 2014**). The Global gold recycling has increased by 60% since 2007 (**World Gold Council 2013**). Similarly, silver was made available in 2012; 31267.85 tons against a demand of 29684.7032tons. By recycling of silver scrap 7856.6178 tons of silver supplied. This quantity is inclusive in the total silver made available. For the fabrication of electrical and electronics equipment's etc.; a 7371.5 t of silver has demanded (**Thomson Reuters 2014)**. It means 94% of the silver demand is being fulfilled by silver scrap alone. It encourages the recycling of metals from all sources. The Global report of Nokia (**Nokia 2008**) in 2008 reveals for unserviceable mobile sets that hardly 3% people are handing over the mobile phones for recycling, 44% remains in the possession of users. In developing countries, for old and serviceable mobile sets 25% are being gifted to family members and friends and of 16% sets spare parts are being sold for refurbishment (**Hageluken 2008**).

Development of infrastructure for metal recovery from mobile phone PCB is based on feasible recoverability of such metals. The study presents the assesses and anticipates the yield of precious metals namely gold and silver in mobile phone printed circuit boards.

The presence of metals in printed circuit boards has been studied by various authors with different methodologies and confirmed the existence of metals in it. In mobile phone, high performance printed circuit board is used. The weighted percentage of major metals in PCB is presented in **Table 10.**The PCB contains metalloids, polymers, and ceramics.

Table 10: Weighted percentage of major metals in PCB (World Gold Council 2013).

Sr. No.	Metals	Weighted percentage
1.	Copper (Cu)	49.0%
2.	Zinc (Zn)	21.8%
3.	Iron (Fe)	11.6%
4.	Nickel (Ni)	6.5%
5.	Aluminium (Al)	5.5%
6.	Lead (Pb)	1.9%
7.	Tin (Sn)	1.7%
8.	silver (Ag)	1.5%
9.	Chromium (Cr)	0.5%
10.	gold (Au)	0.1%
11.	Palladium (Pd)	Trace

The typical medium grade PCB in 2002 contains **gold (0.025%), Palladium (0.010%), silver (0.100%), Copper (16%), Tin (3%), Lead (2%), Nickel (1%), Aluminium (5%), Iron (5%) and Zinc (1%) respectively (Chatterjee 2012).** One of the study reveals the PCB feed by weight percentage as **gold (0.039%), silver (0.156%), Palladium (0.009%),**

Copper (18.448%), other metals (9.35%) and non-metals (70%) **(Chehade 2012)**.In the equipment, the components contain metals in prorate. The major metal elements in components are presented in **Table11**.Many studies focus on recoverable metals in mobile PCBs. It is revealed that the concentration of precious metals in one ton mobile phone is 3573g silver, 368g gold and 287g palladium respectively **(Chancerel 2009**). A study found that 1000 million units of cell phones contain 250 tons silver, 24 tons gold, 9tons Palladium and 9000 tons Copper **(Hageluken 2008).** Another study revealed that 1000 Kg of PCBs contain a recoverable metals such as gold (279.93 g), precious metals-Pt, Pd, in (93.31 g),

Table 11: Major Metal Elements in Components (Takahashi 2008)

S. No.	Type of Part	Elements Detected
1.	Circuit Board	Au, Ag, As Ba, Bi, Cr, Cu, Ga, Mn, Ni, Pb, Pd, Pt, Si, Sn, Ta, Ti, Zn, Zr
2.	Flexible Substrate	Au, Ag, Cu, Pt
3.	Liquid Crystal Display	Au, Ag, As, Ba, Ca, Cu, In, Ni, Sb, Si, Sn
4.	Motor	Au, Ag, Cu, Pt
5	Camera	Au, Cu, Ni
6.	Speaker/Microphone	Cu, Mn, Zn

Copper (190.512 kg), Aluminium (145.152 Kg), Lead and tin (30.844 Kg) and silver (450 g) **(Kumar 2014)**.It is also predicted that 6000 mobile sets weighing one tonne approximately would contain 130 Kg Copper **(UNU 2009).** It is also mentioned that non-metallic fractions take up almost 70 weight percentage of the PCBs **(Guo 2009).** Hence; the metals of interest for recovery in mobile phone are copper, gold, silver, palladium and ferrous metals. The metal composition also assessed in 2013 as copper (82.2%), lead (1.19%), tin (1.48%), Zinc (6.31%), Nickel (6.35%) and iron (0.12%) **(Ajier 2013).**The composition of metals in a typical PCB is presented in **Table 12**.

The exponential growth of E-waste and presence of recoverable metals of all kinds in mobile phone PCB encourages the recovery and recycling of metals from the waste. The recovery of metals from e-waste is a sustainable approach as it does not lead to an over exploitation of resources in any form. In view of that, recycling and recovery of metals from E-waste is an appropriate option because the energy consumption for mining the virgin material is ten times to the recovery from E-waste equipment.

Table 12: Typical compositions of PCBs (Hall2007)

Materials	**Typical Concentrations (in weight percentage and ppm)**			
Metals (Max. wt. 40%)	**Shuey & Taylor 2004)**	**Kim *et al.* 2004**	**Iji & Yokoyama 1997**	**Ewasteguide.info 2013**
Cu	20	15.6	22	6.9
Al	2	-	-	14.2
Pb	2	1.35	1.55	6.3
Zn	1	0.16	-	2.2
Ni	2	0.28	0.32	0.85
Fe	8	1.4	3.6	20.5
Sn	4	3.24	2.6	1.0
Sb/ppm	0.4	-	-	20
Au/ppm	1000	420	350	20
Ag/ppm	2000	1240	-	200

Pd/ppm	50	10	-	-
Ge/ppm	-	-	-	20
As/ppm	-	-	-	10
Ti/ppm	-	-	-	200
In/ppm	-	-	-	20
Ta/ppm	-	-	-	200
Co/ppm	-	-	-	200
Se/ppm	-	-	-	20
Ga/ppm	-	-	-	10
Ceramics (Max. wt. 30%)				
SiO2	15	41.86	-	-
Al_2O^3	6	6.97	-	-
Alkali and alkaline earth oxides	6	CaO 9.95	30	24.9
Plastics (Max. wt. 30%)				
Polyethylene	9.9	-	Total of all plastics 16 wt %	Total of all plastics 23 wt %
Polypropylene	4.8	-		
Polyesters	4.8	-		
Epoxies	4.8	-		
Polyvinyl chloride	2.4	-		
Polytetra-flouroethane	2.4	-		
Nylon	0.9	-		

The recovery and recycling of metals from the mobile phone is not only safeguarding the environment from toxic elements but helps in reduction of E-waste also. The metals so recovered from all sources fulfil the 30% demand of virgin metals in developing national markets for the manufacturing of new EEEs (Electrical and Electronic Equipment).The typical composition of mobile phone PCB is presented in **Table 12** for the mobile Phones discussed at the early stage of electronics.

CHAPTER 3
MATERIAL AND METHODS

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The usage of mobile phone has enhanced manifolds world over and its waste is escalating with abrupt changes in mobile phone technology. In India, the mobile waste is under exploitation absolutely in terms of material resource due to non-availability the facts of recoverable in the discarded mobile phones and drain down in the waste. The study is conducted to unveil the facts about a mobile phone.

3.1. MATERIAL

Mobile phone is one of the electronic equipment in maximum use in the country and its accessibility to the public is escalating in the country. After its end of life it is deprived for material recovery absolutely. However, the formal recycling is incorporating it and its base is expanding slowly in the country. Presently formal recycling infrastructure is deficit it in proportion to the E-waste produce in the country. The study finds the way to deal with mobile waste of country used mobile phones; so that its management may be shaped in the country. The samples of discarded mobile phones of various brands have been collected randomly. The dimension of the samples covers maximum population of the mobile users in the country. At the outset, the 1st generation and 2nd generation mobile phones are being used by the public. However, the 3rd generation and 4th generation phones are in place. The maximum 1stand 2nd generation phones are obsolete and have become waste. In view of that the selected 1st and 2nd generation phones are being selected for the study because they are maximum in waste and need appropriate disposal. These samples belong to heterogeneous face values and features. They are being used by different scales of gentry and covers more than 80% mobile phone users in the country used these brands and models. The sample length is 10 in numbers of assorted brands. Ten key metals of precious, base and toxic characteristics are being assessed from the PCB of each sample by qualitative and quantitative analysis. These samples are Nokia 2700, Nokia 1650, Nokia 1108, Meni-Max D-5027, Siemens A-50, Motorola-C1-68, Movil-MCI-CDMA, Samsung-D 500, Nokia- 72, and Motorola W-220 respectively.

The metals are the key material in the mobile phone waste because they are being casted off in various layers while manufacturing the PCB of mobile phone. In view of that the metals in PCB are being accommodated as metalloids to serve the intended use of PCB. After the end of life of the mobile phone equipment, the metalloid concept keeps all metals safe and intact from probable leakages caused by environmental variations like heat, humidity etc. These metals are not visible elementally in the components. In view of that recyclers leave such items unloved in waste. The material in an equipment decides its disposal. But, as far as the mobile phone is concerned, the particular information is still awaited in the country. In view of that, it has put question mark on its disposal. It encourages the curiosity of researcher to attempt the quantitative and qualitative assay for actual metals present in the PCB, so that these metals may be kept safe as resources for the further retrieval. The toxic metals are part of other metals also in the PCB. But, it is very difficult to keep them separate elementally from the condensed lump. But, the present study explores it and identifies an ample amount of various metals are available in the PCB of the mobile phone samples.

3.2. METHODS

The selection of appropriate method for the analysis is a challenging task and it becomes tedious and unpersuasive when considerable overlapping in method’s capabilities.

However, the relative strengths and weaknesses of each method make them distinctive from each other. The factors so called infrastructure cost, the sensitivity Limit of Detection (LOD), availability of instrumentation, method reliability are decisive for the selection of particular method. The AAS, Inductively Coupled Plasma Atomic Emission Spectrometry (ICP AES), Inductively Coupled Plasma Mass Spectrometry (ICP-MS), Ion Chromatography (IC) and X-ray Fluorescence (XRF) methods are normally used for the assessment of the trace metal contents in analyte. The method AAS separate itself inter alia methods significantly due to its accuracy in results, technique reliability, LOD is below micro gram per litre, coverage of more than 60 metal elements, ease in handling the instruments and infrastructural cost is less. The Study selected the FAAS to carry out analysis of metals in analyte. The comprehensive methodology includes manual dismantling for separation of different components, segregation to keep PCB, display, battery, plastics, and steel separately. Further, PCB roasting is carried out for removing the organic material from PCB sample. PCB is roasted at 850^{0}c and the outcome is combusted gases, carbon, non-ferrous metalloid, steel. In continuation, the segregation isolates carbon, non-ferrous metalloids, and steel. In the next step, the metalloid is treated with HCl and solution is digested and finally a solution of dissolved metalloids with residue of insoluble of non-ferrous metalloids is obtained. The solution is filtered again and obtained un-dissolved metalloids, inert material, metal salts as residue. The analyte of HCl digested solution is put to FAAS for metal analysis in HCl. The residue is further treated with aqua-regia digestion of un-dissolved salts and metalloids and obtains dissolved metalloids, inert material and further it is filtered and isolates the residue and analyte to be digested and put to FAAS for the observation of metals in the solution. In the final filtration insoluble oxides of metals **(Figure 24).**The grinding process after roasting the samples is un-layering the various metals present in the PCBs.

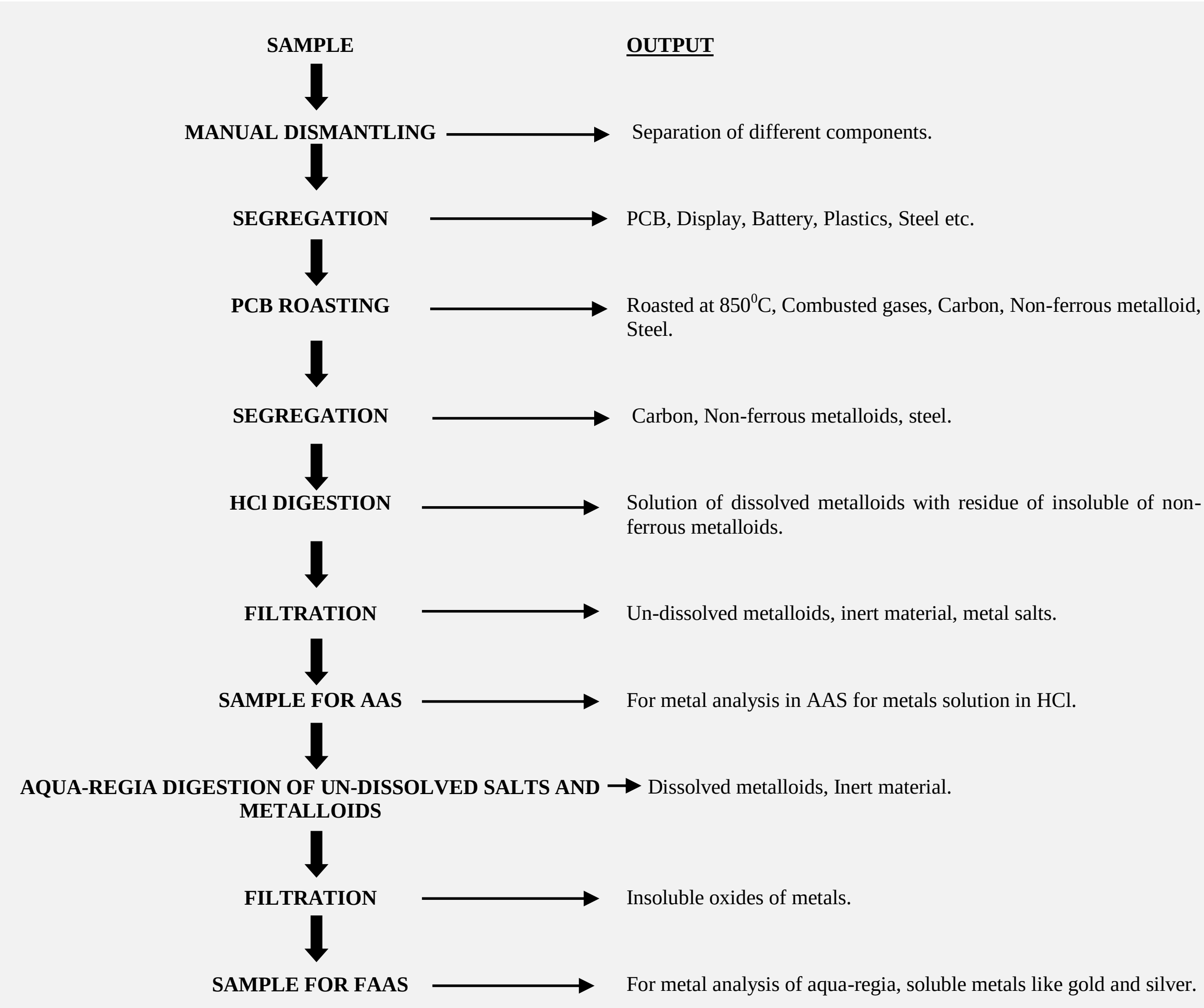

Figure 24: Flow diagram of Methodology used

The hydrometallurgical processes as acid digestion (HCl and Aqua-regia) have been employed to the grounded sample for dissolution metalloids and analysed them separately by FAAS. The flow diagram of all activities contributing in methodology is presented in **Figure 24**.

Ten metals as gold, silver, copper, manganese, lead, tin, zinc, aluminium, iron and nickel have been assessed from these samples. The assessment of metals in PCBs is arrived at by acid digestion followed by AAS. The individual PCB samples are roasted and leached with acids and the acid solution is further evaluated with spectrometry.

3.3. DISMANTLING AND SEGREGATION

The samples are manually dismantled and stored safely for further analysis, so that the occurrence of any hazards may be obviated at site. The dismantled and segregated the typical PCB samples used in the study are shown in **Figure 25**. After dismantling, it has been found that a mobile phone contains glass, steel, plastics, PCB and battery. A typical mobile phone is composed of casing, display, keypad, printed circuit board, antenna, microphone, speaker, battery. The casing is made of plastic (polycarbonate-PC), acrylonitrile butadiene styrene (ABS) or a combination of the both), steel and aluminium. Display is made of liquid crystal and mercury. With these samples, the result of dismantling and segregation is presented in **Table 13**.

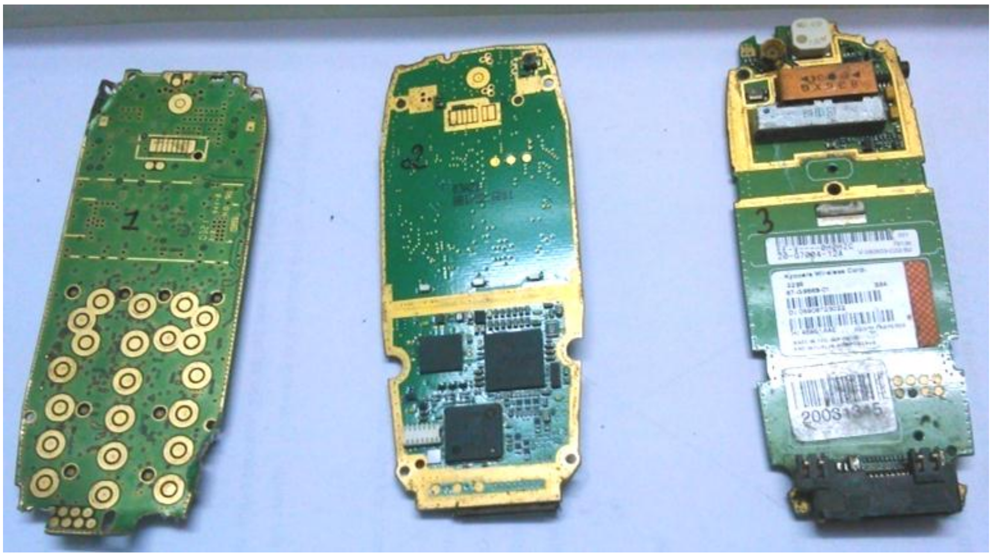

Figure 25: Mobile Phone PCBs used in the study.

By and large, battery is composed of lithium-ion (Li-ion), nickel-metal-hydride (NiMH), and nickel-cadmium. In PCB, the solder, copper, ceramics, epoxy resins, precious metals are usually used. Among all samples Meni Max D-5027 weighed most and Nokia 1650 weighed least. The PCB of Siemens A-50 mobile phone weighed most and Samsung-D 500 weighed least among the samples. Similarly weight of plastics is most in Motorola W-220 and least in Samsung D -500. The glass, plastic and steel have not been looked at in the study; however, these materials can also be recycled easily.

Table 13: Dismantling and Segregation (wt. in g)

Sr. No.	Model	Sample (without Battery)	Glass	Steel	Plastics	PCB
1.	Nokia 2700	60.2687	5.0341	14.2065	22.1331	18.895
2.	Nokia 1650	48.7164	5.3535	6.1431	21.4698	15.75
3.	Nokia 1108	66.14	3.8092	16.1521	32.0368	14.1419
4.	Meni Max D-5027	84.1563	6.7275	34.0731	30.7726	12.5831
5.	Siemens A-50	67.69	9.37	1.01	28.14	29.17
6.	Motorola-C1-68	53.76	7.25	1.2	31.18	14.13
7.	Movil-MCI-CDMA	58.4451	6.15	5.7	28.66	17.9351
8.	Samsung-D 500	56.1138	7.08	7.63	27.31	14.0938
9.	Nokia- 72	69.2683	7.23	0.92	39.88	21.2383
10.	Motorola W-220	71.1153	9.01	4.11	43.14	14.8553

3.4. PCB ROASTING

The metals in mobile phone PCBs are printed and encapsulated in the components. The metal recovery in elemental form is a tedious task. While PCB manufacturing, the metals are laid in multiple layers for circuits and fabricated to execute the assigned function of the network.

Figure 26: PCB after Roasting

Figure 27: Sieved Material after Hammer mill treatment

Metals as metalloids are used in the manufacturing of PCB possessing physical characteristics like melting point, malleability, ductility, conductance etc. which enables various metals to be used in PCBs. The PCB appears in different look as one form of metals after roasting.

The PCB roasting has been carried out at 850^0 C in high temperature furnace as all organic and combustible material is separated from the metal contents. The PCB samples have been weighed before putting them in combustion and mark them according to samples.

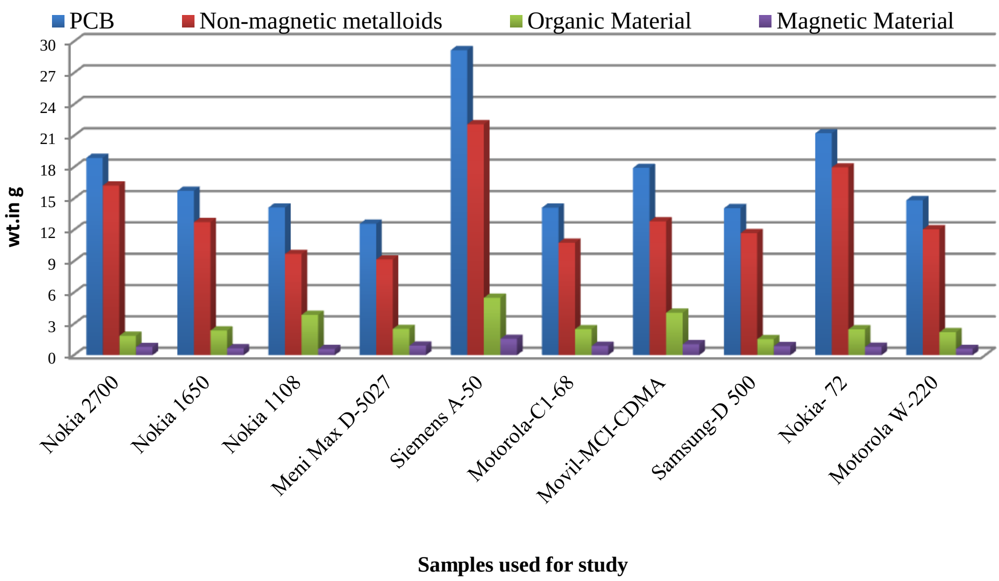

Figure 28: Ingredients of Sample

After roasting, all samples are kept separate and then further put to hammer milling process so that these metal contents can be put in manageable form. The output of hammer milling of roasted PCB is shown in **Figure 26** and **Figure 27** respectively. The steel contents are being separated with the help of bar magnets applied across the grounded material. The ingredients of PCB after roasting are graphically presented by **Figure 28**. The non-magnetic metals are more in PCB in prorate as compared to the magnetic metal and organic material. The total weight of the PCB has reduced to 10% to 27% after roasting.

Table 14: Roasting Analysis of various brands and models of mobile phone PCBs

		Weight(g)					
Sr. No.	**Model**	**PCB**	**PCB (roasted)**	**Organic material**	**Magnetic**	**Non-magnetic**	**Percentage reduction**
1.	Nokia 2700	18.895	17.0328	1.8622	0.7835	16.2493	9.85
2.	Nokia 1650	15.75	13.396	2.354	0.6497	12.7463	14.94
3.	Nokia 1108	14.1419	10.2772	3.8647	0.5817	9.6955	27.32
4.	Meni Max D-5027	12.5831	10.0719	2.5112	0.905	9.1669	19.95
5.	Siemens A-50	29.17	23.672	5.498	1.567	22.105	18.84
6.	Motorola-C1-68	14.13	11.643	2.487	0.8769	10.7661	17.60
7.	Movil-MCI-CDMA	17.9351	13.8765	4.0586	1.0498	12.8267	22.62
8.	Samsung-D 500	14.0938	12.5643	1.5295	0.8654	11.6989	10.85
9.	Nokia- 72	21.2383	18.768	2.4703	0.7875	17.9805	11.63
10.	Motorola W-220	14.8553	12.653	2.2023	0.5986	12.0544	14.82

The results of the PCB roasting are presented in **Table 14.** Nokia 2700 mobile phone PCB has least organic and combustible material and in contrast Nokia-1108 has most. On average from all samples, a PCB of 17.2793g reduced to 14.3955g containing 2.8838g organic combustible material, 0.8665g magnetic metal, 13.5289g non-magnetic metals. The reduction in weight of PCB after roasting is 16.842%. The high contents of organic material in PCB poses environmental loading of pollutants.

3.5. ACID DIGESTION

The metals, which are exposed in hammered and powdered material, are to be dissolved in appropriate acids for further analysis in FAAS. Recovery of these metals from metalloids is a challenging task to the recyclers by a single approach, but by roasting and acid digestion, these can be separated from the non-metals like plastic, glass etc. Most of the metallic portion from PCB sample gets dissolved in acids. The metal leachability depends upon its affinity to the acid solution. Most of the metals get leached out by conc. HCl and aqua-regia solutions if treated separately. Metals in the PCB are present in the form of metalloids in various layers. Gold has good dissolution affinity to the conc. HCl in contrast to the silver metal having good dissolution affinity to aqua-regia. Similarly, aluminium, copper, lead, manganese, iron, have good affinity with concentrated HCl and tin, nickel and zinc have good affinity with aqua-regia in most of samples. All metals are chemically different and their recovery processes are also indifferent to each other. The leached solution provides ease to the metallurgical processes in the recovery of dissolved metals.

Figure 29: Hot plate digestion

Figure 30: Filtration of digested solution

3.5.1. Digestion by HCl

The metals are layered in the PCB and layers are not mentioned metal wise because in single layers metals are being condensed according to the PCB design. Also, the metals affinity towards the acid is not identified. The physical and chemical properties of each metal are different by proportion. In view of that it is applied based on the design requirement. Hence, it is difficult to predict the particular metals. In view of that the application of acid is essential so that these metals are to be dissolved. The Conc. HCl (35% pure) is added after hammer mill process.

It is to note that an ample quantity of acid solution is to be added so that all metals get submerged in the acid completely. The ratio is generally 1:10 is kept in this study and 1ml is assumed equal to 1g

Table 15: HCl Treatment of non-magnetic material

Sr. No.	Model	Wt of non-magnetic metal in g	Volume of HCl added in ml	Final volume after digestion in ml	%age volume reduced	Wt. of residue left in HCl digested solution in g
1.	Nokia 2700	16.2493	170	142	16.47	6.8266
2.	Nokia 1650	12.7463	130	110	15.38	4.4732
3.	Nokia 1108	9.6955	100	82	18	3.276
4.	Meni Max D-5027	9.1669	100	73	27	2.6353
5.	Siemens A-50	22.105	230	185	19.56	10.9743
6.	Motorola-C1-68	10.7661	110	87	20.90	5.0723
7.	Movil-MCI-CDMA	12.8267	130	95	26.92	7.943
8.	Samsung-D 500	11.6989	120	100	16.67	5.084
9.	Nokia- 72	17.9805	180	147	18.34	7.342
10.	Motorola W-220	12.0544	120	98	18.34	6.1743

The digestion of the all metals takes place overnight time and for further metal digestion hot plate at 60^0 C is also used **Figure 29**. The digested solution is being filtered through 40 micron filter paper **Figure 30**. The volume of solvent reduced appreciably. In case of Mani Max D-5027, the volume of the solvent is on higher side by 27%. In contrary, Nokia 2700 has least value of reduction as 16.47%. In the array of assorted samples, the typical value of solvent reduction arrives at 19.758% to the original volume added for the digestion. The detail of each sample is presented in **Table 15**. The residue left after HCl digestion is more in Siemens A-50 as 10.9743g and least in Meni max D-5027 as 2.6353g. The filtered solution is being analysed by

AAS. The composition of the metals in the PCB is different for different metals. So, in the analysis, the solution is diluted as per AAS instrument, so that the actual concentration of individual metals may be observed.

3.5.2. Digestion by Aqua-regia

The filtered residue from HCl treatment is dissolved in aqua-regia. Two steps for acid digestion i.e. HCl and Aqua-regia selected. The HCl digestion was done to analyse all metals soluble in HCl. The insoluble mainly precious metals shall be dissolved in aqua-regia.

Table 16: Aqua-regia Treatment for residue obtained after HCl treatment

Model	Wt of Residue in g	Volume of Aqua-regia added in ml	Final volume after digestion in ml	%age volume reduced
Nokia 2700	6.8266	40	26	35
Nokia 1650	4.4732	30	21	30
Nokia 1108	3.276	20	13	35
Meni Max D-5027	2.6353	20	14	30
Siemens A-50	10.9743	60	37	38
Motorola-C1-68	5.0723	30	19	37
Movil-MCI-CDMA	7.943	50	30	40
Samsung-D 500	5.084	30	19	37
Nokia- 72	7.342	50	33	34
Motorola W-220	6.1743	40	26	35

Aqua regia digests almost all the base and noble metals (**Iji 1997**). The residue left on the filter paper denotes that some metals still remained un-dissolved in the conc. HCl and need further treatment. For precious metals digestion, aqua-regia (1:3 solutions of HNO_3 and HCl) is added to the residue. The volume of aqua-regia should be sufficient to get the residue submerged fully. The ratio of residue to solution is 1: 5 to 6 for this analysis. The digestion of the residue takes overnight time to get digested and further the hot plate at 60^0C is also used to accomplish the digestion of the residue. The volume of solvent added as aqua-regia to the dry residue also reduced more as to the HCl digestion. The volume reduction ranges 30-40% to the added solution (**Table16**).

Now again the digested solution is filtered and the residue remained on filter paper is separated out. This residue also needs further treatment before its disposal as it also contains various heavy metals and other metals in traces. It should not ever be mixed with soil, otherwise it can get mixed in food chain again. Both the solutions obtained by HCl and Aqua-regia treatment are analyzed with the help of AAS. The specific metal is detected by the respective metal lamp setup. Click on element window and install the particular lamp.

3.6. AAS OBSERVATIONS OF DIGESTED SAMPLES

Atomic spectrometry is a technique to determine the elemental composition in an analyte by its electromagnetic or mass spectrum. It works on Beers Lambert law. Atomic absorption occurs when a ground state atom absorbs energy in the form of light of a specific wavelength and is elevated to an excited state. The amount of light energy absorbed at this wavelength will increase as the number of atoms of the selected element in the light path increases. The relationship between the amount of light absorbed and the concentration of analytes present in known standards can be used to determine unknown sample concentrations by measuring the amount of light they absorb. The model of AA 400 of Perkin Elmer is used for the study.

The standard operating procedure of the AAS of model AA400 make Perkin Elmer is operated with the help of MS Window programmed with compatible Win lab 32 confirming industry standard PC equipped with exhaust ventilator stainless steel with capacity 200 to 300 cubic feet per minute, regulators for acetylene and oxygen gas, absorber pipe etc.

Figure 31: AAS Setup

The FAAS set up is shown in **Figure 31**. It works at room temperature ranging 15-35^{o}C with a maximum rate of change of 3^{0}C per hour. The **RH** (Relative humidity) should be between 20 to 80% dry (non-condensing). The instrument should have circulation area all around and should be installed on an island bench.

Acetylene (99.6%) is the main fuel for the burning flame in the equipment. Generally, welding grade acetylene is preferred. The supplement air flow through compressor should be of between 44- 58 psi and it should be dry, oil free, and filtered.

Review all safety norms mentioned in the user's guide before upload the system so that any possibility of hazards can be obviated easily.

3.6.1. HCl Digested Sample Observations

The extracted solution of each sample has been analysed. For each sample three dilutions are being prepared as high, medium and low in metal contents solution, so that the appropriate dilution, suitable to the instrument range is tested **Figure 32**. For single approach for AAS, four metals can be assessed at a time. The observations are presented in the subsequent tables with all details. The HCl digested solutions for ten metals are being assessed and calculated the particular metal contents in it. The following steps are used for the AAS observation from analyte.

a. Turn on the equipment of all accessories, gas flow cylinders, and compressor.

b. Turn on the fuel gas supply to the instrument.

c. Turn on the compressed air supply to the instrument. Generally oxygen cylinder is connected to the compressor.

d. Turn on the power supply of e-box and wait for the instrument to initialize.

e. The instrument run a self-test program after initialized.

f. Start AA400 WinLab32 and click ‘start’ and then ‘Programs’.

g. On PC display the system status screen appears having a green line indicating IEEE.

h. A red X line indicates a fault connection.

i. Click ‘X’ to close the diagnostics window. The ‘X’ is located at upper right hand corner of the window.

j. Insert the 4 lamps; one should be of Copper lamp, in the turret assembly.

k. Click the icon ‘Lamps’ in tool bar to open the ‘lamps setup’ Window and click on ‘Lamp #’ button corresponding to the lamp installed location. The lamp will automatically install in terms of wavelength and slit.

l. Now, click ‘Cont.’ in tool bar to open the continuous graphics Window.

m. Adjust the burner height.

n. Press ‘Auto Zero Graph’ icon.

o. Adjust the burner height slowly as absorbance starts increase. Stop when a positive going value is achieved.

p. Turn the height adjuster a quarter of a turn back.

q. Place sample capillary into a beaker of distilled water.

r. Click “Flame” icon under the tool bar to open the “Flame Control Window”.

s. Ignite the flame by pressing the “On/Off” switch on the “Flame Control Window”.

t. Allow the flame to stabilize for two minutes.

u. Aspire the blank solution and press “Auto Zero Graph” button in the ‘Continuous

v. Graphics Window’.

w. Further aspire a fresh 4 mg/l copper solution.

x. Adjust the burner horizontal and rotational position for maximum absorbance reading.

y. Look for a stable absorbance reading of 0.500 or higher Absorbance Units.

z. Compare the absorbance achieved with the published expected performance details found in the analytical methods for atomic absorption spectroscopy supplied with the instrument. The AAS observations of HCl and aqua-regia digested solutions are being presented in respective.

aa. This completes the routine operation of the spectroscopy instrument for the observations for the specific metals in analyte.

bb. Aspirate a blank solution for 1 minute after analysis to flush the burner system. Press the “On/Off” button on the PC display to extinguish the flame. Power off the A Analyst 400 instrument using the power switch on the e-box and turn off power to all peripherals.

cc. Turn off the Acetylene fuel supply.

dd. Turn off the compressed air supply.

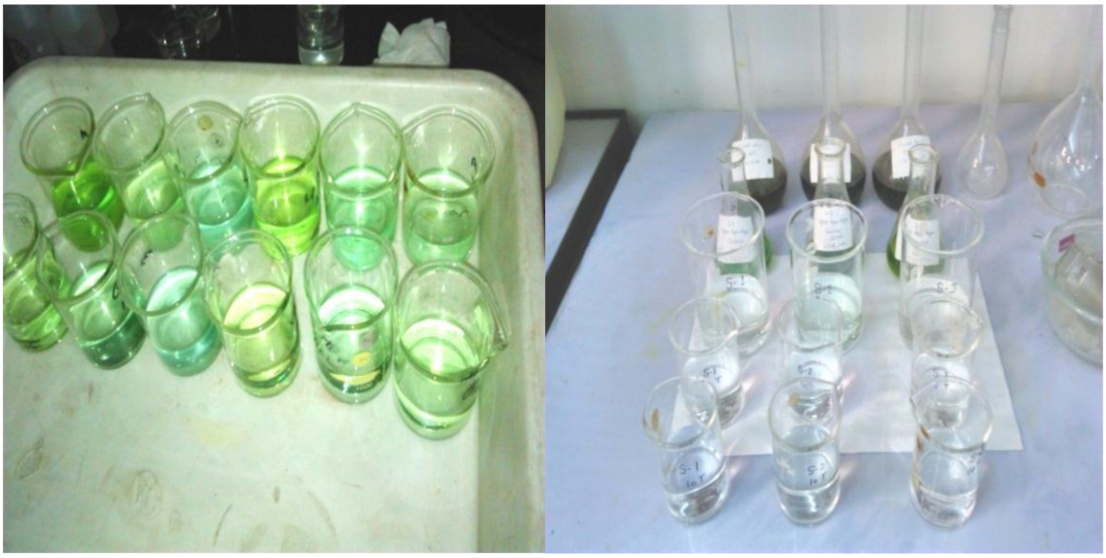

Figure 32: Sample Preparations for AAS analysis

The certified reference material (CRM) has its unique place to ratify the observation of AAS. In the study, the following reference material is being used mentioned in **Table 17**.

Table 17: Certified reference material (CRM)

Sr. No.	Metal	CRM
1	Aluminium	Al $(NO_3)3$ **(Merck)**
2	Gold	Pure **(Merck)**
3	Copper	Pure **(Merck**
4	Manganese	Pure **(Merck**
5	Lead	Pb $(NO_3)2$ **(Merck)**
6	Silver	Pure **(Merck)**
7	Iron	Pure **(Merck)**
8	Nickel	Pure **(Merck)**
9	Zinc	Pure **(Merck)**
10	Tin	Pure **(Merck)**

The more dissolution of metals shows more metals contents and good affinity towards the conc. HCl. If the dilution factor is high, means more metal contents and directly has good affinity towards the particular acid/aqua-regia. In subsequent tables, the AAS observations are being recorded for each metal in all samples. The volume of the HCl digested solution of model Siemens A-50 is 185 ml, which is highest among all samples. Perhaps more metals in digested solution of the samples Similarly, Meni-Max D-5027 digested sample has least volume as 73 ml. (**Table 18).** All observations are considered upto five decimal points in ppm.

Aluminium

The **Table 17** shows the observations of Al metal in HCl digested solution. The observations are in ppm. The observations show that the less metal contents in the digested solution because the dilution factor is merely100. The variability in observation shows that almost same amount of metal contents are available in each PCB. The typical AAS observation among ten samples for aluminium is 1.32593. The highest AAS value is 1.87284 ppm in Movil-MCI-CDMA sample and least as 1.02929 ppm in Nokia 2700 sample. The highest observation contains maximum metal contents provided the volume of the digested solution is highest.

Table 18: AAS Observations for Al in HCl Digested solution

Samples	**Nokia 2700**	**Nokia 1650**	**Nokia 1108**	**Meni Max D-5027**	**Siemens A-50**	**Motorola-C1-68**	**Movil-MCI-CDMA**	**Samsung-D 500**	**Nokia-72**	**Motorola W-220**
Volume in ml	142	110	82	**73**	**185**	87	95	100	147	98
Dilution Factor	100	100	100	100	100	100	100	100	100	100
AAS Reading	**1.02929**	1.21309	1.65853	1.31616	1.31416	1.38482	**1.87284**	1.06001	1.16789	1.24244

Gold

The observation shows that the Au is available in traces in all samples. The dilution factor is 100 for all samples. The AAS observation ranges from 0.078 ppm–0.147 ppm (**Table 19**). The typical AAS observation for ten samples is 0.10865 ppm. The highest observation is 0.136 ppm and lowest is 0.078 ppm. The observation shows that a large variability of gold contents in the samples.

Table 19: AAS Observations for Au in HCl Digested solution

Samples	Nokia 2700	Nokia 1650	Nokia 1108	Meni Max D-5027	Siemens A-50	Motorola-C1-68	Movil-MCI-CDMA	Samsung-D 500	Nokia-72	Motorola W-220
Volume in ml	142	110	82	73	185	87	95	100	147	98
Dilution Factor	100	100	100	100	100	100	100	100	100	100
AAS Reading	0.133	0.081	**0.078**	0.107	0.147	0.101	0.079	0.1265	**0.136**	0.098

Copper

The high dilution factor shows the presence of metals in abundance. The AAS observation shows that the copper metal contents are available in ample amount in PCB as the dilution factor is quite high in all samples. The dilution factor is 20000. However, the copper metal exists in different proportions in diverse samples. The observations range from 0.6565 ppm-1.0406 ppm. The typical value of the AAS observation is 0.87249 (**Table 20**). The highest observed value is 1.0406 ppm and lowest is 0.6565ppm.

Table 20: AAS Observations for Cu in HCl Digested solution

Samples	Nokia 2700	Nokia 1650	Nokia 1108	Meni Max D-5027	Siemens A-50	Motorola-C1-68	Movil-MCI-CDMA	Samsung-D 500	Nokia-72	Motorola W-220
Volume in ml	142	110	82	73	185	87	95	100	147	98
Dilution Factor	20000	20000	20000	20000	20000	20000	20000	20000	20000	20000
AAS Reading	0.9427	0.9119	**1.0406**	0.7586	**0.6565**	0.8702	0.8867	0.9435	0.9453	0.7689

Lead

The **Table 21** shows the AAS observations of Pb in HCl digeted solution. It shows that Pb exists in traces. The dilution factor is 100. The lead metal exists in each sample. The typical observation is 0.01811 ppm. However, Pb is in the list of RoHS. The highest observation is 0.0576 ppm and lowest is 0.0001 ppm.

Table 21: AAS Observations for Pb in HCl Digested solution

Samples	Nokia 2700	Nokia 1650	Nokia 1108	Meni Max D-5027	Siemens A-50	Motorola-C1-68	Movil-MCI-CDMA	Samsung-D 500	Nokia-72	Motorola W-220
Volume in ml	142	110	82	73	185	87	95	100	147	98
Dilution Factor	100	100	100	100	100	100	100	100	100	100
AAS Reading	0.002	0.0104	**0.0001**	0.0395	0.0435	0.0155	**0.0576**	0.0043	0.0035	0.0047

Manganese

AAS observations show that Mn exists in each sample more than lead, in traces. The dilution factor is used as 100 uniformly for each sample. The typical AAS value in array of ten samples is 1.64941 ppm (**Table 22**). The observations range from 1.922 ppm to 1.188 ppm. The observations have least variation. The observations shows that a uniform almost uniform presence of metal in the PCB because the variability in observations is less.

Table 22: AAS Observations for Mn in HCl Digested solution

Samples	Nokia 2700	Nokia 1650	Nokia 1108	Meni Max D-5027	Siemens A-50	Motorola-C1-68	Movil-MCI-CDMA	Samsung-D 500	Nokia-72	Motorola W-220
Volume in ml	142	110	82	73	185	87	95	100	147	98
Dilution Factor	100	100	100	100	100	100	100	100	100	100
AAS Reading	1.714	1.698	**1.188**	1.601	1.895	1.7001	1.845	1.542	**1.922**	1.389

Silver

The AAS observations for Ag show that it exists in traces in all samples. The dilution factor is 100 for all samples. AAS observation ranges from 0.058 ppm -0.172 ppm. The typical value of AAS of ten samples is 0.1377 ppm (**Table 23**).

Table 23: AAS Observations for Ag in HCl Digested solution

Samples	Nokia 2700	Nokia 1650	Nokia 1108	Meni Max D-5027	Siemens A-50	Motorola-C1-68	Movil-MCI-CDMA	Samsung-D 500	Nokia-72	Motorola W-220
Volume in ml	142	110	82	73	185	87	95	100	147	98
Dilution Factor	100	100	100	100	100	100	100	100	100	100
AAS Reading	0.165	**0.172**	0.159	**0.058**	0.157	0.165	0.062	0.164	0.153	0.122

Iron

The **Table 24** shows that iron contents are exist in all samples. The dilution factor is 1000 for all samples. The typical observation of AAS is 1.17596 ppm. The highest observation is 1.3675 ppm and lowest is 0.9806 ppm.

Table 24: AAS Observations for Fe in HCl Digested solution

Samples	Nokia 2700	Nokia 1650	Nokia 1108	Meni Max D-5027	Siemens A-50	Motorola-C1-68	Movil-MCI-CDMA	Samsung-D 500	Nokia-72	Motorola W-220
Volume in ml	142	110	82	73	185	87	95	100	147	98
Dilution Factor	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
AAS Reading	1.2769	1.2005	**0.9806**	1.2633	1.1863	1.1302	**1.3675**	1.0423	1.10327	1.20873

Tin

The observation shows metal tin exists in traces in all samples of PCB. The dilution factor 100. The typical value of AAS observation is 0.19708 ppm (**Table 25**). The highest observation is 0.3197 ppm and lowest is 0.1538 ppm.

Table 25: AAS Observations for Sn in HCl Digested solution

Samples	Nokia 2700	Nokia 1650	Nokia 1108	Meni Max D-5027	Siemens A-50	Motorola-C1-68	Movil-MCI-CDMA	Samsung-D 500	Nokia-72	Motorola W-220
Volume in ml	142	110	82	73	185	87	95	100	147	98
Dilution Factor	100	100	100	100	100	100	100	100	100	100
AAS Reading	0.2902	0.1906	0.1559	0.1834	0.1674	0.1543	**0.3197**	0.1763	**0.1538**	0.1792

Nickel

The **Table 26** shows that nickel metal is available in each sample in ample amount. The dilution factor is 1000. The typical value of the nickel is 0.47593 ppm. The highest observation is 0.948 ppm and lowest is 0.313 ppm.

Table 26: AAS Observations for Ni in HCl Digested solution

Samples	Nokia 2700	Nokia 1650	Nokia 1108	Meni Max D-5027	Siemens A-50	Motorola-C1-68	Movil-MCI-CDMA	Samsung-D 500	Nokia-72	Motorola W-220
Volume in ml	142	110	82	73	185	87	95	100	147	98
Dilution Factor	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
AAS Reading	0.344	**0.948**	0.3792	0.3937	0.4879	0.3976	0.7389	0.3965	0.3605	**0.313**

Zinc

The **Table 27** shows that the metal zinc exists in all samples in abundance. The dilution factor is 2000 for all samples. The typical value of AAS observation is 0.46293 ppm. The highest observation is 0.9321 ppm and lowest is 0.136 ppm.

Table 27: AAS Observations for Zn in HCl Digested solution

Samples	Nokia 2700	Nokia 1650	Nokia 1108	Meni Max D-5027	Siemens A-50	Motorola-C1-68	Movil-MCI-CDMA	Samsung-D 500	Nokia-72	Motorola W-220
Volume in ml	142	110	82	73	185	87	95	100	147	98
Dilution Factor	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
AAS Reading	0.322	0.1809	0.104	**0.136**	0.7021	0.768	**0.9321**	0.4007	0.3145	0.769

3.6.2. Aqua-regia Digested Sample Observations

It is fact that all metals are not miscible in particular solution because affinity of metals towards the particular acid varies chemically. In view of that the residue left after HCl treatment ought to have metals in its composition. Hence, the residue needs to be analysed for the metals. It is fact that maximum metals have good affinity with concentrated HCl and aqua-regia. Hence, it is mandatory to treat the residue with aqua-regia; so that the metals present in the residue may be analysed separately. But, the wet residue cannot put directly to aqua-regia solution because it reduces its concentration. So, it is dried before aqua-regia treatment. The wet residue is dried at 120 ^{0} C in desiccator for 72 hrs. The dry residue has become the sample for Aqua-regia treatment. The dry residue is treated with aqua-regia solution so that it is submerged fully. Generally 1:5 ratios are observed for solute to solvent. The solution is digested at hot plate at 60 ^{0} C for five to ten minutes. Further, the aqua-regia digested solution is filtered and separated from the residue. The digested solution so obtained is being analysed again for ten metals in ten samples as mentioned in HCl treatment. However, the residue obtained after aqua-regia treatment still contains metals in micro. The metals are aluminium. In the subsequent tables the observations of AAS have been recorded from aqua-regia treated analyte.

Aluminium

The **Table 28** shows the AAS observations of Al contents in the aqua-regia solution. The Al metal is more in the analyte as the dilution factor is merely 1000. The observation shows that the metal contents are almost uniformly exist in each PCB samples. The typical AAS observation among ten samples for aluminium is 1.59014 ppm. The highest observation is 2.6153 ppm and lowest is 1.1709 ppm.

Table 28: AAS Observations for Al in Aqua-regia Digested solution

Samples	Nokia 2700	Nokia 1650	Nokia 1108	Meni Max D-5027	Siemens A-50	Motorola-C1-68	Movil-MCI-CDMA	Samsung-D 500	Nokia-72	Motorola W-220
Volume in ml	26	21	13	14	37	19	30	19	33	26
Dilution Factor	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
AAS Reading	1.4054	1.5885	**2.6153**	1.7157	1.6427	1.5852	1.4826	1.3947	1.3006	**1.1707**

Gold

The FASS observation shows that the Au is available in traces in all samples. The dilution factor is 100000 for all samples. The observation ranges from 0.0001ppm–0.0006 ppm (**Table 29**). The typical AAS observation for ten samples is 0.000468 ppm. The observation shows that the variability in gold contents in the samples.

Table 29: AAS Observations for AuinAqua-regia Digested solution

Samples	Nokia 2700	Nokia 1650	Nokia 1108	Meni Max D-5027	Siemens A-50	Motorola-C1-68	Movil-MCI-CDMA	Samsung-D 500	Nokia-72	Motorola W-220
Volume in ml	26	21	13	14	37	19	30	19	33	26
Dilution Factor	100000	100000	100000	100000	100000	100000	100000	100000	100000	100000
AAS Reading	0.0005	0.0005	**0.0013**	0.0003	**0.0001**	0.00035	0.0001	0.0006	0.00046	0.00046

Copper

The AAS observation shows that the copper metal contents are more than the gold in all samples. The dilution factor is 25000 for all samples. Higher dilution factor shows the presence of metals in abundance. However, the copper metal exists in different proportions in the samples. The observation ranges from 0.7632 ppm-1.97 ppm. The typical value of the AAS observation is 1.318812 ppm (**Table 30**).

Table 30: AAS Observation for Cu in Aqua-regia Digested solution

Samples	Nokia 2700	Nokia 1650	Nokia 1108	Meni Max D-5027	Siemens A-50	Motorola-C1-68	Movil-MCI-CDMA	Samsung-D 500	Nokia-72	Motorola W-220
Volume in ml	26	21	13	14	37	19	30	19	33	26
Dilution Factor	25000	25000	25000	25000	25000	25000	25000	25000	25000	25000
AAS Reading	**1.97**	1.384	1.156	1.01852	1.194	1.3941	**0.7632**	1.4683	1.5965	1.2435

Lead

The AAS observations show that Pb exists in traces. The dilution factor is 100. The lead metal exists in each sample. The typical observation of Pb is 0.446188 ppm (**Table 31**). However, Pb is in the list of RoHS. The highest observation is 0.79032 ppm and lowest is 0.325 ppm.

Table 31: AAS Observations for Pb in Aqua-regia Digested solution

Samples	Nokia 2700	Nokia 1650	Nokia 1108	Meni Max D-5027	Siemens A-50	Motorola-C1-68	Movil-MCI-CDMA	Samsung-D 500	Nokia-72	Motorola W-220
Volume in ml	26	21	13	14	37	19	30	19	33	26
Dilution Factor	100	100	100	100	100	100	100	100	100	100
AAS Reading	0.25769	**0.25**	0.355	0.512	0.46743	0.50432	**0.79032**	0.3675	0.39762	0.56

Manganese

AAS observation shows that Mn exists in each sample more than lead in traces. The dilution factor is used as 100 uniformly for each sample. The typical AAS value in array of ten samples of Mn is 0.53903 ppm (**Table 32**). The highest value of observation is 0.893 ppm and 0.224 ppm.

Table 32: AAS Observations for Mn in Aqua-regia Digested solution

Samples	**Nokia 2700**	**Nokia 1650**	**Nokia 1108**	**Meni Max D-5027**	**Siemens A-50**	**Motorola-C1-68**	**Movil-MCI-CDMA**	**Samsung-D 500**	**Nokia-72**	**Motorola W-220**
Volume in ml	26	21	13	14	37	19	30	19	33	26
Dilution Factor	100	100	100	100	100	100	100	100	100	100
AAS Reading	**0.224**	0.69	0.842	0.7275	0.612	0.458	**0.893**	0.3128	0.244	0.387

Silver

The AAS observations for Ag shows that it exists in traces in all samples and but less to Mn metal. The dilution factor is 10000 uniformly to all samples. AAS observation ranges from 0.13043 ppm-0.56923 ppm. The typical value of AAS of ten samples is 0.326483 ppm (**Table 33)**.

Table 33: AAS Observation for Agin aqua-regia Digested solution

Samples	**Nokia 2700**	**Nokia 1650**	**Nokia 1108**	**Meni Max D-5027**	**Siemens A-50**	**Motorola-C1-68**	**Movil-MCI-CDMA**	**Samsung-D 500**	**Nokia-72**	**Motorola W-220**
Volume in ml	26	21	13	14	37	19	30	19	33	26
Dilution Factor	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000
AAS Reading	**0.56923**	0.2143	0.4905	0.2963	0.19903	0.27905	**0.13043**	0.3891	0.4236	0.27329

Iron

The AAS observation shows that iron contents are exist in the samples more to the silver. The dilution factor is 10000, used uniformly for all samples. The typical observation of AAS for Fe is 0.209811ppm (**Table 34**). The highest value of observation is 0.3369 ppm and lowest value is0.13358 ppm.

Table 34: AAS Observations for Fe in Aqua-regia Digested solution

Samples	Nokia 2700	Nokia 1650	Nokia 1108	Meni Max D-5027	Siemens A-50	Motorola-C1-68	Movil-MCI-CDMA	Samsung-D 500	Nokia-72	Motorola W-220
Volume in ml	26	21	13	14	37	19	30	19	33	26
Dilution Factor	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000
AAS Reading	**0.3369**	0.2085	**0.13358**	0.16814	0.2109	0.19673	0.24677	0.19653	0.16032	0.23965

Tin

The **Table 35** shows that metal Sn exists in traces in all samples of PCB. The dilution factor is 1000. The typical value of AAS observation is 0.136024 ppm. The highest observation is0.22634 ppm and lowest is 0.09259 ppm.

Table 35: AAS Observations for Sn in Aqua-regia Digested solution

Samples	Nokia 2700	Nokia 1650	Nokia 1108	Meni Max D-5027	Siemens A-50	Motorola-C1-68	Movil-MCI-CDMA	Samsung -D 500	Nokia-72	Motor ola W-220
Volume in ml	26	21	13	14	37	19	30	19	33	26
Dilution Factor	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
AAS Reading	0.2	0.13392	0.12452	**0.09259**	0.1043	0.1105	**0.22634**	0.10056	0.12653	0.14098

Nickel

The **Table 36** shows that nickel exists in each sample. The dilution factor is 10000 for each sample. The typical value of the Ni is 1.547387 ppm. The highest observation is 2.0392 ppm and lowest is 0.6153 ppm.

Table 36: AAS Observations for Ni in Aqua-regia Digested solution

Samples	Nokia 2700	Nokia 1650	Nokia 1108	Meni Max D-5027	Siemens A-50	Motorola-C1-68	Movil-MCI-CDMA	Samsung-D 500	Nokia-72	Motorola W-220
Volume in ml	26	21	13	14	37	19	30	19	33	26
Dilution Factor	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000
AAS Reading	**0.6153**	**2.0392**	1.2415	1.3111	1.4096	1.5598	2.1067	1.40867	1.891	1.891

Zinc

The metal zinc exists more in the samples. The AAS observation shows that the metal is available in abundance. The dilution factor is 25000 uniformly. The typical value of AAS observation is 0.37078 ppm (**Table 37**). The highest value is 0.7874 ppm and lowest value of observation is 0.028 ppm.

Table 37: AAS Observations for Zn in Aqua-regia Digested solution

Samples	Nokia 2700	Nokia 1650	Nokia 1108	Meni Max D-5027	Siemens A-50	Motorola-C1-68	Movil-MCI-CDMA	Samsung-D 500	Nokia-72	Motorola W-220
Volume in ml	26	21	13	14	37	19	30	19	33	26
Dilution Factor	25000	25000	25000	25000	25000	25000	25000	25000	25000	25000
AAS Reading	0.3343	0.664	**0.028**	0.0245	0.687	0.2067	**0.7874**	0.332	0.2674	0.3765

3.6.3. Equation for Calculation

The metal contents are always directly proportional to the analyte volume. The general formula is used for metal calculation from FAAS reading is presented as:

$$\textbf{Metal Contents (in mg)} = (\textbf{Total volume of Digested solution}(\textbf{ml}^{*})\ \textbf{x Dilution Factor x FAAS Reading}^{+}$$

*convert ml in litre,

+in mg per litre.

The volume of the digested sample is proportion to the weight of the non-magnetic metals present as metalloid after roasting.

The observations are the mean of three observations already concluded by the equipment. These observations are converted into the respective weights of the specific metals available in the digested samples of the aqueous solution of both HCl and Aqua-regia. The AAS observations are in ppm and the volume of the digested solution in ml. Convert these observations as per desired metal content units. In the next chapter, the weight of the respective metals in each sample is tabulated.

CHAPTER 4
RESULTS AND DISCUSSION

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The results and discussion is important aspect to measure the dimensions of the problem. The PCB of the mobile phone has precious, base and toxic metals in different composition. The presence of these metals clarifies the definite metallic composition of the PCB. In India, the management of mobile phone is in transition and need reforms accordingly.

4.1. METALS ANALYSIS OF DIGESTED SAMPLES

The analyte of digested solution of HCl and aqua-regia have been analysed qualitatively and quantitatively for ten metals for ten samples. The metals are gold, silver, copper, aluminium, iron, manganese, tin, zinc, lead and nickel and Samples are Nokia 2700, Nokia 1650, Nokia 1108, Meni-Max D-5027, Siemens A-50, Motorola-C1-68, Movil-MCI-CDMA, Samsung-D 500, Nokia- 72, and Motorola W-220. Based upon the AAS observation, the weight of the individual metal in each sample in digested analyte of conc. HCl and aqua-regia are being calculated to ascertain the affinity of each metal towards both solutions. In the subsequent figures, all metals are being presented.

4.1.1. Aluminium

The aluminium metal has more affinity towards conc. HCl and less towards the Aqua-regia solution in all samples (**Figure 33**). The sample Siemens A-50 has more aluminium metal in HCl and Aqua-regia solutions, **Table 38**. Among all samples, the typical value of aluminium contents in Conc. HCl and Aqua-regia solutions is 0.14521g and 0.03628g respectively. The SD of the aluminium contents in HCl solution of all samples is 0.043 and in Aqua-regia solution it is 0.011.

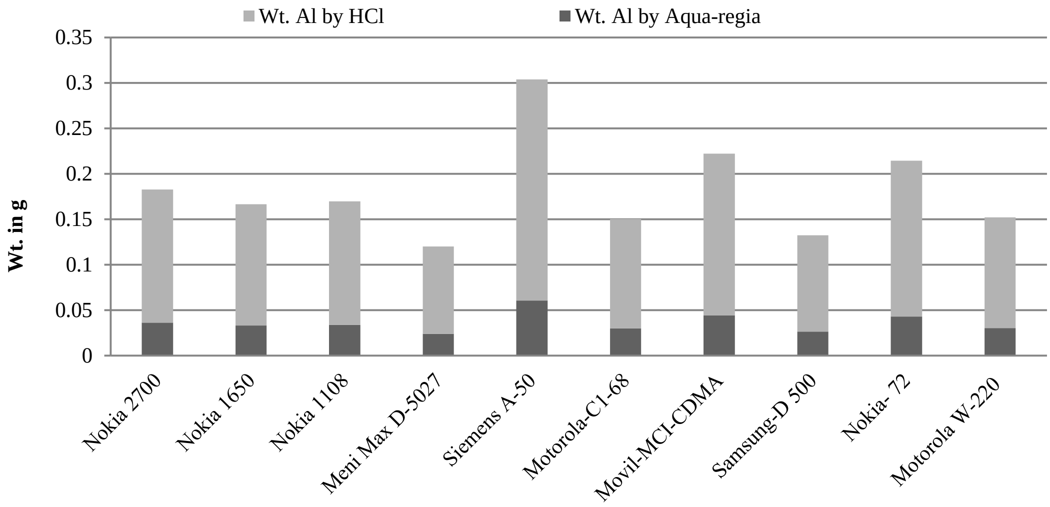

Figure 33: Metal Composition of Al in PCB by HCl and Aqua-regia Digestion

Table 38: Aluminium in HCl and Aqua-regia Digested Solution (g)

Sample	Al in HCl	Alin Aqua-regia
Nokia 2700	0.1461	0.0365
Nokia 1650	0.1334	0.0333
Nokia 1108	0.1359	0.034
Meni Max D-5027	0.096	0.024
Siemens A-50	0.2431	0.0607
Motorola-C1-68	0.1204	0.0301
Movil-MCI-CDMA	0.1779	0.0444
Samsung-D 500	0.106	0.0265
Nokia- 72	0.1716	0.0429
Motorola W-220	0.1217	0.0304

4.1.2. Gold

Similarly, Gold has more affinity towards conc. HCl and less towards the aqua-regia solution in maximum samples (**Figure 34**). The sample Siemens A-50 has more gold in HCl solution and Nokia 1108, Nokia 72 have more gold contents in Aqua-regia solutions, **Table 39**. Among all samples, the typical value of gold contents in Conc. HCl and Aqua-regia solutions is 0.0012g and 0.00089g respectively. The SD of the gold contents in HCl solution of all samples is 0.0011 and in Aqua-regia solution it is 0.0009.

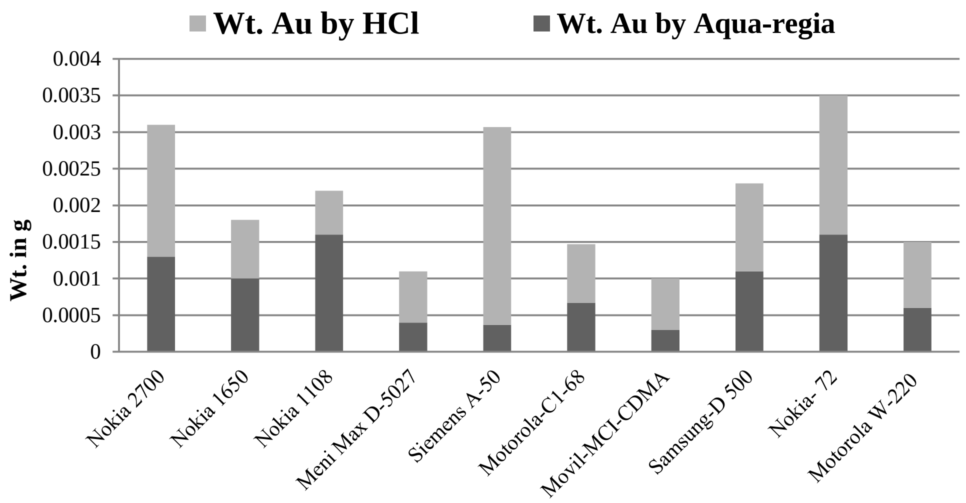

Figure 34: Metal Composition of Au in PCB by HCl and Aqua-regia Digestion

Table 39: Gold in HCl and Aqua-regia Digested Solution (g)

Sample	Au in HCl	Au in Aqua-regia
Nokia 2700	0.0018	0.0013
Nokia 1650	0.0008	0.001
Nokia 1108	0.0006	<u>0.0016</u>
Meni Max D-5027	0.0007	0.0004
Siemens A-50	<u>0.0027</u>	0.00037
Motorola-C1-68	0.0008	0.00067
Movil-MCI-CDMA	0.0007	0.0003
Samsung-D 500	0.0012	0.0011
Nokia- 72	0.0019	<u>0.0016</u>
Motorola W-220	0.0009	0.0006

4.1.3. Copper

Copper has more affinity towards conc. HCl and less towards the aqua-regia solution in all samples (**Figure 35**). The sample Nokia 72 has more copper in HCl solution as well as in Aqua-regia solutions, **Table 40**. Among all samples, the typical value of copper contents in Conc. HCl and Aqua-regia solutions is 1.92982g and 0.79006g respectively. The SD of the copper contents in HCl solution of all samples is 0.545 and in Aqua-regia solution it is 0.342.

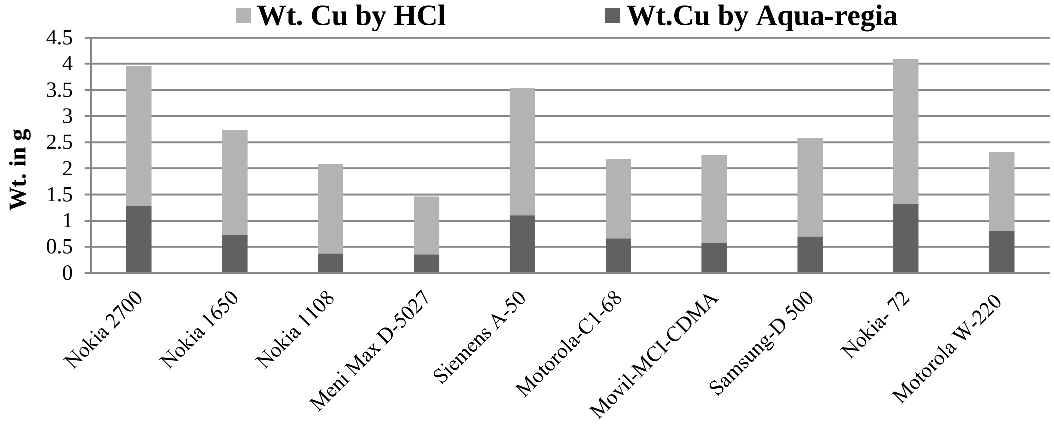

Figure 35: Metal Composition of Cu in PCB by HCl and Aqua-regia Digestion

Table 40: Copper in HCl and Aqua-regia Digested Solution (g)

Sample	Cu in HCl	Cu in Aqua-regia
Nokia 2700	2.6772	1.2804
Nokia 1650	2.0061	0.7266
Nokia 1108	1.7065	0.3756
Meni Max D-5027	1.1075	0.3564
Siemens A-50	2.429	1.1044
Motorola-C1-68	1.5141	0.6621
Movil-MCI-CDMA	1.6847	0.5724
Samsung-D 500	1.887	0.6974
Nokia- 72	2.7791	1.3171
Motorola W-220	1.507	0.8082

4.1.4. Lead

Lead has utmost affinity towards conc. HCl and least towards the aqua-regia solution in all samples (**Figure 36**). The sample Movil MCI CDMA has more lead in HCl solution as well as in Aqua-regia solutions, **Table 41**. Among all samples, the typical value of lead contents in Conc. HCl and Aqua-regia solutions is 0.018g and 0.0.0011g respectively. The SD of the lead contents in HCl solution of all samples is 0.018 and in Aqua-regia solution it is 0.0006.

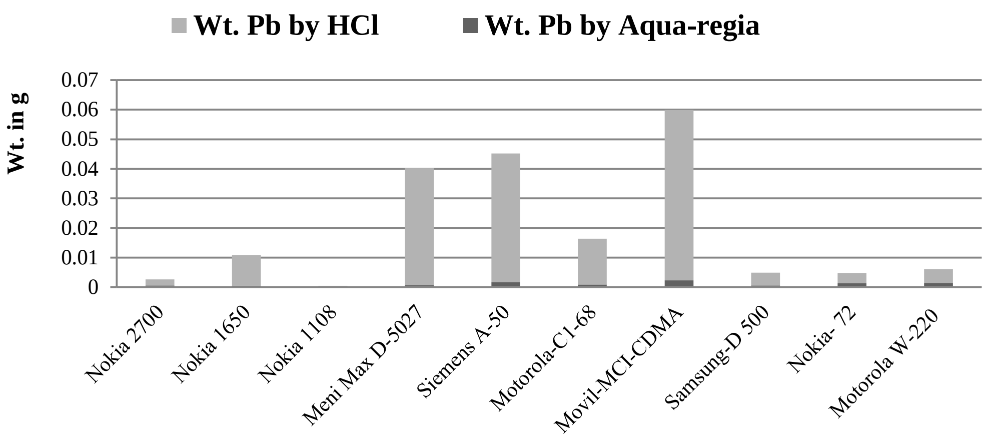

Figure 36: Metal Composition of Pb in PCB by HCl and Aquaregia Digestion

Table 41: Lead in HCl and Aqua-regia Digested Solution (g)

Sample	Pb in HCl	Pbin Aqua-regia
Nokia 2700	0.002	0.0006
Nokia 1650	0.0104	0.0005
Nokia 1108	0.0001	0.0004
Meni Max D-5027	0.0395	0.0007
Siemens A-50	0.0435	0.0017
Motorola-C1-68	0.0155	0.0009
Movil-MCI-CDMA	0.0576	0.0023
Samsung-D 500	0.0043	0.0006
Nokia- 72	0.0035	0.0013
Motorola W-220	0.0047	0.0014

4.1.5. Manganese

Similarly, Manganese has utmost affinity towards conc. HCl and least towards the aqua-regia solution in all samples (**Figure 37**). The sample Siemens A-50 has more manganese in HCl solution as well as in Aqua-regia solutions, **Table 42**. Among all samples, the typical value of manganese contents in Conc. HCl and Aqua-regia solutions is 0.019g and 0.0.0012g respectively. The SD of the manganese contents in HCl solution of all samples is 0.008 and in Aqua-regia solution it is 0.0007.

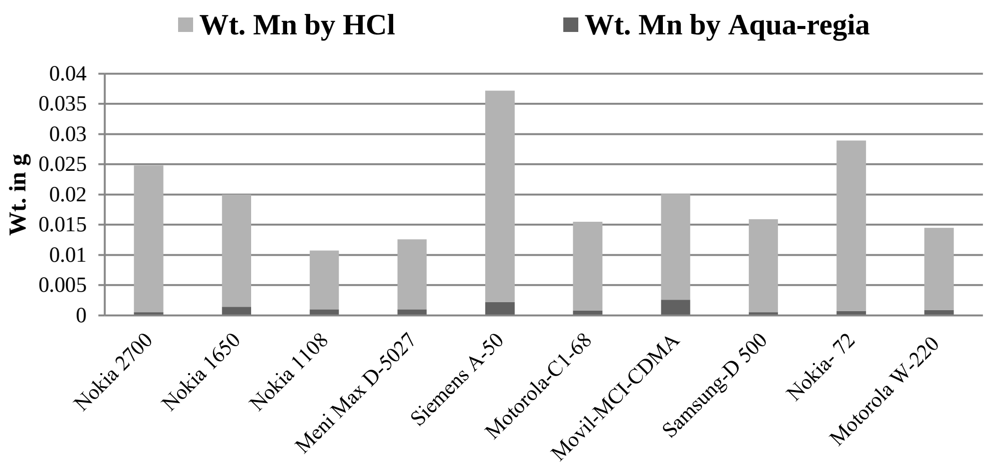

Figure 37: Metal Composition of Mn in PCB PCB by HCl and Aquaregia Digestion

Table 42: Manganese in HCl and Aqua-regia Digested Solution (g)

Sample	Mn in HCl	Mnin Aqua-regia
Nokia 2700	0.0243	0.0005
Nokia 1650	**0.0186**	**0.0014**
Nokia 1108	0.0097	0.001
Meni Max D-5027	**0.0116**	**0.001**
Siemens A-50	0.035	0.0022
Motorola-C1-68	**0.0147**	**0.0008**
Movil-MCI-CDMA	0.0175	0.0026
Samsung-D 500	**0.0154**	**0.0005**
Nokia- 72	0.0282	0.0007
Motorola W-220	**0.0136**	**0.0009**

4.1.6. Silver

Silver has utmost affinity towards Aqua-regia solution and least in conc. HCl in all samples (**Figure 38**). The sample Nokia 2700 has more silver in aqua-regia and Siemens A-50 has more silver contents in HCl solution, **Table 43**. Among all samples, the typical value of silver contents in Aqua-regia solutions and Conc. HCl is 0.07482g and 0.0.01886g respectively.

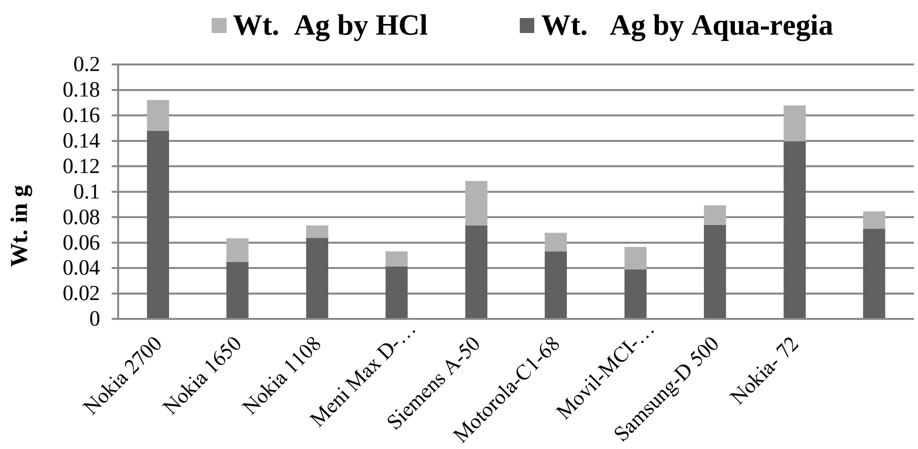

Figure 38: Metal Composition of Ag in PCB by HCl and Aqua-regia Digestion

The SD of the silver contents in Aqua-regia solution is 0.0387 and in HCl solution it is 0.0079.

Table 43: Silver in Aqua-regia and HCl Digested Solution (g)

Sample	Agin Aqua-regia	Ag in HCl
Nokia 2700	0.1479	0.0243
Nokia 1650	0.0449	0.0186
Nokia 1108	0.0637	0.0097
Meni Max D-5027	0.0414	0.0116
Siemens A-50	0.0736	0.035
Motorola-C1-68	0.053	0.0147
Movil-MCI-CDMA	0.0391	0.0175
Samsung-D 500	0.0739	0.0154
Nokia- 72	0.1397	0.0282
Motorola W-220	0.071	0.0136

4.1.7. Iron

Similarly, Iron has utmost affinity towards conc. HCl and least towards the aqua-regia solution in all samples (**Figure 39**). The sample Nokia 2700 has more iron in HCl solution as well as in Aqua-regia solutions, **Table 44**. Among all samples, the typical value of iron contents in Conc. HCl and Aqua-regia solutions is 0.1263g and 0.0.052g respectively.

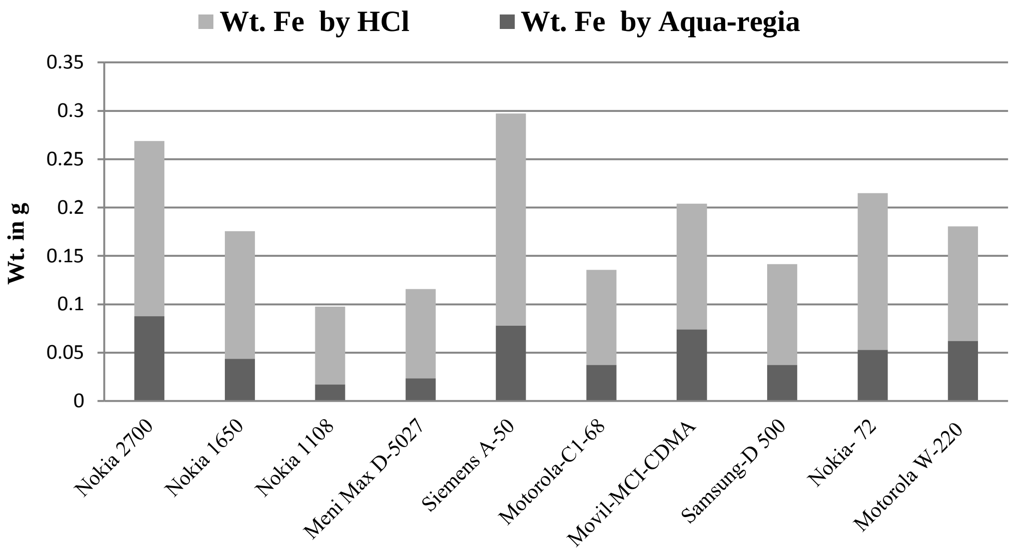

Figure 39: Metal composition of Fe in PCB by HCl Digestion and Aqua-regia

The SD of the iron contents in HCl solution of all samples is 0.057 and in Aqua-regia solution it is 0.024.

Table 44: Iron in HCl and Aqua-regia Digested Solution (g)

Sample	Fe in HCl	Fein Aqua-regia
Nokia 2700	0.1813	0.0875
Nokia 1650	0.132	0.0437
Nokia 1108	0.0804	0.0173
Meni Max D-5027	0.0922	0.0235
Siemens A-50	0.2194	0.078
Motorola-C1-68	0.0983	0.0373
Movil-MCI-CDMA	0.1299	0.074
Samsung-D 500	0.1042	0.0373
Nokia- 72	0.1621	0.0528
Motorola W-220	0.1184	0.0623

4.1.8. Tin

Tin has utmost affinity towards Aqua-regia solution and least in conc. HCl in all samples (**Figure 40**). The sample Nokia 2700 has more tin in aqua-regia as well as in HCl solution, **Table 45**.

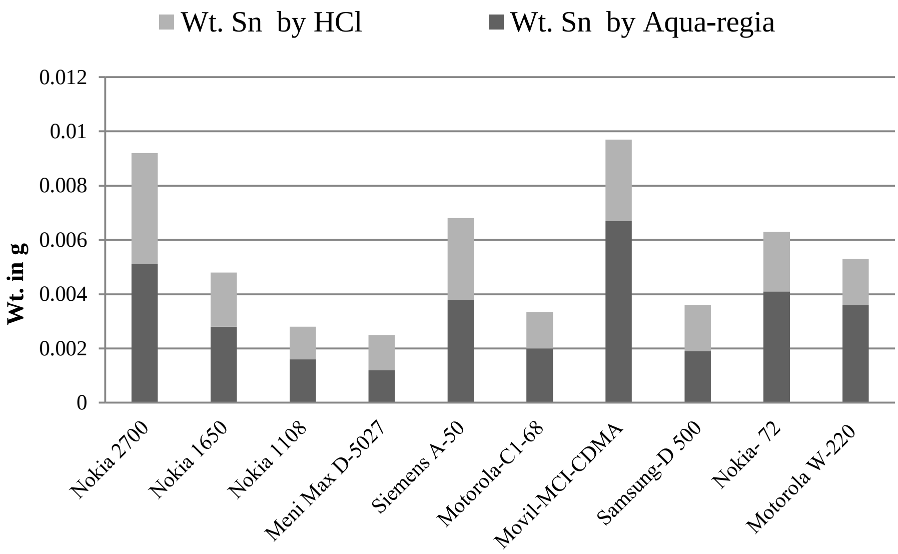

Figure 40: Metal Composition ofSn in PCB by HCl and Aqua-regia Digestion

Among all samples, the typical value of silver contents in Aqua-regia solutions and Conc. HCl is 0.0033g and 0.0.0022g respectively. The SD of the tin contents in Aqua-regia solution is 0.0017 and in HCl solution it is 0.0009.

Table 45: Tin in HCl and Aqua-regia Digested Solution (g)

Sample	Snin Aqua-regia	Sn in HCl
Nokia 2700	0.0051	0.0041
Nokia 1650	0.0028	0.002
Nokia 1108	0.0016	0.0012
Meni Max D-5027	0.0012	0.0013
Siemens A-50	0.0038	0.003
Motorola-C1-68	0.002	0.00134
Movil-MCI-CDMA	0.0067	0.003
Samsung-D 500	0.0019	0.0017
Nokia- 72	0.0041	0.0022
Motorola W-220	0.0036	0.0017

4.1.9. Nickel

The metal Nickel has utmost affinity towards Aqua-regia solution and least in conc. HCl in all samples (**Figure 41**). The sample Nokia 72 has more tin in aqua-regia and Nokia 1650 has more Nickel contents in HCl solution (**Table 46)**.

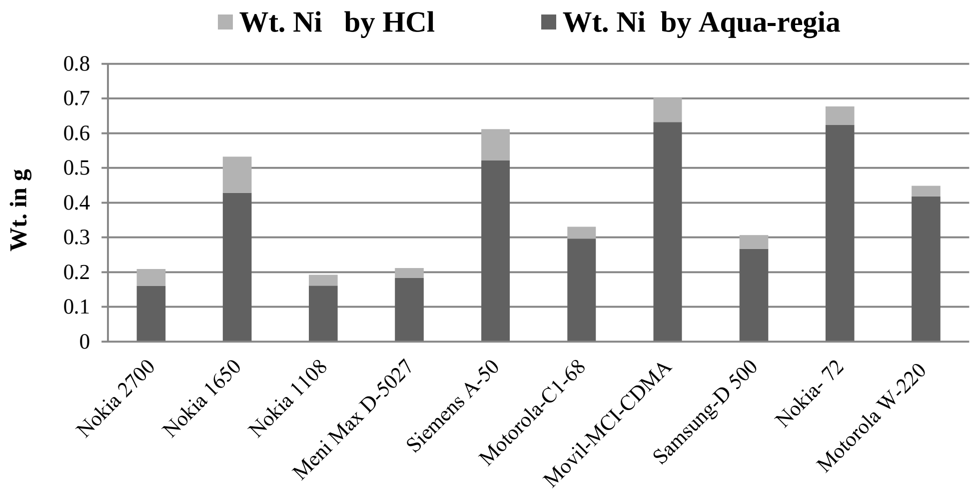

Figure 41: Metal Composition of Ni in PCB by HCl and Aqua-regia Digestion

Among all samples, the typical value of nickel contents in Aqua-regia solutions and Conc. HCl is 0.369g and 0.0.053g respectively. The SD of the aluminium contents in Aqua-regia solution is 0.183 and in HCl solution it is 0.027.

Table 46: Nickel in HCl and Aqua-regia Digested Solution (g)

Sample	Ni in Aqua-regia	Ni in HCl
Nokia 2700	0.1599	0.0488
Nokia 1650	0.4282	0.1042
Nokia 1108	0.16138	0.031
Meni Max D-5027	0.1835	0.0287
Siemens A-50	0.5215	0.0902
Motorola-C1-68	0.2963	0.0345
Movil-MCI-CDMA	0.632	0.0701
Samsung-D 500	0.2676	0.0396
Nokia- 72	0.624	0.0529
Motorola W-220	0.4182	0.0306

4.1.10. Zinc

Zinc has utmost affinity towards Aqua-regia solution and least in conc. HCl in almost all samples (**Figure 42**). The sample Movil-MCI CDMA has more zinc in aqua-regia and Siemens A-50 has more Nickel contents in HCl solution, **Table 47**. Among all samples, the typical value of nickel contents in Aqua-regia solutions and Conc.

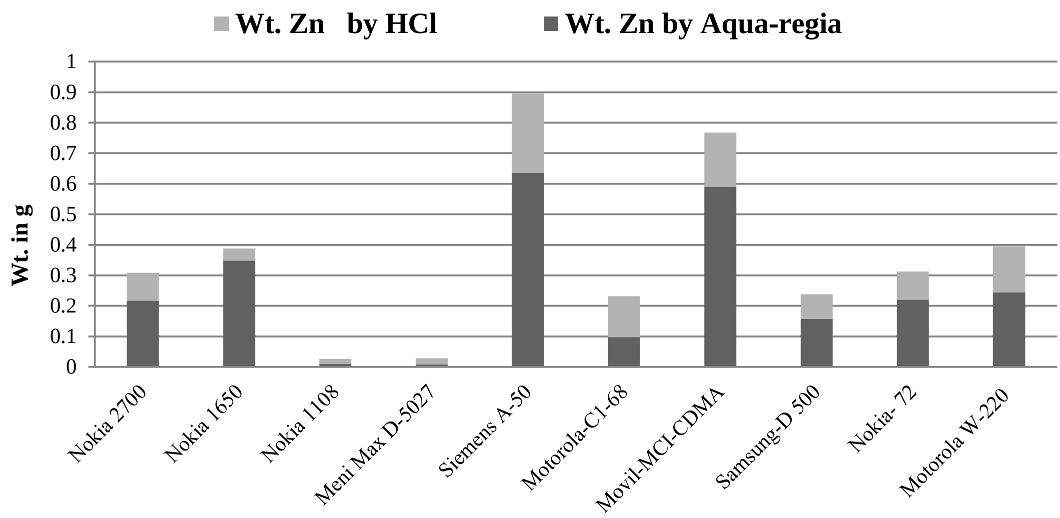

Figure 42: Metal Composition of Zn in PCB by HCl Digestion and Aqua-regia

HCl is 0.257g and 0.0.106g respectively. The SD of the aluminium contents in Aqua-regia solution is 0.217 and in HCl solution it is 0.076.

Table 47: Zinc in HCl and Aqua-regia Digested Solution (g)

Sample	Zn in Aqua-regia	Zn in HCl
Nokia 2700	0.2172	0.0914
Nokia 1650	0.3485	0.0397
Nokia 1108	0.0091	0.017
Meni Max D-5027	0.0086	0.0198
Siemens A-50	0.6354	0.2597
Motorola-C1-68	0.0981	0.1336
Movil-MCI-CDMA	0.5905	0.177
Samsung-D 500	0.1577	0.0801
Nokia- 72	0.2205	0.0924
Motorola W-220	0.2447	0.1507

4.2. METALS BALANCE OF PCB

The study focuses on ten metals of precious, base, and toxic attributes of mobile phone PCB samples. The metals are aluminium, gold, copper, lead, manganese, silver, iron, tin, nickel, and zinc. The metals composition of PCB varies with their intended usage for the features in the mobile phone as more features have more components and circuits in PCB and concurrently more metals in it. Among all samples, aluminium co-exists maximum in Siemens A-50 as 0.3038g and minimum in Meni Max D-5027 as 0.12g.

Table 48: Metal Balance in PCB (g)

Sample	Al	Au	Cu	Pb	Mn	Ag	Fe	Sn	Ni	Zn	Total
Nokia 2700	0.1826	0.00319	3.9577	0.0026	0.0249	**0.1722**	0.2689	0.0093	0.2088	0.3087	**5.13889**
Nokia 1650	0.1667	0.00189	2.7327	0.0109	0.0201	0.0635	0.1758	0.0049	0.5325	0.3883	**4.09729**
Nokia 1108	0.1699	0.00234	2.0822	**0.0005**	**0.0108**	0.0734	**0.0977**	0.0028	**0.1924**	**0.0261**	**2.65814**
Meni Max D-5027	**0.12**	0.00118	**1.464**	0.0402	0.0127	**0.053**	0.1157	**0.0026**	0.2122	0.0284	***2.04998***
Siemens A-50	**0.3038**	0.00302	3.5335	0.0452	0.0373	0.1086	**0.2974**	0.0069	0.6118	0.8952	**5.84272**
Motorola-C1-68	0.1505	0.00148	2.1763	0.0164	0.0156	0.0677	0.1357	0.0034	0.3309	0.2318	**3.12978**
Movil-MCI-CDMA	0.2223	**0.00105**	2.2571	**0.06**	0.0202	0.0566	0.2039	**0.0098**	**0.7022**	**0.7676**	**4.30075**
Samsung-D 500	0.1325	0.00236	2.5844	0.005	0.016	0.0893	0.1415	0.0036	0.3072	0.2378	**3.51966**
Nokia- 72	0.2145	**0.0035**	**4.0962**	0.0048	**0.029**	0.1679	0.215	0.0064	0.677	0.313	**5.7273**
Motorola W-220	0.1521	0.00156	2.3153	0.0062	0.0146	0.0846	0.1807	0.0054	0.4489	0.3954	**3.60476**
Mean	0.18149	0.00216	2.71994	0.0191	0.0201	0.0936	0.18323	0.0055	0.4223	0.3592	4.00692
STDEV	**0.0538**	**0.0008**	**0.867**	**0.022**	**0.0082**	**0.0434**	**0.0647**	**0.0025**	**0.1989**	**0.282**	**1.27**

Similarly, gold in Nokia 72 is utmost as 0.0035g and lower most in Movil-MCI-CDMA as 0.00105g; copper maximum in Nokia 72 as 4.0962g and minimum in Meni Max D-5027 as 1.464g; lead in Movil-MCI-CDMA is maximum as 0.06g and minimum in Nokia 1108 as 0.0005g; manganese in Nokia 72 as 0.029g and minimum in Nokia 1108 as 0.0108g; silver in Nokia 2700 is maximum as 0.1722g and minimum in Meni Max D-5027 as 0.053g; iron in metalloids in Siemens A-50 is maximum as 0.2974g and minimum in Nokia 1108 as 0.0977g; tin in Movil-MCI-CDMA maximum as 0.0098g and minimum in Meni Max D-5027 as 0.0026g; nickel in Movil-MCI-CDMA is maximum as 0.7022g and minimum in Nokia 1108 as 0.1924g and zinc in Movil-MCI-CDMA is maximum as 0.7676g and minimum in Nokia 1108 as 0.0261g, **(Table 48)**. The maximum metals are recoverable from Siemens A-50 as 5.84272g and the least metals are recoverable from Meni Max D-5027 as 2.04998g from each sample.

The variability in individual metals is presented by mean and standard deviation in respective metals in the samples. The typical value of aluminium is 0.18149g, gold 0.00216, copper 2.71994, lead 0.0191, manganese 0.0201g, silver 0.0936g, iron 0.18323g, tin 0.0055g, nickel 0.4223g and zinc 0.3592g among all samples respectively. The mean value of recoverable metal is 4.00692g. The standard deviation in aluminium is0.0538, in gold it is 0.0008, in copper it is 0.867, in lead it is 0.022, in manganese, it is 0.0082, in silver it is 0.0434, in iron it is 0.0647, in tin, it is 0.0025, in nickel, it is 0.1989 and in zinc, it is 0.282. The standard deviation in copper is maximum and least in gold. The standard deviation in recoverable metals is 1.27.

4.3. METALS BALANCE PERCENTAGE

The metals in the PCB are available in proportion to its weight. The weight percentage varies with weight of the individual metal and the weight of the PCB.

More the weight of the metal to the less weight of PCB arrives to be more weight percentage as compared to the less weight of the metal and more weight of the PCB and vice versa. The individual weight is quite different to the weight percentage. It may or may not be equal to the weight percentage.

$$\textbf{Weight Percentage} = \frac{\textbf{Weight of Metal}}{\textbf{Weight of PCB}} \times \textbf{100}$$

Table 49: Metal Balance Weight Percentage of Recoverable Metals from each PCB

Sample	PCB(g)	Al	Au	Cu	Pb	Mn	Ag	Fe	Sn	Ni	Zn	Total wt. %age
Nokia 2700	18.895	0.96	**0.017**	**20.94**	0.01	**0.13**	**0.92**	**1.42**	0.04	**1.1**	1.63	**27.197**
Nokia 1650	15.75	1.05	0.012	17.35	0.06	0.12	0.41	1.11	0.03	3.38	2.46	**26.01**
Nokia 1108	14.1419	1.2	0.016	14.72	**0.004**	**0.07**	0.52	**0.69**	**0.02**	1.36	**0.18**	**18.79**
Meni Max D-5027	**12.5831**	**0.95**	**0.009**	**11.63**	**0.31**	0.10	0.42	0.92	**0.02**	1.68	0.22	***16.29***
Siemens A-50	**29.17**	1.04	0.010	12.11	0.15	0.12	0.37	1.01	**0.02**	2.09	3.06	**20.02**
Motorola-C1-68	14.13	1.06	0.010	15.4	0.11	0.11	0.48	0.96	**0.02**	2.34	1.64	**22.14**
Movil-MCI-CDMA	17.9351	**1.23**	0.006	12.58	0.33	0.11	**0.32**	1.13	**0.05**	**3.91**	**4.28**	**23.97**
Samsung-D 500	14.0938	0.94	**0.017**	18.33	0.03	0.11	0.64	1	**0.02**	2.18	1.68	**24.97**
Nokia- 72	21.2383	1.01	0.016	19.28	0.02	**0.13**	0.79	1.01	0.03	3.18	1.47	**26.96**
Motorola W-220	14.8553	1.02	0.010	15.58	0.04	0.09	0.57	1.21	0.03	3.02	2.66	**24.26**
Mean	**17.3**	**1.046**	**0.012**	**15.79**	**0.106**	**0.109**	**0.54**	**1.05**	**0.03**	**2.42**	**1.9**	**23**
STDEV	4.95	0.099	0.004	3.164	0.122	0.019	0.19	0.19	0.01	0.92	1.2	3.7

Sample Siemens A-50 bears heaviest PCB of 29.17g and Meni Max D-5027 is the lightest as 12.5831g among all samples. In PCB samples, aluminium weight percentages varies from 1.23 to 0.95%, gold weight percentage ranges from 0.017 to 0.009%, weight percentage of copper varies from 20.94 to 11.63%, lead weight percentage varies from 0.31 to 0.004%, the weight percentage of manganese varies from 0.13 to 0.07%, silver weigh percentage varies from 0.92 to 0.32%, the weight percentage of iron varies from 1.42 to 0.69%, tin weight percentage varies from 0.05

to 0.02%, the weight percentage of nickel varies from 3.91 to 1.1% and zinc weight percentage ranges from 0.18 to 4.28% respectively. The weight percentage of total recoverable metals varies from 16.29 to 27.197%, **Table 49**.

The typical value of weight percentage of aluminium 1.046, gold 0.0123, copper 15.792, lead 0.1064, manganese 0.109, silver 0.544, iron 1.046, tin 0.028, nickel 2.424 and zinc 1.928respectively. The minimum weight percentage of aluminium 0.94, gold 0.006, copper 11.63, lead 0.004, manganese 0.07, silver 0.32, iron 0.69, tin 0.02, nickel 1.1 and zinc 0.18 respectively. The typical weight percentage of ten metals under consideration is 23.067%. The weight percentage of recoverable metals of Nokia 2700 is highest among all samples.

The standard deviation of PCB and metals of samples are as PCB – 4.95, aluminium-0.099, gold-0.004, copper-3.164, lead-0.122, manganese-0.019, silver-0.19, iron-0.19, tin-0.01, nickel-0.92, zinc-1.2 and total recoverable metals-3.7 respectively.

4.4. PCB MATERIAL BALANCE

The PCB is composed of organic and inorganic material. The organic material turns to ash during roasting process. The inorganic material also remains along with ash present in residue. In organic material metals are mainly present as metalloids. The material balance of PCB is presented in Table 50. The organic material in PCB ranges from 1.5295g to 5.498g, the magnetic material ranges from 0.5817g to 1.567g and the metalloids ranges from 9.1669g to 22.105g. The extractable metals fluctuate from2.0393g to 5.8111g. The residue remained after aqua-regia treatment in the scale of 7.0451 to 16.2939g. However, the other meals are also available in residue. The typical value of organic material is 2.88378g, magnetic material is 0.86651g, extractable metals are 3.9901g and residue is 9.53886g.

Table 50: Material Balance of PCB (g).

Model	PCB	Organic	Magnetic	Metalloids	Extractable Metals	Residue
Nokia 2700	18.895	1.8622	0.7835	16.2493	5.1173	11.132
Nokia 1650	15.75	2.354	0.6497	12.7463	4.0811	8.6652
Nokia 1108	14.1419	3.8647	**0.5817**	9.6955	2.6504	**7.0451**
Meni Max D-5027	**12.5831**	2.5112	0.905	**9.1669**	**2.0393**	7.1276
Siemens A-50	**29.17**	**5.498**	**1.567**	**22.105**	**5.8111**	**16.2939**
Motorola-C1-68	14.13	2.487	0.8769	10.7661	3.1169	7.6492
Movil-MCI-CDMA	17.9351	4.0586	1.0498	12.8267	4.2841	8.5426
Samsung-D 500	14.0938	**1.5295**	0.8654	11.6989	3.5063	8.1926
Nokia- 72	21.2383	2.4703	0.7875	17.9805	5.7019	12.2786
Motorola W-220	14.8553	2.2023	0.5986	12.0544	3.5926	8.4618
Mean	**17.3**	**2.88378**	**0.86651**	**13.52896**	**3.9901**	**9.53886**

4.5. MOBILE PHONE MATERIAL BALANCE

The mobile phone is made of glass, plastics, steel body, PCB and battery. The mobile phone composition of individual material and component is presented in **Table 50**. The samples of mobile phone are without battery. The weight of the mobile phone is in the range of 48.7164g to 84.1563g; glass in the scale of 3.8092g to 9.37g; steel in the range of 0.92- 34.0731g; plastics ranges from 21.4698g to 43.14g, **Table 51**. The mean value of mobile phone is 63.56739g, glass mean value is 6.7014g, steel value is 9.11448g and plastics mean value is 30.47223g.

The mobile phone weight differs from the mean value by 10.25g. The mean value is also called expected value. Similarly, the glass SD is 1.71g, steel SD is 10.23g, and the SD of plastics is 6.84g. The SD of PCB weight is 4.9g, the SD of organic material is 1.2g and magnetic material is 0.29g and metalloids SD is 4.07g and SD of recoverable metals 1.26g and SD of residue 2.91g, **Table 51**.

Table 51: Material Balance of Mobile Phone without Battery(g)

Model	**Mobile Phone**	**Glass**	**Steel**	**Plastics**	**PCB**	**Organic**	**Magnetic**	**Metalloids**	Metals	Residue
Nokia 2700	60.2687	5.0341	14.2065	22.1331	18.895	1.8622	0.7835	16.2493	5.1173	11.132
Nokia 1650	**48.7164**	5.3535	6.1431	**21.4698**	15.75	2.354	0.6497	12.7463	4.0811	8.6652
Nokia 1108	66.14	**3.8092**	16.1521	32.0368	14.1419	3.8647	**0.5817**	9.6955	2.6504	**7.0451**
Meni Max D-5027	**84.1563**	6.7275	**34.0731**	30.7726	**12.5831**	2.5112	0.905	**9.1669**	**2.0393**	7.1276
Siemens A-50	67.69	**9.37**	1.01	28.14	**29.17**	**5.498**	**1.567**	**22.105**	**5.8111**	**16.2939**
Motorola-C1-68	53.76	7.25	1.2	31.18	14.13	2.487	0.8769	10.7661	3.1169	7.6492
Movil-MCI-CDMA	58.4451	6.15	5.7	28.66	17.9351	4.0586	1.0498	12.8267	4.2841	8.5426
Samsung-D 500	56.1138	7.08	7.63	27.31	14.0938	**1.5295**	0.8654	11.6989	3.5063	8.1926
Nokia- 72	69.2683	7.23	**0.92**	39.88	21.2383	2.4703	0.7875	17.9805	5.7019	12.2786
Motorola W-220	71.1153	9.01	4.11	**43.14**	14.8553	2.2023	0.5986	12.0544	3.5926	8.4618
Mean	**63.56739**	**6.7014**	**9.11448**	**30.47223**	**17.27925**	**2.88378**	**0.86651**	**13.52896**	**3.9901**	**9.53886**
STDEV	10.25	1.71	10.23	6.84	4.9	1.2	0.29	4.07	1.26	2.91
CV	**16.13**	**25.58**	**112.22**	**22.45**	**28.63**	**42.1**	**33.07**	**30.05**	**31.66**	**30.47**

The coefficient of variation (CV) of the composition depends upon the individual component and material in the mobile phone.

$$\textbf{Coefficient of Variation}(\textbf{CV}) = \frac{\textbf{Standard Deviation}}{\textbf{Mean}} \times \textbf{100}$$

The variability in respective material is explained as in mobile phone CV is 16.13%, in glass, it is 25.58%, in steel it is 112.22% and in plastics it is 22.45%, PCB it is 28.63% and in organic material it is 42.1%, in magnetic material it is 33.07%, in metalloids, it is 30.05% and in metals 31.66% and in residue it is it is 30.47%.More value indicates more variation and small value indicate slight variation. The value 112.22% indicates abrupt variation of steel in the PCB.

4.6. TYPICAL METALS IN PCB

The present study makes public the PCB composition as copper (20.94%), aluminium (1.23%), lead (0.33), zinc (4.28%), nickel (3.91%), iron (1.42%), tin (0.05%), manganese 0.13%), gold (170 ppm) and silver 9200 (ppm) respectively. These values are maximum among all values as presented in **Table 52**. It is clear that mobile phone PCB samples have more silver metal contents than gold. Copper and silver metals are being used maximum in the PCB. The toxic metals lead and tin are being used very little in PCB. Zinc and nickel metal contents are being used maximum in PCB manufacturing. Manganese is also present in PCB in low concentration. The presence of precious metals is monetarily more in the samples. The variation in the values may be adjudged by various mathematical calculations and formulae.

The presence of precious, base and toxic metals in E-waste have their own impacts on environment, human health and country economy. In the subsequent paragraphs these aspects are being discussed.

Table 52: Typical metals in PCBs

Material	**Typical Metals (in Wt. percentage and ppm)**				
Metals	**Vats and Singh (2015) Max. Value****	**Ewasteguide.info (2013)**	**Shuey and Taylor (2004)**	**Kim *et al.* (2004)**	**Iji and Yokoyama 1997**
Cu	20.94	6.9	20	15.6	22
Al	1.23	14.2	2	-	-
Pb	0.33	6.3	2	1.35	1.55
Zn	4.28	2.2	1	0.16	-
Ni	3.91	0.85	2	0.28	0.32
Fe	1.42	20.5	8	1.4	3.6
Sn	0.05	1.0	4	3.24	2.6
Mn	**0.13**	-	-	-	-
Au/ppm	170	20	1000	420	350
Ag/ppm	9200	200	2000	1240	-

** The result of present study

4.7. TOXIC METALS HAZARDS

The toxic metals are present in each PCB samples in prorate. These metals are hazards prone and need precautions while deal with them. The concentration of toxic metals varies models to model and brands to brand. The toxic metals beyond permissible limit are harmful to the environment. The consumed toxic metals participating in metabolic process within and beyond permissible limit decide the benefit and harm to the human body.

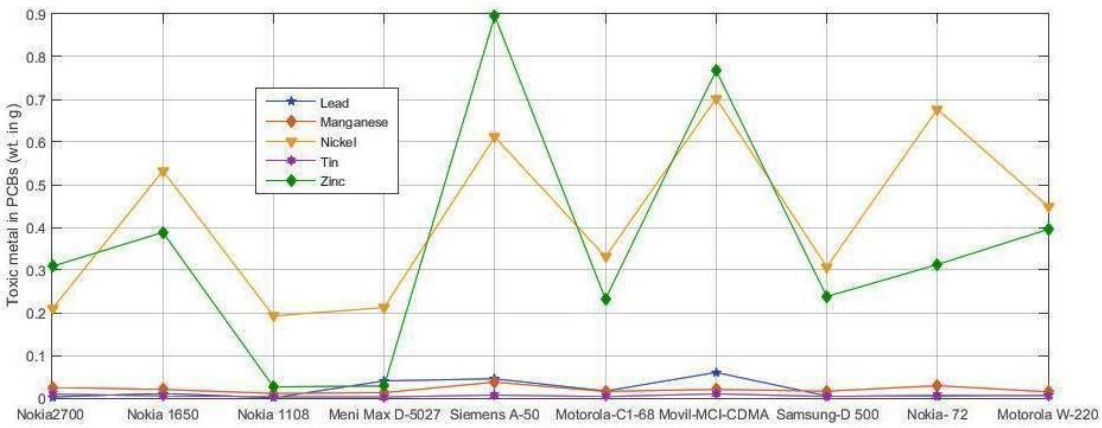

Figure 43: Toxic metal content in assorted mobile phones (g)

But, the toxins through the exposure and ingestion routes are apparently harmful to the human body.

The toxic metals in the assorted samples are presented in **Figure 43**. A huge amount of mobile phone waste is available untouched and expected more in the years to come as its useful life is falling continuously. In the world, only 3% mobile waste is being recycled and 97% waste remains unattended in municipal waste (**Nokia 2008).**An enormous mobile waste remains neglected in the world.

The toxic metals are presented in whisker box plot, **Figure 44**. Nickel metal is available in abundance, followed by zinc and lead. lead is hazardous with respect to the others as it has more damaging potential at minimum concentration. The metals manganese and tin are in traces.

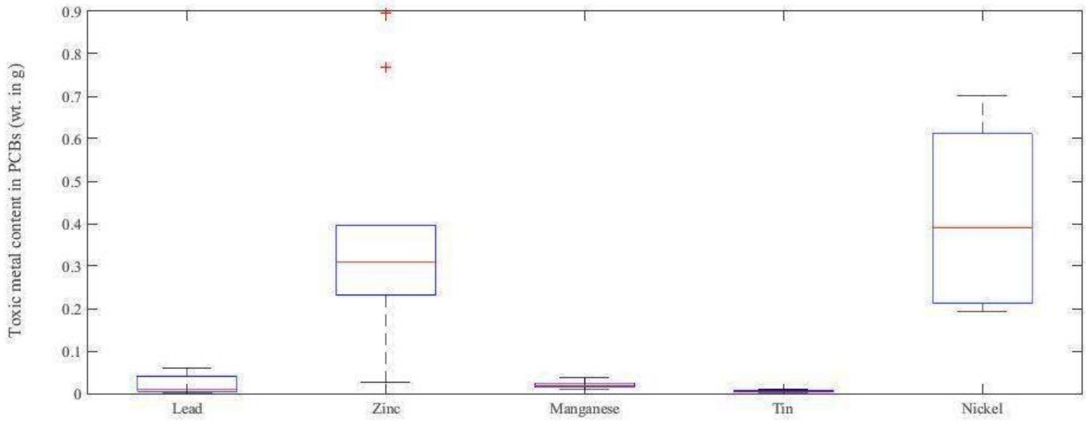

Figure 44: Box plot for toxic metals content in mobile phone PCBs (g)

In 10 million samples, 192 kg lead, 3592 kg zinc, 202 kg manganese, 55 kg tin and 4224 kg nickel is available in discarded mobile phones. The recovery of these metals not only mitigates the pollutants loading on the environment but compensate the metals need also. Additionally, the quality of air, water, and soil also improve. The accumulation of toxic metals in open causes numerous diseases to the public and enhances the treatment overheads in the country. Still, users keep end of life mobile phones either in self-possession or dispose of blithely in the municipal waste. The toxic metals analysed in the study are explained with their potential in the subsequent paragraphs. The toxic metals source and affects are being described along with their permissible limits of exposure as in uncontrolled condition all toxic metals are perilous.

Lead: It is cumulative, neurological poison and carcinogenic to human **(IPMI 2003).** The permissible limit of Lead in air 1.5 µg/m^3, in water 15µg/litre and at work place 50 µg/m^3 **(IPMI 2003)** respectively. It is used in PCB to solder the components. It causes damage to the central and peripheral nervous systems, blood systems, and kidney. It also effects adversely on development of child brain, damage to the circulatory system and kidney **(Poonam 2011).**

Nickel: It is provided in metals layers as metalloids in PCB. While exposure, it causes allergy to the skin disease dermatitis further allergy to the lung causing asthma, when human body exposed to them **(Poonam 2011).** Nickel is carcinogenic to human body **(IPMI 2003).** At workplace, the occupational safety and health administration (OSHA) permissible safe limit is 1 mg/m^3 in a stretch of 8 hours exposure **(Cheryl 2008).**

Tin: It is used as tin, silver and copper (SAC) solder in PCBs. It causes acute diseases as: eye and skin irritations, headaches, stomach-aches, sickness and dizziness, severe sweating, breathlessness, urination problems. The in-organic tin is non-carcinogenic and at workplace its OSHA permissible limit is $2mg/m^3$ **(Cheryl 2008).**

Manganese: It is used for structural and magnetivity purpose in PCB. Its exposure damages central nervous system and pneumonia. Further, it causes weakness, fatigue, confusion, hallucinations, odd or awkward manner of walking (gait), muscle spasms (dystonia), rigidity of the trunk, stiffness, awkwardness of the limbs, tremors of the hands, and psychiatric abnormalities. OSHA permissible exposure limit of manganese is 5.0 $mg/m^3$and National Institute for Occupational Safety and Health (NIOSH) limit is 1.0 mg/m^3. It is pyrophoric with chlorine **(Cheryl 2008).**

Zinc: It is used as metalloids in PCB. It's Over dosage can cause dizziness and fatigue **(Hess, Schmid 2002).** It is non-carcinogenic to human body and at workplace its US OSHA permissible limit is 5 mg/m^3**(IPMI2003).**

The studies in the past confirm the presence of toxic metals in mobile phone PCBs. The PCB is rich in metals used as metalloids including toxic metals in the equipment to support circuits design. In the coming paragraphs, the assessment of nickel, zinc, lead, manganese, and tin by Atomic Absorption spectrometry is described in the subsequent paragraphs.

Toxic metals in mobile phone PCB in varied proportionately. Among all metals, nickel is utmost and tin is least in the PCB samples. In PCB samples, nickel lies between 0.193-0.703g, tin 0.003-0.009g, manganese 0.011g-0.07g, zinc 0.026g-0.895g and lead 0.001-0.06g respectively. The damaging potential of toxic metals varies metal to metal and its magnitude in particular sample.

The PCB of Nokia 1108 model is less toxic, contains 0.001g lead, 0.026g zinc, 0.011g manganese, 0.003g tin and 0.193g nickel. The PCB of Movil-MCI CDMA is most toxic, contains 0.06g lead, 0.7676g zinc, 0.021g manganese, 0.009g tin and 0.703g nickel.

The PCB incineration and land filling are rudimentary and primitive disposal methods stated hazardous and insufficient to recover all metals from PCB. The metals like As, Cd and Sb volatilize while incineration and Ga and Ni remain in residue after incineration **(Electronics take back Coalition 2014)**.

E-waste hazard takes place in the developing countries, there neither compatible infrastructure is available nor environmental laws compliance are so stringent.

4.8. ECONOMIC ASPECT OF METALS IN MOBILE PHONE PCB

In EEE, in addition to toxic metals the precious and base metals also remain intact even after its end of life. The developed countries recuperate the available metal resources from discarded equipment efficiently with the aid of advanced recycling and recovery methodologies due to prevailing technology boom. However, besides Basel convention, E-waste is being dispatched to the developing countries due to obvious reasons. The presence of all kinds of metals, attract the recyclers for further operations required for expected yield. This study has achieved this land mark and allows to establish formal recycling. The available data convince the traders to plan the recycling and recovery of metals and earn a lot in terms of monetary and maintain environment wellness. The data encourage the new avenues in mobile phone waste treatment arena. The mobile waste is continuing and escalates with time in years to come and its monetary benefits will increase with the quantity.

Table 53: Economic aspect of Precious and Base metals in 10000 samples

Sr. No.	Samples	Recoverable weight of metal (10 x1000 Samples)				
		Au (g)	Ag (g)	Cu (g)	Fe(g)	Al(g)
1.	Nokia 2700	3.19	172.2	3957.7	268.9	182.6
2.	Nokia 1650	1.89	63.5	2732.7	175.8	166.7
3.	Nokia 1108	2.34	73.4	2082.2	97.7	169.9
4.	Meni Max D-5027	1.18	53	1464	115.7	120
5.	Siemens A-50	3.02	108.6	3533.5	297.4	303.8
6.	Motorola-C1-68	1.48	67.7	2176.3	135.7	150.5
7.	Movil-MCI-CDMA	1.05	56.6	2257.1	203.9	222.3
8.	Samsung-D 500	2.36	89.3	2584.4	141.5	132.5
9.	Nokia- 72	3.5	167.9	4096.2	215	214.5
10.	Motorola W-220	1.56	84.6	2315.3	180.7	152.1
Total (g)		21.57	936.8	27199.4	1832.3	1814.9
Current Rate (Rs. per g)		3000	40	0.370	0.040	0.090
Estimated Value (Rs.)		64710	37432	10064	73	163
Total Value (Rs.)				**112442**		

The economic aspect of 10000 mobile PCBs is being present in **Table 53**. The precious metals are significant to support the E-waste recycling business as particularly informal recyclers are much concerned about them. However, other metals have their own significance as they act as a building block for the PCB. The metals in PCB construction are of refined characteristically. The copper metal is always in perception of recyclers and in first step, its recovery is proposed.

The recovery of precious metals is mandatory not only for the monetary benefit but also for obviating resources exploitation. From 10 x1000 samples, it is evident that precious metals of high value are recoverable out of 173 Kg PCB material.

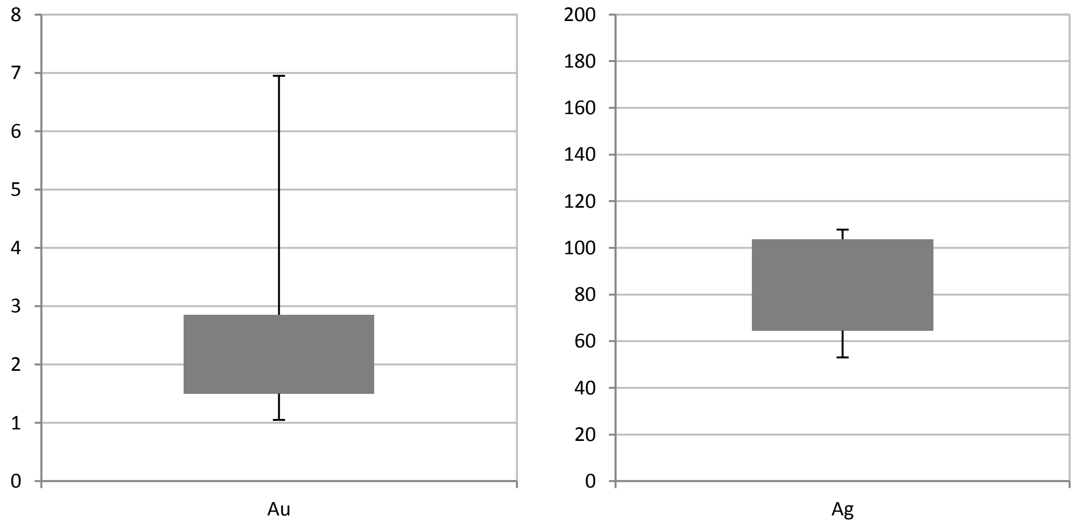

Figure 45: Whiskers-Box Plots for Au & Ag

The box-and-whisker plot shows a summary of recoverable quantity of Au and Ag present in the samples, as shown in **Figure 45**. The Y-axes represents weight of Au and Ag in gm per 1000 samples respectively. The exploratory research has given the descriptive stats of Au and Ag metals in terms of dispersion is (2.157 ± 0.698257) and (93.68 ± 43.49342) respectively.

Similarly copper, iron and aluminium metals are also being analysed for 10000 samples. The recovery of the base metals is also in the interest of environment. It brings monetary benefit and mitigates the environmental degradation, further maintains the ecological balance.

In Nokia 2700 alone, gold 3.19g, silver 172.2g, copper 3957.7g, aluminium 182.6g and iron 268.9g co-exists in 1000 samples (**Table 52**). One billion samples of Nokia 2700, contains metals of Rs. 17.950 billion. In view, that the metal recovery from a particular mobile sample may be planned.

4.9. ENVIRONMENT CONCERN OF THE METALS

All metals are scarce and always consumed for the public needs. The recovery of these metals needs ores mining, preparation, transportation of raw material, chemical transformation, and beneficiation. In the production of metals a huge energy is consumed and CO_2 and other greenhouse gases produce while carrying out the recovery processes. About 80% copper is extracted by pyrometallurgical processes and need embodied energy of 33 GJ per tonnes of metal producing 3.25 tonnes CO_2 adding in green houses gases by 0.21%. Similarly aluminium needs embodied energy as 211.5 GJ per tonne of metal production producing 21.81 tonnes CO_2 and adding 2.9% in greenhouse gases but in case of steel metal it adds 7% in greenhouse gases. In case of aluminium, it is very difficult to extract from ore as it is very reactive and difficult to refine because it oxidized very quickly. It is used in many applications in the society, so its presence is to be addressed essentially. The metals recovery has become critical because as it adds not only pollution but consumes a huge energy. In local mining the energy consumption is less than one tenth to the existing. Preferably, the local mining need to be encouraged comprehensively, whatever yield may be because it safeguards our environment from all metals threats.

These metals are not let unrecovered because their presence in air, water, soil will harm human health because; their excess presence in any environment segment will cause diseases in human body. For instance copper can cause irritation of nose, mouth and eyes causing headache, stomach aches, dizziness, vomiting and diarrhoea, also can damage liver kidney. Similarly, aluminium can cause damage to the central nervous system, dementia, loss of memory, listlessness, severe trembling.

The accumulation of copper in plants, animals and soils confirms that it does not degrade. In copper rich soils, the plant survival chances and plant diversity are very less and hamper in the preparation of farmlands for further crops. The copper in soil endanger the survival of microorganisms and earth worms and slow down the decomposition of organic matter present in the soil

Similarly, aluminium is acidifying the environment and particularly harmful for the animals consuming the plants contain aluminium. The concentration of aluminium is highest in acidifying lakes. The presence of aluminium in fish can harm to the birds consuming fishes of acidifying lakes.

The hazardous metals like lead, antimony, beryllium, etc. in landfill leach out and contaminate the soil and underground water bodies, harm the water quality and soil fertility. In mobile phones, PCB individually impacts the environment by 59% **(Casper Books 2000).** Moreover, recycling and recovery of these materials also reduces the volume of the e-waste disposed drastically. The quality of metals remains same even after repetitive recycling **(Jennifer Namias 2013).**

The toxic metals in the mobile phone PCB is of much concerned, the beyond permissible limit, they are all harmful. The unorganised E-waste management made the situation critical in the country as unscientific methodologies and unsafe implements used by the innocent engaged in this occupation, encouraging the informal E-waste recycling in the country. The data acknowledge the forthcoming threat due to the mishandling of mobile phone waste in the country.

4.10 INNOVATIVE MODEL FOR E-WASTE MANAGEMENT

The E-waste management in India is scalene in respect of environmental laws and its compliance on grounds. Due to the dearth of data, it is difficult to handle the enormous waste generating in the countries. E-waste generation is becoming critical day by day in the country. Public is not scaling the E-waste problem in the country as not knowing about the actual length and breadth of its existence. In view of that the public participation for E-waste management is very low in the country, which only can enable it for removing adequacy in the network and maintain overall effectiveness. The state pollution control boards (SPCBs) in the country strive to scale down the problem by enacting various environmental laws and defining various responsibilities of stakeholders; but still the expected results are awaited. It indicates the inadequacy in network of E-waste management as some part or parts are lagging behind as per need of the stakes.

The globalization and innovations in EEEs products enhanced the production as well utilization of equipment manifolds. The life span of the equipment has also reduced drastically because technology of the equipment shifting quickly. In view of that the inventory of discarded and obsolete electronic equipment has grown up quickly.

The 70% E-waste produced in the country is being produced by ten states only and 60% by 65 cities **(Research Unit 2011).** Also, the E-waste is being generated by trans-boundary movement of waste. Annually, 0.05 million tons E-waste is being received from importation, which is 13% of the indigenous e-waste generated **(Khatter 2007).** In the total imported E-waste, 80% waste is from USA and rest from EU countries **(Pratap 2009)**. In the indigenous E-waste, only 1,44,143 tonnes of e-waste has been reported back out of 3,82,979 tonnes, and remaining 62.36% either wasted or treated informally **(Khatter 2007).** However, only 19000 tonnes (13%) of e-waste has been recycled out of 1, 44,143 tonnes **(Khatter 2007).** However, E-waste inventory is prepared based upon the population of the states considering 1 kg per capita per annum. The new inventory of ten states and ten metropolitan cities is presented in **Table 6**.

The viable e-waste treatment facilities have been commissioned by registered recyclers as per CPCB norms in nine states of the country, other states are supposed to divert their E-waste towards the nearest installed facility easily.

The Innovative E-waste management model adheres to the Indian conditions involving users, manufacturers, stockists, local collectors original equipment manufacturers centres, registered recyclers. The E-waste collection efficiency is the key of success of its management. The working of the model relies on voluntarily handing over the E-waste to the SPCB affiliated stakeholders as E-waste payload is allotted to the registered recyclers as per their capabilities. The modalities regarding monetary benefits and subsidy in any form to be given to the recycler rest with SPCB.

A mammoth E-waste needs an effective collection for further treatment. The objective of this innovative model is to provide a safe environment and prevent human health from the ill effects of E-waste. The objective of this E-waste management model is to organise E-waste collection and its sustainable disposal. It prevents the occurrence of any hazards due to leakages of resources.

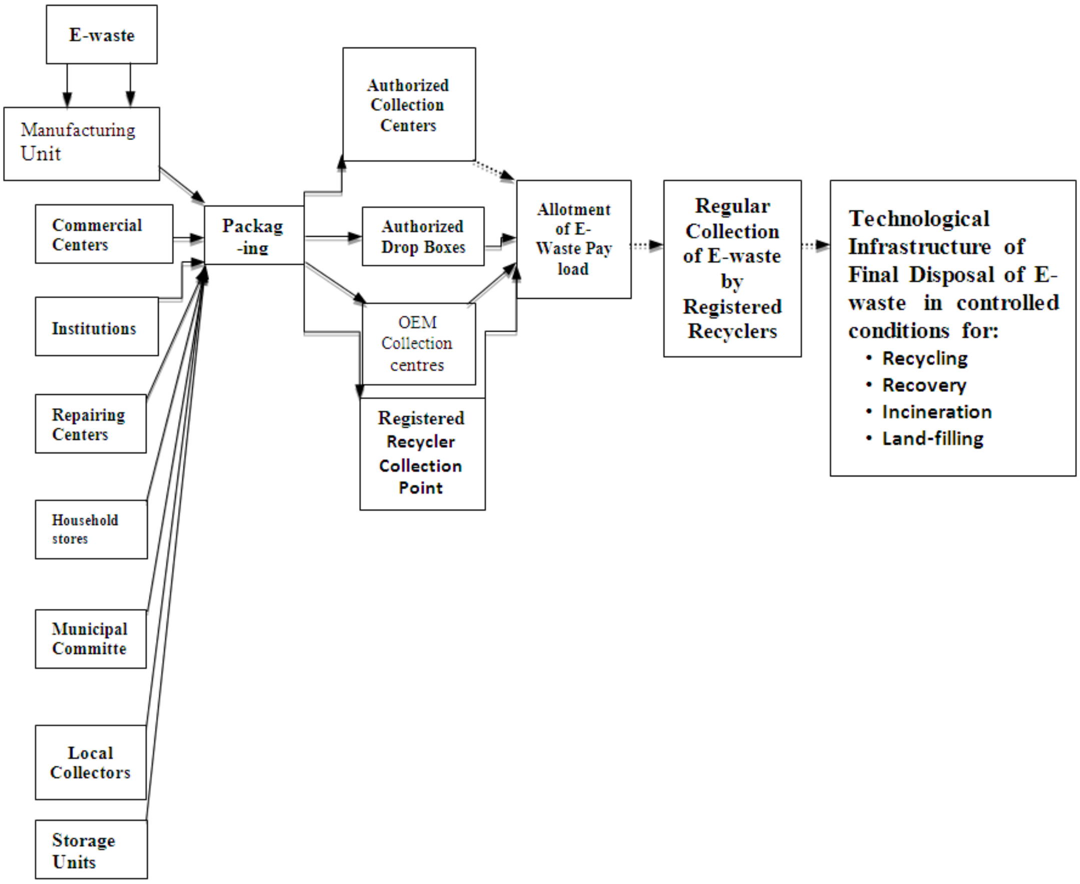

Figure 46: Proposed innovative model for E-waste Management in India

In India, for E-waste treatment, a plant is under operation in Roorkee, owned by M/s Attero recycling limited, carrying out recovery of valuables and checking the emission of poisonous gases. However, similar plant is operational in Umicore (Hanau Germany), Belgian recycling solutions, Kaldo technology of Boliden are the world leaders in E-waste recycling and recover more than 80% material out of E-waste.

This model provides an effective E-waste management for all equipment including discarded mobile phones in the country. The unexplained E-waste trading code practices have hampered/troubled the E-waste management in the country. In the end, the model will restrain the unsafe movement of E-waste in the community and establish a user friendly way of E-waste treatment in the chain of its healthy management.

In the innovative model eight sources of E-waste have been identified in the country. It includes manufacturing units, commercial centres, and institutions, repairing centres, household stores, municipal committee, local collectors and storage units and further activities are being explained in the subsequent paragraphs. Among E-waste sources most of them are either sole generators or storing E-waste from various local sources of the community. A brief about these sources and activities involved in the innovative model is as under **Figure 46.**

Manufacturing units: It includes the manufacturing units producing electronic equipment and its peripherals. During the manufacturing processes as well as after quality control certification, few equipment are not put in intended use and declare defective and the manufacturers destine them for further recycling and recovery of materials.

Commercial centres: The commercial centres need update electronic equipment regularly and in contrary, obsolescing the contemporary equipment in large scale. It is one of the whopping sources of E-waste in the country.

Institutions: The colleges, schools and research centres are the main source of E-waste in the country. A large number of electronic equipment are being used in these institutions and with the pace of the technology, numerous equipment are retiring daily and are being replaced by new equipment as per need.

Repairing centres: The defective electronic equipment are being refurbished after negotiating necessary repair in the equipment. But, beyond economical repair of the equipment, compels the user to leave the equipment at the repairing centres as it is of no use of the user further. In such circumstances, the repairing centreis one of the sources of E-waste.

Household stores: People are keeping some equipment like defective mobile phones, defective PC, defective television with the hope that it will be repaired now and then. But these continue defective as a high price perception always in mind when it is purchased and they never allow them to hand over for further disposal. It is one of the perennial sources of E-waste.

Municipal committee: People are putting the defective electronic equipment in the municipal waste just to get rid of it and feel that it is an appropriate methodology to dispose of them. The municipalities are segregating these electronic items and put them aside and treat the bio-degradable stuff accordingly. The accumulated E-waste may be diverted to the concerned agencies. Hence, municipal committees are one of the E-waste sources.

Local collectors: The street corner collectors collect every discarded household material from the users continuously including electronic equipment. They segregate and sell off them to local collectors for monetary benefits. The local collectors are getting these items on regular basis and further put them in informal recycling. So, it is one of the major sources of E-waste.

Storage units: In the defective electronic equipment, most of the components remain intact and may be utilized for refurbishment of the other electronic equipment. For refurbishing, the defective equipment of various models are being kept in storage units. Hence, it is one of the sources of E-waste.

Packaging: The electronic equipment in full or in partial need its packaging as the equipment and its peripherals are being manufactured by the consumption of precious, base and toxic material. Any leakage from the equipment results loss to the environment all together. After packing, it is easy to handle the equipment and any further leakages from equipment may be prevented.

Authorized collection centres: As per pollution control board's policy, the authorised collection centres may be established for accepting discarded electronic equipment in the metropolitan cities as well most E-waste generating places in the country. People can avail this privilege and handover the electronic equipment easily. All kinds of equipment are being included for acceptance for their disposal at these centres.

Authorized drop boxes: In this sequence, the drop boxes may be put at various locations as per pollution control board guidelines. People may drop all kind of electronic equipment here.

OEM collection centres: The extended producer responsibility allows the collection of their defective, discarded and obsolete electronic equipment of sole manufacturer. In this chain, the original equipment manufacturers (**OEM)** established their authorised collection centres in the city. In these centres, the user put their equipment and get rid of their outdate equipment easily.

Registered recycler collection point: For the collection of more E-waste, the collections point of registered recyclers may be established at every location susceptible to produce E-waste in the country. It will add one more dimension in the E-waste collection. It will facilitate the user for disposing their obsolete equipment easily.

Allotment of E-waste payload: The state pollution control boards (SPCBs) are registering recyclers to deal with E-waste in the country. The pay load of the E-waste is to be allotted to the recyclers as per their capabilities and may be authorised to collect E-waste from the collected pool of the waste.

Regular collection of E-waste by registered recyclers: The collected E-waste is to be lifted by the recyclers continuously from the collection points. It will set a chain of actions involved in the E-waste management.

Technological infrastructure: The trend and expansion of technology for E-waste treatment is in transition in the country. But sooner or later it comes to true and deal with complete E-waste generated in the country sustainably. In that sequence, the collected E-waste once reached to the technological infrastructure, it will be dealt by sustainable approaches.

After the implementation of the innovative E-waste management model in the country, it will handle the entire E-waste to be produced in the country and check the scattering the E-waste all around in the community. It will stop the dispersion of toxins in the environment and improve the health condition of the people engaged in the E-waste management in the country. It is gaining in terms of resources from E-waste and minimizes the exploitation of natural resources. The model will phase out informal recycling of E-waste from the country.

The mobile waste is toxic characteristically as contains both hazardous and non-hazardous material in its composition. The recovery of both materials is not easy task as both are condensed homogenously in the manufacturing of electronic equipment. The informal E-waste recycling has limited scope the safe recovery of precious metals and toxic metals simultaneously as the awareness as well as infrastructure to deal with enormous E-waste is minimal. The precautions are to be considered while mobile phones recycling are essentially required to prevent the dispersion of toxins in the environment. The new E-waste management model provides the effective and reliable results to carry out the formal E-waste recycling in India.

The informal E-waste recycling will be benefited by this study because a lucrative business in E-waste management can be established and the diseases caused by the informal recycling can be minimized to a large extent. It will improve the quality of environment as it reduces environmental loading of pollutants.

The findings in the past conclude only the metals in the PCB; but their models are still unknown. This study complements all required information desired for the sustainable disposal of mobile phone waste and educates people about mobile phone waste and enhances the sustainable E-waste treatment.

The study has selected limited samples, however so many other brands and models of mobile phones are in use. But, the selected samples cover the maximum population of the country.

Nowadays, the mobile phone waste is not part of E-waste recycling in India because public believes that it is worthless and nothing can be recovered out of it as its composition of material is not known to them. The study carries out a comprehensive analysis for the material in the discarded country used mobile phones of assorted brands and models collected from different layers of the society. It is a cutting edge approach in the direction of E-waste management and narrow down the mobile phone waste of enormous potential. The sample length is large and evaluated glass, plastic, metals in each sample. The precious, base and toxic metals in PCB of the mobile phone are being determined qualitatively and quantitatively. This study makes public the material composition of mobile phone, which is a milestone for the E-waste management in India for discarded mobile phones and mobile phones will get more attention after its useful life in the country and supplement the soundness of it in years ahead.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

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CONCLUSIONS AND RECOMMENDATIONS

5.1. CONCLUSIONS

These are the following conclusions of the study drawn based upon the study on E-waste.

- The material composition of assorted sample varies model to models and brand to brands. The weight of the mobile phones varies model to models and brand to brands and weight of discrete constituents in mobile phones like glass, plastics, steel, organic substances and PCB also varies correspondingly.

- The high end mobile phone has minimum weight percentage of glass, plastics, steel and organic substances as compared to low end mobile phone. Similarly, the weight percentage of PCB in high end mobile phone is more than low end mobile phones. The PCB weight ranges from 20.90 to 43.00% to the weight of the mobile phones.

- Among all samples, Meni Max D-5027 is weightiest and Nokia 1650 is the lightest sample. The sample Siemens A-50 has highest glass contents and Nokia 1108 has least glass contents. In the body of mobile phone of Meni Max D-5027 sample has highest steel contents and Nokia 72 has fewer steel contents. Due to the weight of the steel it contributes more in its total weight. The plastic has also an addendum in sample weight. The Motorola W-220 has highest plastic content among samples and Nokia 1650 has least plastic content. The main component of the mobile phone is printed circuit board. In the samples, Siemens A-50 bears heaviest one and Motorola C1-68 has lightest PCB. The typical values of mobile phone (without battery) is 63.57g, glass 6.7g, steel 9.12g, plastics 30.47g, and PCB 17.28g respectively. The organic material in PCB ranges from 9.85% to 27.32% and magnetic material 3.75% to 7.19% to the weight of the PCB.

- The study validates the presence of gold, silver, copper, aluminium, iron, manganese, tin, lead, zinc and nickel in mobile phone PCB metals composition. The precious metals are fundamentally obligatory for PCB edifice.
- The high end mobile phone PCB has more precious and base metals and minimum toxic metals and in contrary, low end mobile phone has less precious and base metals and maximum toxic metals. The typical discrete metal in PCB is available as Auminium-1.10%, Gold- 0.013%, Copper-15.79%, Lead- 0.11%, Manganese - 0.11%, Silver - 0.54%,Iron - 1.05%, Tin- 0.03%, Nickel- 2.30% and Zinc- 2.08% correspondingly. The weight fraction of total retractable metals exists in PCB ranges from 16.20% to 27.08% to its weight. The copper metal is utilized utmost in each PCB. It firms up that copper metal extant conquers over other metals and exists in ample quantity in PCB.
- The standard deviation of metals in ten samples PCB is: Aluminum-1.03, Gold-1.10, Copper-5.57, Lead-1.09, Manganes-1.09, Silver - 1.05, Iron-1.03, Tin-1.10, Nickel -1.17 and Zinc -1.19 respectively
- The gold contents in the respective samples are present in descending order as Nokia 2700=Nokia- 72> Nokia 1108=Siemens A-50> Nokia 1650> Motorola W-220 =Movil-MCI-CDMA=Motorola-C1-68>Meni Max D-5027>Samsung-D 500.
- The Silver contents in samples are present in descending order as Nokia 2700> Siemens A-50> Nokia 72> Motorola W-220>Nokia 1108>Movil-MCI-CDMA>Meni Max D-5027>Noika 1650> Motorola-C1-68> Samsung-D 500

- The copper contents in the respective sample are present in descending order as Nokia 2700> Siemens A-50>Nokia- 72> Nokia 1650> Motorola W-220>Movil-MCI-CDMA> Nokia 1108> Samsung-D 500> Motorola-C1-68>Meni Max D-5027.

- The study discovers a perennial source of metals from E-waste because it is uncultivated till now for metal recovery in India. The metals recovery from E-waste is cost effective and ample metals may be recuperated from E-waste. E-waste ensures the availability of metals for the installation of treating facility to deal with mobile phone waste.

- In the present scenario, the E-waste management is not uniform in country. The metropolitan cities are partially equipped to deal with E-waste because the awareness about the E-waste disposal is minimal among all stakeholders. Now, the E-waste management has become the global issue. Hence, it is mandatorily rationalise it in the country. The living style and attitude of the people contribute are significant in the E-waste management for which an innovative approach to address the E-waste management is required. The new model is introduced to deal Indian conditions for E-waste. The introduced innovative E-waste management model works suitably as it involves all E-waste stakeholders. It enhances the collection of E-waste. It reduces the environmental pollution and provides metal resource.

- The E-waste management in the country is benefitted by the study in two ways as it looks at metal avenues for societal needs and studies the toxic metals for health safety.

5.2. RECOMMENDATIONS

In this study E-waste management in India has been deliberated comprehensively. Presently, a wide scope of improvement in Indian E-waste management is noticed. A sustainable, resourceful, effective and efficient E-waste management is demanding in the country. In view of that the following recommendations are being put forward to achieve a viable E-waste management in the country.

- E-waste is escalating sharply in the country and it is not exploited for the retrieval of recoverable precious and base metals. The E-waste is mammoth in the country. It is significant opportunity to address the E-waste appropriately in the interest of both metal resources as well as environmental safety. For the sustainable recovery of metals from E-waste, the viable infrastructure should be in place, so that dual gain from E-waste can be obtained and the public and environment may be protected from the ill effects of E-waste. The material available in the electronic equipment should be exploited as a resource. The individual material like plastics, glass and metals should be recuperated formally as per their standard methods and the informal recycling for E-waste management should be discouraged from tip to toe in the entire country.

- The data of the study should be commercially utilized for the material exploitation from mobile phone waste as it provides an outcome of material, which acts as an economic supplement in this profession andchannelize it to the the formal recycling for job opportunities, metal recoveries, environmental safety and health concern.

- Presently, in India the inventory management for E-waste is far lagging in the entire country. For the E-waste treatment an engineered E-waste disposal infrastructure should be mobilized to deal with existing as well as upcoming E-waste in the country as the assortment of E-waste is possibly done effectively by the suggested innovative model. The inventory of the used up electronic equipment in E-waste should be prepared categorically, so its sustainable disposal may be planned.

- The accountability of the electronic equipment user should be fixed for its disposal to strengthen the EPR, so that the end of life equipment is to be destined to the registered recyclers. At the time of selling of equipment, the user should abreast about its disposal details; so that it is disposed of after its end of life viably. The useful life of the equipment should be mentioned, so that its due disposal may be monitored both by user as well producer.

- The compliance of the E-waste rules and regulations should be checked regularly so that any escape may be plugged timely and the guilty should be punished as per provisions. The cognizance about the prospective and consequences of E-waste in the public should be enriched. Hence, a campaign about the effects of material composition of the electronic equipment should be planned analogous to the promotion of equipment sale.

5.3. SCOPE FOR FUTURE STUDY

The present study put forward E-waste for the evaluation of material in mobile phones of assorted brands and models and establishes that a wide scope of the metals recovery exists in discarded mobile phones. Henceforth, the other electronic equipment like laptops, computer servers, and 3rd generation mobile phones can be appraised correspondingly and more metals avenues and job opportunities may be opened up accordingly because in India, the electronic equipment disposal is still uncared and has a wide scope for the material resource recovery and employment.

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2. Vats M C, Singh S K., 2017. Challenges in E-Waste management in India, International Journal of Hazardous Materials (Elsevier).

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Mobile Phone samples of various brands

PCBs from Dismantled Mobile Phone samples

Other Items of Dismantled Mobile Phone Samples

Dismantled Samples

Dismantled Samples

Dismantled Samples

Dismantled Samples

Typical PCB Samples of 2nd Generation mobile Phones

Mobile Phones PCB put to Roasting High Furnace

Furnace Voltage Stabilizer

Tools to handle the sample

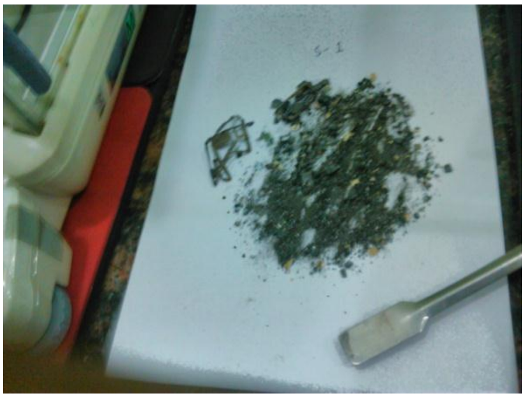
Combustion of Samples

PCB after Roasting in a high temperature Furnace

Tools for Milling

PCB Samples after Sieving

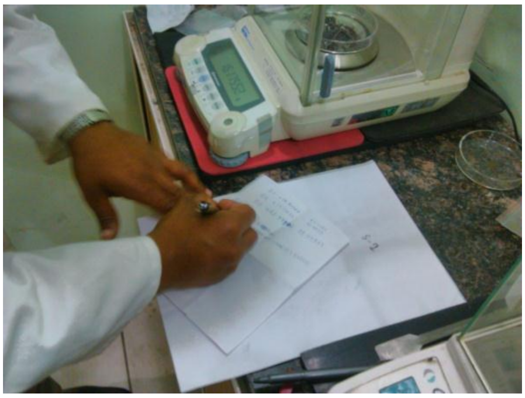
PCB Samples after Grounding



Separation of Material

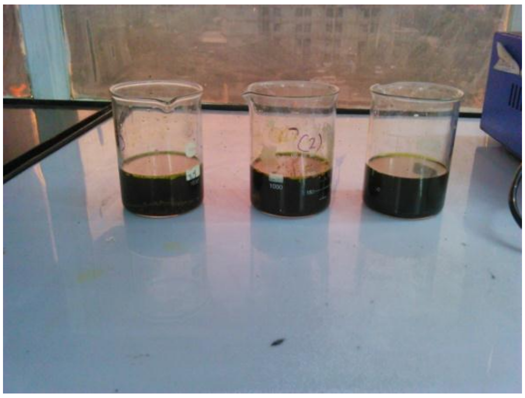
Weighing of Samples

Bar Magnate Treatment for Fe

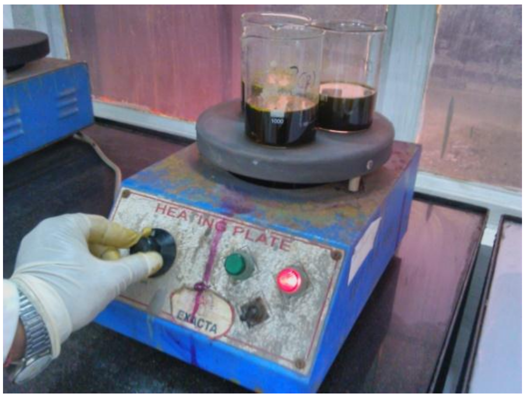


Weighing of Samples

Samples for Acid Treatment



Digestion of Samples



Hot Plate Digestion

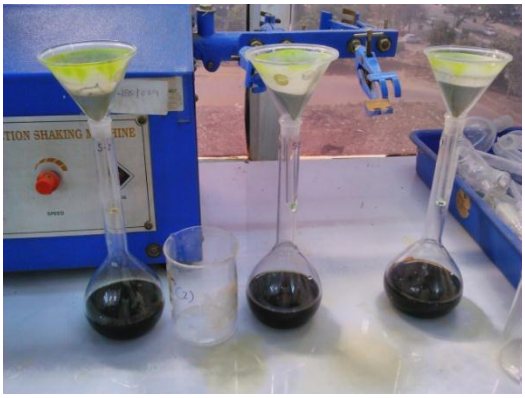
Preparation of Standards

Digested Samples for AAS Observation

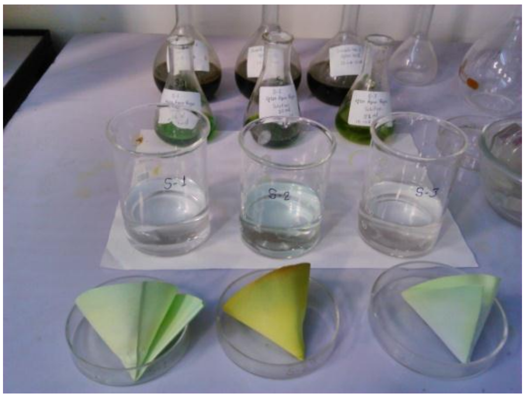
FAAS Infrastructure

Acetylene and Oxygen gas Cylinders

Waste Trough of FAAS



Filtered Samples after HCl Treatment



Dry Samples after Filtration